STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION

BULLETIN No. 3

# Water Resources of Tulare County and Their Utilization

1922

(Based on Investigation in Cooperation With Tulare County)

CALIFORNIA STATE PRINTING OFFICE
SACRAMENTO, 1922

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
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Division of Engineering
and Irrigation

August 29, 1922.

A. B. FLETCHER, *Director*,
Department of Public Works,

BUILDING.

*Subject: Water Resources of Tulare County.*

DEAR SIR: Early in the year 1920 I was approached by a committee from Tulare County which committee was very eager to have assistance in determining something more definite concerning the water supply of the county than then existed. We were, at that time, engaged in the examination of the problems of Kern River which examination has been completed and a report of which is contained in our Bulletin No. 9. The Tulare County committee had knowledge of our work in Kern County and expressed a desire for such service in their county, offering to aid in meeting the necessary expenses.

The State Department of Engineering was in great need of such a study in relation to the water supply of the Lindsay-Strathmore and Terra Bella Irrigation Districts. Arrangements were made for the work, Tulare County to supply $7,500 toward the expense, the County Water Users Association $2,500 and the state the remainder. The total cost has been about $22,000.

It would have been impossible for us to have secured the information now assembled within the period such work has been done and within the financial means of the Department of Engineering.

The value of the work will depend largely upon a generous circulation among Tulare County people.

Our division should have it in more permanent form.

I herewith submit text of same ready for printer.

Yours very truly,

W. F. MCCLURE,
*Chief, Division of Engineering*
*and Irrigation*

Approved for publication, August 30, 1922.
A. B. FLETCHER, *Director of Public Works.*

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# INTRODUCTION.

The following report is based on field investigations and study of data relating to the water resources of the portions of Tulare County dependent on the Kaweah and Tule rivers and on smaller streams in the southern portion of the county. The portions of the county dependent on Kings River for its water supply were not included. Some areas in eastern Kings County have been included as they are a part of the areas affected by Tulare County streams.

The work on which the report is based was undertaken by the State Department of Engineering in May, 1920, and has been continued since the reorganization of the state's engineering work in July, 1921, by the Division of Engineering and Irrigation of the Department of Public Works. The work was undertaken at the request of those interested in the development of the water resources of the county, expressed through the organization of the Tulare County Water Users Association. The costs of the work have been paid by the state, Tulare County, and the Tulare County Water Users Association. The total cost has been about $22,000 of which Tulare County has supplied $7,500, the Water Users Association $2,500, and the state $12,000. The work has been materially assisted by the cooperation of all parties having data relating to the water supply and its use. Without such cooperation it would not have been possible to have secured the extent of data on which this report is based within the time given to the field work and the indebtedness to such assistance is gratefully acknowledged. Special acknowledgment should be made to the Tulare County Water Users Association and its officers, and to all parties concerned in the pending litigation on Kaweah River, to the Southern California Edison Company and to the landowners who have furnished data in connection with the ground water studies.

The general planning of the work and its supervision has been under the direction of Mr. S. T. Harding. Mr. Chester Marliave has carried out the field work on the Tule River and southern portion of the county and Mr. G. H. Russell has handled the investigations relating to the Kaweah River areas. The report has been written by Mr. Harding assisted by both field engineers.

The full utilization of the water resources of Tulare County requires a coordination of the use by direct diversion and by pumping of ground water. The extent to which present use of the available water supply has been extended is greater than is realized by many as the recent development has proceeded largely by means of individual pumping plants. The increase in such plants does not come to public attention to the same extent as the construction of canal systems. No development of the water resources of the county can be complete which does not fully utilize the available ground water supplies but it must be remembered that a ground water supply like those flowing in streams has limits to its volume and development can not exceed such limits without depletion of the supply. A large part of the field work in these investigations has been directed toward a study of ground water conditions and use as there had been less data collected on these subjects than on the extent and use of surface streams.

The method of presentation consists of a discussion of the more general factors relating to irrigation including the records of run-off of the tributary streams followed by a detail discussion of the conditions in each of the portions of the area covered for which physical conditions makes the water supply relatively separate and distinct. For convenience in following the purpose and the relation of the different factors in the detail report a brief summary of the conclusions is presented at this point. The divisions of the area used are shown on Map 2 and the areas irrigated in 1921 on Map 1.

## SUMMARY AND CONCLUSIONS.

### Water Supply.

1. The only sources of water supply available to this area are the discharges of the streams entering the area as surface flow except in the southwestern part of the county where the ground water is derived from mingled sources.

2. The records available on Kaweah River indicate that the total long time mean annual discharge is 451,000 acre-feet. Measurements made in these investigations show no appreciable seepage from the river above McKay Point.

3. The records available on Tule River indicate a total long time mean annual discharge of 106,000 acre-feet from the main Tule River, 29,000 acre-feet from the South Fork and 2000 acre-feet from areas below the gaging station or a total of 137,000 acre-feet for the entire drainage area.

4. An analysis of the available data on the smaller drainage areas gives an estimated mean annual discharge of Deer Creek of 19,000 acre-feet; of White Creek of 6300 acre-feet and for other miscellaneous areas of 20,500 acre-feet. For all areas including Kaweah and Tule rivers the total mean annual run-off is estimated to be 633,700 acre-feet.

5. The mean annual outflow or surface discharge from Kaweah delta is estimated as 55,000 acre-feet. This represents the water leaving the Kaweah delta. Of the total estimated outflow in the last eighteen years, 80 per cent occurred in the three years of largest run-off.

6. Similar estimates of the outflow of Tule River indicate a mean annual discharge of 17,000 acre-feet, appreciable outflow having occurred in only eleven years of the last thirty-two years. No outflow from other drainage areas occurs.

### PART II. UTILIZATION OF THE RUN-OFF OF KAWEAH RIVER.

7. Available records of the diversions by Kaweah River ditches are given with a discussion of the indicated loss from river channels.

8. The areas served by ditches diverting from Kaweah River is estimated as 101,828 acres of which about one-fourth also receives supplemental water by pumping.

9. The general average diversion for Kaweah River ditches is estimated as about 2.9 acre-feet per acre.

10. The total irrigated area dependent on Kaweah River for its water supply either by canal diversion or pumping is estimated to be 175,000 acres. This is equivalent to one acre for each 2.3 acre-feet of mean annual available water supply.

11. There were about 8500 acres of additional land subirrigated from Kaweah River in 1920.

12. The estimated total net pumping draft in 1920 on the Kaweah River area is estimated to have been 162,000 acre-feet.

13. An investigation of sources of possible loss of ground water from the Kaweah area by outward movement into other areas results in the conclusion that such losses do not occur.

14. The ground water fluctuations for each year since 1917 are analyzed. The lowering for the whole area in 1920 and 1921 indicates an amount of loss of ground water storage about equal to the deficiency in the available run-off for these two years. On this basis present development is consuming the mean net annual available water supply.

15. A gross area of 135,000 acres within which the main canal service occurs maintained its ground water elevation in 1921. About one-half of the total irrigated area is within this area. In the other portions of the area there was a lowering of the ground water, the amount varying with the extent of the pumping draft and the distance to direct sources of replenishment. The ground water conditions for the different parts of the area are discussed in detail.

16. Available storage sites are considered. The only site having sufficient capacity to regulate the Kaweah River is the Ward site. Costs for different capacities are given with the conclusion that for full regulation of the run-off a regulated supply of 375,000 acre-feet per year supported by 150,000 acre-feet of storage capacity is as large as is feasible under existing conditions of run-off and storage costs. Such storage would represent a change in method of use rather than the addition of any material amounts of new water supply. As the estimated cost of storage alone is $7,500,000 such construction is not recommended.

17. It is estimated that power development at the dam for 150,000 acre-feet of storage might be able to produce a sufficient earning in excess of direct costs to carry about $1,000,000 of the cost of the dam.

18. The storage of winter flow and summer surplus waters would permit the securing of a fairly dependable annual supply of 50,000 acre-feet with 50,000 acre-feet of storage capacity at an estimated cost for storage of $3,500,000.

19. The storage of winter flow only would permit obtaining a fairly dependable annual supply of 45,000 acre-feet with 50,000 acre-feet of storage capacity.

20. The storage of excess summer flood flow only would require an extent and cost of storage in excess of present standards of feasible cost.

21. The possible means of improving present conditions of use on the Kaweah area are discussed with the following suggestions as to the changes most likely to be feasible:

1. Complete a determination of existing rights on a basis which protects existing diversions in their essential needs but in which the standards of practice required are commensurate with present economic conditions of value of land and water. Such a determination should include a definition of the rates of diversion to which each right is entitled and a limitation of the season in which such rights

may be exercised. It may be secured through existing legal means or probably much more quickly and effectively by voluntary adjustment among the parties concerned if agreement by such methods can be reached.

2. Improve existing canals so as to reduce seepage losses in areas near the stream so as to deliver a larger part of the diversion to areas away from the stream in which ground water is now lowering. Increase canal capacities for those systems serving such outer areas.

3. Increase pumping in areas near the river channels using pumped water as a substitute for present canal use in these areas so that the present canal use can be transferred to areas of deficient ground water supply. This will also increase ground water storage capacity for absorption of flood flow from the river channels.

4. Permit use of winter flow by storage for upper lands either in surface or ground water basins or a combination of both as may prove to be most economical.

5. Make direct transfers of present canal use from areas of less production per unit of water supply to those of a higher type of use where such transfers can be arranged.

22. It is considered that it is to the interest both of the individuals concerned and of the community as a whole that land on which the cost of development has already been incurred should have its water supply protected before additional lands are brought under irrigation. Such developed lands can offer security for higher costs in securing the water needed to supplement their existing supply than lands not developed and requiring a complete water supply.

23. The continuance without change of present conditions of diversion and pumping must eventually result in a reduction in the areas now irrigated in some parts of the Kaweah delta due to the increase of the lift to a point where pumping will no longer be profitable.

## UTILIZATION OF WATER SUPPLY OF SOUTHERN PART OF TULARE COUNTY.

### Tule River Area.

24. There was a total area of 63,703 acres irrigated in 1921 in the area considered to be dependent on Tule River for such water supply as it may receive. This is equivalent to one acre irrigated for each 1.9 acre-feet of mean annual available run-off.

25. An area of 16,723 acres received some canal irrigation in 1921. Over 80 per cent of this area also received some pumped water.

26. The total pumping draft in 1921 was 132,000 acre-feet.

27. The ground water conditions are discussed in detail for the various parts of the area with the following conclusions:

1. The present pumping draft closely approaches the total mean annual available run-off of Tule River.

2. While the general conditions are relatively favorable for the addition of a large part of the run-off of Tule River to the ground water, the present draft exceeds the average replenishment.

3. A consideration of the conditions on the different parts of the area shows that the greatest lowering of the ground water has occurred on those areas least directly supplied and at the greatest

distance from sources of percolation. The maintenance of present conditions can only be expected to result in a continued lowering of the water table in such areas.

4. Any increase in draft on such outer portions will directly increase the rate of lowering of the ground water. Any increase in draft in the portions of the area adjacent to sources of percolation will indirectly increase the lowering of the outer area by a reduction in the ground water supply available for outward movement.

28. The most desirable reservoir site on the Main Tule River is at Pleasant Valley. A storage of 50,000 acre-feet capacity with an estimated cost of $2,050,000 would give a fairly dependable regulated supply of 100,000 acre-feet per year.

29. On the South Fork of Tule River a reservoir could be built below the Indian Reservation with a capacity of 5000 acre-feet at an estimated cost of $535,000 which would support a fairly dependable regulated supply of 20,000 acre-feet.

30. A combination of 60,000 acre-feet of storage at Pleasant Valley and 5000 acre-feet on South Fork would support a regulated annual supply of 120,000 acre-feet at an estimated total storage cost of $2,750,000.

31. As such storage represents mainly a change in method of use and does not make available any materially larger part of the run-off of these streams than are now used by other methods their construction is not recommended.

**Deer Creek Area.**

32. A total area of 15,447 acres, of which the Terra Bella Irrigation District supplied 3841 acres were irrigated in the Deer Creek area in 1921. The total pumping draft was 35,000 acre-feet or nearly twice the estimated mean annual run-off of Deer Creek, an average lowering of the ground water of two feet occurred in 1921.

**White Creek Area.**

33. An area of 11,600 acres was irrigated in 1921 in the area considered to be dependent on White Creek for such ground water supply as it may receive. The total pumping draft was 27,000 acre-feet or about four times the estimated mean annual run-off of White Creek. An average lowering of the ground water of 1.3 feet occurred in 1921.

34. There was an area of 10,800 acres irrigated in 1921 in the area in southwestern Tulare County considered to have ground water supplied from mingled sources. The total pumping draft within the area was 9500 acre-feet. The water rose an average of one foot in 1921. No estimates of the amount of the available ground water can be made for this area.

35. The investigations were extended into the northern edge of Kern County. Similar conditions of draft in excess of tributary water supply with a resulting lowering of the ground water were found as in parts of southern Tulare County.

# MAIN REPORT.

## CHAPTER I.

## GENERAL FEATURES.

### Climate.

The climatic conditions in the San Joaquin Valley portions of Tulare County are such that while irrigation is essential for full crop production a wide variety of crops can be produced. Temperature conditions vary in different localities so that the growth of certain crops is limited to special areas but there are no portions of the area in which crops can not be profitably grown. The larger portion of the areas is suited to orchards, either citrus or deciduous, including vines. For those portions where local conditions may be less favorable for orchards a sufficiently wide variety of other crops are available to make irrigation profitable. No detail consideration has been given to temperature conditions in these investigations.

The precipitation of the areas furnishing the run-off for the water supply is discussed in the next chapter. For the agricultural portions of the county the rainfall is limited in amount and confined in its occurrence to the winter months. The mean annual rainfall is 10.31 inches at Visalia, 10.02 inches at Porterville and 16.71 inches at Lemon Cove. While such precipitation enables grain to be grown in many years without irrigation it is not sufficient for more intensive cultivation. It is doubtful if any of the winter precipitation reaches the ground water directly on the area on which it falls although there may be some increment to the ground water in areas of high water table in years of excessive rainfall.

### Soils.

The portion of Tulare County in the San Joaquin Valley is included in the areas of the Reconnaissance Soil Survey of the Middle San Joaquin Valley published by the U. S. Bureau of Soils except the southern nine miles of the county, which is included in the Reconnaissance Soil Survey of the Upper San Joaquin Valley.

While the soil texture varies widely in different parts of the area, there are few localities in which the soil is sufficiently unfavorable to control development. The deltas of Kaweah and Tule rivers are largely sandy loams, fine sandy loams and loams. Nearer the side of the valley between the streams the soils tend to be heavier and in some cases have hardpan within six feet of the surface. Alkali in sufficient amounts to affect crop growth occurs in portions of the area, particularly in the western part of the county. There is, however, adjacent to all streams an area of good land in excess of the area which the water supplies are capable of irrigating.

The differences in soil texture affect the irrigation practice both as to frequency and amount of single irrigations and as to the total use per season. In some portions of the area ground water also affects the conditions of surface application, the ground water being sufficiently high to result in its direct use by the plants.

### Crops.

In all parts of the irrigated areas in Tulare County there are a sufficient variety of crops which can be grown to make irrigation desirable. The crop distribution varies with the conditions of temperature, water supply and soil. In the areas adjacent to the upper edges of the valley citrus fruits, olives and vines are largely grown. In intermediate areas vines and deciduous fruits are mingled with general crops. In the western portion of the county the proportion of alfalfa and summer crops such as corn is larger. The crop distribution is affected both by temperature conditions and by the cost of water, the crops of larger water requirement being grown more generally in areas of lower pumping lifts. The yields of all classes of crops where properly handled with adequate water supplies compare well with those obtained in other areas. Some areas not directly cultivated under irrigation are used for pasturage, being irrigated at such times as excess water may be available. Some land of high ground water is also used for pasturage without direct irrigation.

## CHAPTER II.

# WATER SUPPLY.

The water supply for the portion of Tulare County in the San Joaquin Valley can come from only three sources. These are (1) visible surface flow of streams entering the area; (2) invisible subsurface ground water movement; and (3) direct precipitation on the area.

The first of these sources can be measured and sufficient records are available for the greater portion of the drainage area tributary to the valley lands to furnish a dependable basis for determining the run-off. The extent of the natural precipitation has been given and the opinion expressed that this adds little if any supply to the ground water. The natural precipitation on the valley lands is of benefit to plants by direct use and reduces the amount of water it is necessary to apply by irrigation. It does not, however, add materially to the water supply available for irrigation.

The subsurface ground water movement into this area from outside areas, if such movements exist, would be difficult to measure. Their study can best be approached by a process of elimination of possible sources of such supply.

There are three possible general sources from which ground water might move into the area covered by these investigations. One of these is ground water movement from areas supplied by Kings River water. The ground water contuors shown on Map 2 and the detail records of wells discussed later indicate that there is little if any movement south of Cottonwood Creek of any water supply derived from Kings River. The second possible source is general San Joaquin Valley ground water moving northerly from the south end of the valley. This affects some areas in the southwestern portion of the county. Its extent is discussed in connection with the discussion of the ground water there. The ground water contours on Map 2 demonstrate that such sources can not affect the higher lying ground water of any of the areas except the southwestern part of the county. The third possible source is deep movements westerly under the valley of water absorbed within the Sierra Nevadas. Belief in the existence of such a source of supply has been expressed by various individuals during the progress of this work and some discussion of the probabilities of its occurrence is considered warranted.

The formation of the Sierra Nevadas is generally granitic and of an older geological age than the valley formations. The present San Joaquin Valley is the result of the filling by erosion from the adjacent mountains. Portion of such filling have taken place while the valley was submerged giving sediments more or less stratified; other portions have taken place, as at present, as deposits by streams giving the alluvial formations which compose the recent valley fill. The total depths of these different deposits is not known but is considered to be several thousand feet in the central portion of the valley, wells over 4000 feet in depth have not reached the underlying formation.

In order for water absorbed on the upper drainage areas within the Sierras to reach these valley fills by underground movement it would have to pass through the granite and into the valley fills. While ground water may exist in granitic formations, its amount and movement are small except along lines of fracture or faulting. It would be contrary to experience in other areas to expect any material amount of such movement here. The greatest losses would naturally by expected to occur along present stream channels. Measurements given later show that there is no appreciable loss from the Kaweah River channel above McKay Point. Pumping near Lindsay lowered the water level to a considerable depth, general ground water movement from the upper areas, if it existed in this area, should have served to maintain the pumping supply adjacent to the hills.

Except for the two marginal areas first mentioned all of the water supply for the areas in Tulare County can be considered as entering the area as surface run-off in the definite stream channels. The extent of such run-off measures the extent of the water supply tributary to the area and available for irrigation. The available records are mainly those obtained by the Water Resources Branch of the U. S. Geological Survey since 1901 with some additional records secured by local interests. Estimates of the run-off from 1878 to 1884 have been published based on the data obtained during this period by the State Engineer. As such records are based on less detail of observation than those more recently obtained and as the results are in many cases inconsistent with the more complete recent records no use has been made of the earlier estimates.

In these investigations no study has been given to the feasibility of bringing into this area water supplies not naturally tributary thereto. Such studies are outside the scope and purpose of this work. There can be no question, however, that full utilization of local sources of water supply should take precedence over any plans for securing distant sources of supply.

## KAWEAH RIVER.

Kaweah River is the largest stream in Tulare County and supplies about two-thirds of the area irrigated. The run-off of the main stream has been measured by the U. S. Geological Survey below Three Rivers since 1903. Records are also available for the North and South Forks since 1911. Records at McKay Point have been kept since October, 1916, by Mr. H. H. Holley for parties interested in the diversions from the river. The power companies which have plants on the Middle Fork have kept records on East and Marble Forks as well as Middle Fork. All of these records have been made available for the purposes of this report.

The run-off of the separate branches of Kaweah River is not of direct interest in the study of the utilization of this stream for irrigation as no reservoir sites of sufficient size to be important were found on these branches. The only site offering possibilities of full regulation of the stream is below the junction of the three forks at Three Rivers. The run-off of the main stream at Three Rivers gives the total supply available for irrigation.

The record of the U. S. Geological Survey station at Three Rivers during 1918 to 1920 is open to some question due to uncertainty as to the accuracy of the reported gage heights on which it is based. A somewhat detailed analysis of these records for this period has been made and a substitute record of discharge used. The method of deriving this substitute record is explained in detail later.

For the period 1903 to date the run-off of the Kaweah River at Three Rivers is shown in Table 1. The records, except for 1919 and 1920 are those of the U. S. Geological Survey. The annual mean for the 18-year period is 455,000 acre-feet. Rainfall records for this vicinity are available since 1890. A study of these indicates that the precipitation for the period 1890 to 1903 was only 93 per cent of that for the period 1903 to 1921 and that the recorded run-off for the latter period would exceed the mean for the longer period 1890 to date. A comparison by years indicated an average annual run-off of 416,000 acre-feet for the period 1890 to 1903 which combined with the recorded run-off since 1903 gives a mean annual discharge for the period 1890 to date at Three Rivers of 438,000 acre-feet. The estimated run-off of the small streams entering below Three Rivers, as given later, is 13,000 acre-feet per year, giving a total mean annual run-off of the Kaweah drainage area of 451,000 acre-feet.

**TABLE 1.**

**Discharge of Kaweah River at Three Rivers. Record of U. S. Geological Survey, Except for 1919 and 1920, for Which Discharge is Computed from McKay Point.**

| Month | Discharge in total acre-feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1903 | 1903-04 | 1904-05 | 1905-06 | 1906-07 | 1907-08 | 1908-09 | 1909-10 | 1910-11 | 1911-12 |
| October | -------- | 2,644 | 31,420 | 2,669 | 7,380 | 6,890 | 6,060 | 5,670 | 4,430 | 4,800 |
| November | -------- | 3,332 | 6.962 | 3,368 | 7,080 | 6,250 | 4,260 | 13,000 | 4,240 | 4,960 |
| December | -------- | 2,951 | 5,841 | 5.103 | 15,100 | 12,100 | 5,240 | 46,600 | 6.580 | 5,570 |
| January | -------- | 4,796 | 7,133 | 48,200 | 25,300 | 12,700 | 92,200 | 50,600 | 53,400 | 6,270 |
| February | -------- | 41,933 | 14,330 | 23,200 | 33,300 | 18,800 | 77,200 | 25,900 | 35,800 | 6.040 |
| March | -------- | 39,352 | 34,000 | 150,000 | 63,300 | 36,800 | 53,400 | 48,700 | 70,100 | 12,200 |
| April | -------- | 57,600 | 46,590 | 114,000 | 117,000 | 47,200 | 89,800 | 79,100 | 75,600 | 22,500 |
| May | 123,406 | 126,296 | 85,220 | 197,000 | 120,000 | 54,500 | 162,000 | 86,700 | 106,000 | 67,600 |
| June | 104,073 | 62,598 | 80,210 | 278,000 | 121,000 | 35,900 | 217,000 | 34,900 | 122,000 | 61,300 |
| July | 28,407 | 13,527 | 18,620 | 211,000 | 62,700 | 11,400 | 70,100 | 12,000 | 51,800 | 10,600 |
| August | 3,074 | 6,641 | 4,710 | 42,500 | 16,000 | 5,250 | 16,000 | 3,680 | 11,400 | 3,360 |
| September | 2,559 | 11,306 | 2,690 | 13,400 | 5.380 | 4,850 | 6,600 | 2,880 | 4,680 | 2,210 |
| Total for season | -------- | 373,000 | 338,000 | 1,090,000 | 594,000 | 253,000 | 800,000 | 410,000 | 546,000 | 207,000 |

| Month | Discharge in total acre-feet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1912-13 | 1913-14 | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 |
| October | 2.340 | 3,070 | 4,300 | 2,640 | 19,600 | 3,040 | 9,900 | 2,400 | 7,810 |
| November | 3,040 | 6,550 | 3,460 | 3,370 | 8,630 | 3,300 | 8,510 | 2,740 | 8,750 |
| December | 2,900 | 7,380 | 4,950 | 7,620 | 17,400 | 3,370 | 8,790 | 9,100 | 9,590 |
| January | 5,020 | 71,900 | 8,300 | 94,100 | 17,200 | 3,460 | 6,500 | 6,030 | 16,500 |
| February | 7,610 | 33,700 | 19,200 | 61,600 | 38,300 | 7,890 | 22,100 | 8,400 | 23,700 |
| March | 15,400 | 51,500 | 27,000 | 108,000 | 35,700 | 33,500 | 29,300 | 37,900 | 54,700 |
| April | 37,800 | 67,200 | 52,800 | 127,000 | 70,800 | 46,900 | 58 800 | 72,900 | 49,300 |
| May | 68,200 | 108,000 | 104,000 | 145,000 | 102,000 | 65,200 | 99,000 | 116,500 | 89,200 |
| June | 43,100 | 86,300 | 105,000 | 131,000 | 120,000 | 46,200 | 32,900 | 86,100 | 85,100 |
| July | 15,600 | 38,700 | 30,700 | 59,000 | 30,600 | 9,720 | 9,250 | 22,500 | 20,000 |
| August | 10,700 | 7,500 | 6,400 | 16,700 | 7,870 | 3,200 | 2,650 | 4,900 | 4,060 |
| September | 8,990 | 4,240 | 3,400 | 6,130 | 3,370 | 3,920 | 1,490 | 2,650 | 2,610 |
| Total for season | 221,000 | 486,000 | 370,000 | 762,000 | 471,000 | 230,000 | 289,190 | 372,120 | 371 310 |

The run-off of Kaweah River is subject to relatively wide variations in different years as shown in Table 1. The maximum measured annual run-off at Three Rivers since 1903 is 1,090,000 acre-feet, the minimum is 207,000 acre-feet. Two consecutive years, 1912 and 1913, have had a mean discharge of 214,000 acre-feet or less than one-half the normal. Of recent years, 1916 was a year of excessive run-off; 1917 was about normal; and the last four years have varied from 53 to 89 per cent of normal. The four years 1918 to 1921 are the longest period of record in which no year had a run-off equal to or greater than normal.

### Accuracy of Kaweah River Records.

The records of run-off of the Kaweah River at Three Rivers as obtained by the U. S. Geological Survey have been based on gage height readings taken usually twice per day. During the summer of 1921 an automatic register was also installed by Mr. H. H. Holley. During 1921 the gage height readings have been taken at 7 a.m. and 7 p.m. The resulting discharges as obtained by the recording gages and the two gage height readings are shown in the following table. The same rating table was used for both computations so that the differences in discharge are due to variations of the mean of two gage readings per day from the actual mean.

| Month | Mean discharge, recording gage, second-feet | Mean discharge, 2 gage height readings, second-feet | Difference, second-feet | Difference, per cent |
|---|---|---|---|---|
| April | 826 | 780 | 46 | 5.6 |
| May | 1,440 | 1,360 | 80 | 5.6 |
| June | 1,430 | 1,320 | 110 | 7.6 |

These records indicate that two readings per day at the hours used give a smaller discharge than the actual at this station during the months of snow water flow. This difference is due to the fluctuation of the discharge during the day caused by the variations in the hourly rate of snow melting. As the three tributaries of the Kaweah have an approximately equal length of channel to the portions of their drainage areas contributing the larger portion of the run-off the daily peak of each branch coincides in time at the Three Rivers station. This results in a greater range of daily discharge than would be expected on most of such streams. These daily variations are limited to the months of melted snow flow. Discharge, during the rainy season, does not show similar variations. Typical records are shown in Fig. I.

The comparisons made in 1921 might be used as a basis for a conclusion that the discharge at Three Rivers as published is less than the actual discharge and that some increase in such records would be warranted. Any such corrections would apply only in the summer months and the amount of the correction would depend on the actual time of reading of the gage. The actual time of reading of the gage in the past is not definitely known although it was probably in the early morning and toward evening. The uncertainties as to the time of reading make the application of a correction inadvisable. The conclusion appears warranted, however, that the actual discharge at Three Rivers is probably slightly more rather than less than the amount shown by the record.

**Kaweah River Records 1919 and 1920.**

Since 1916 a record of the discharge of Kaweah River at McKay Point has been kept by the canals interested in the division of flow at that point, the actual record being secured under the supervision of Mr. H. H. Holley, engineer for the canal association. A comparison of the record at McKay Point with that at Three Rivers indicated differences not explainable by intermediate diversions. These differences began to occur late in 1918. In order to secure a check on the Three Rivers record an automatic register was installed at Three Rivers in 1921 by Mr. Holley. A change was also made in the Geological Survey observer. The records during 1921 (Table 2) indicated a close agreement of the discharge at Three Rivers and at McKay Point when allowances for intermediate diversions are made. As the Three Rivers record for 1919 and 1920 appears to be based on inaccurate gage height records a substitute record has been prepared based on the McKay Point record plus the intermediate diversions.

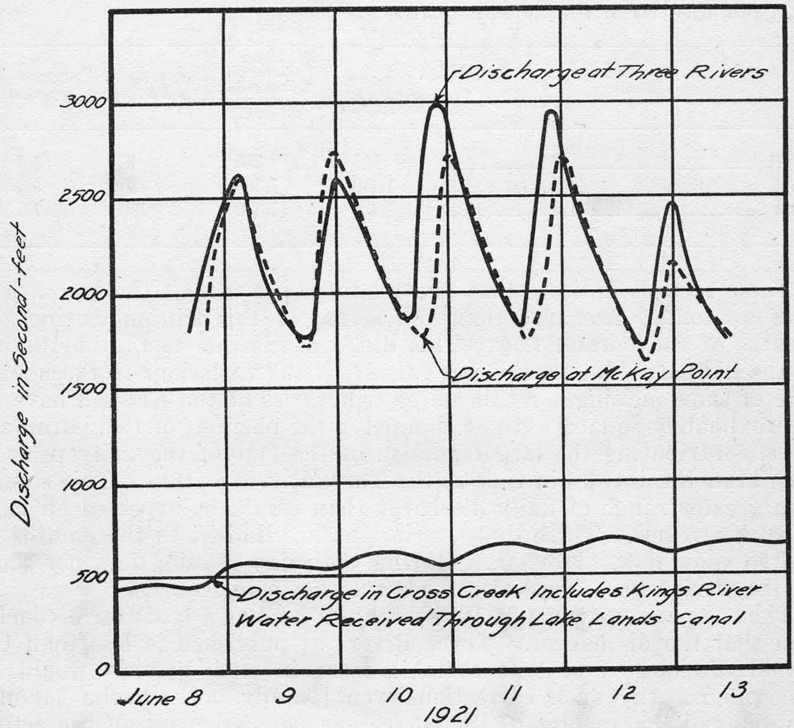


*Fig. 1. Comparison of Discharge of Kaweah River at Three Rivers and at McKay Point Based on Automatic Registers*

TABLE 2.

**Comparison of U. S. Geological Survey Record of Discharge of Kaweah River at Three Rivers for 1918-1921 with Record Computed by Adding Intermediate Diversions to Discharge of Kaweah River at McKay Point.**

| Month | Total acre-feet, 1918-19 | | | Total acre-feet, 1919-20 | | | Total acre-feet, 1920-21 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Computed | U.S.G.S. | Difference U.S.G.S. minus computed | Computed | U.S.G.S. | Difference U.S.G.S. minus computed | Computed | U.S.G.S. | Difference U.S.G.S. minus computed |
| October | *9,900 | 9,900 | ---------- | 2,400 | 3,880 | +1,480 | 6,350 | 7,810 | +1,460 |
| November | *8,510 | 8,510 | ---------- | 2,740 | 3,620 | +880 | 7,910 | 8,750 | +840 |
| December | *8,790 | 8,790 | ---------- | 9,100 | 29,100 | +20,000 | 9,470 | 9,590 | +120 |
| January | 6,500 | 6,640 | +140 | 6,030 | 7,190 | +1,160 | 15,700 | 16,500 | +800 |
| February | 22,100 | 18,900 | —3,200 | 8,400 | 9,610 | +1,210 | 22,700 | 23,700 | +1,000 |
| March | 29,300 | 26,300 | —3,000 | 37,900 | 60,100 | +22,200 | 45,500 | 54,700 | +9,200 |
| April | 58,800 | 66,000 | +7,200 | 72,900 | 69,600 | —3,300 | 51,000 | 49,300 | —1,700 |
| May | 99,000 | 99,000 | ---------- | 116,500 | 108,000 | —8,500 | 89,500 | 89,200 | —300 |
| June | 32,900 | 29,400 | —3,500 | 86,100 | 97,000 | +10,900 | 84,400 | 85,100 | +700 |
| July | 9,250 | 7,130 | —2,120 | 22,500 | 22,800 | +300 | 21,270 | 20,000 | —1,270 |
| August | 2,650 | 2,410 | —240 | 4,900 | 5,830 | +930 | 4,140 | 4,060 | —80 |
| September | 1,490 | 2,340 | +850 | 2,650 | 3,660 | +1,010 | 2,850 | 2,610 | —240 |
| Totals | 289,190 | 285,320 | —3,870 | 372,120 | 420,390 | +48,270 | 360,790 | 371,310 | +10,530 |

*U. S. Geological Survey record used.

The McKay Point record since 1917 has been secured by means of an automatic register. The rating is controlled by the weir used to divide the flow between the Kaweah and St. Johns channels. The records of diversion (secured by Mr. Holley) of the canals diverting between Three Rivers and McKay Point are not complete and estimates have been used for portions of the record. The estimates are considered to be fairly accurate as the diversions are relatively uniform and the amounts estimated are a small part of the computed totals. The intermediate run-off between Three Rivers and McKay Point was relatively small in all of the years used in these comparisons.

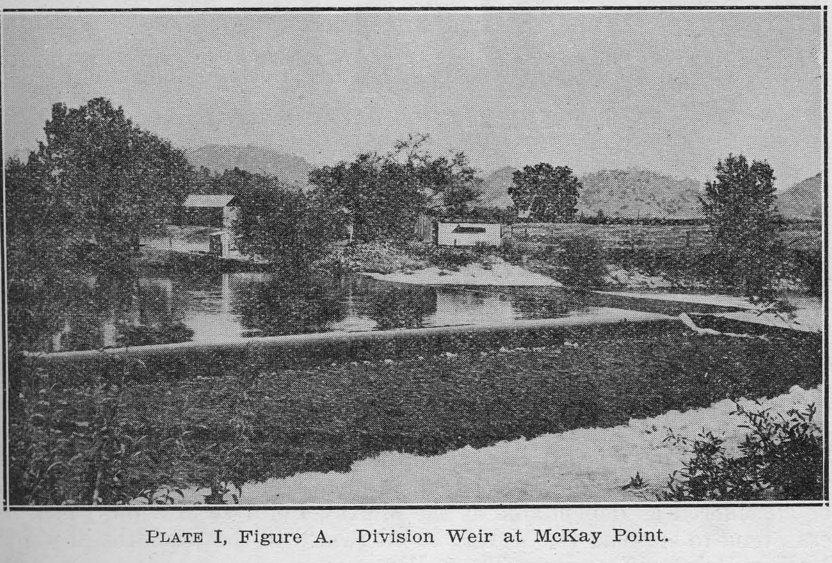

PLATE I, Figure A. Division Weir at McKay Point.

The agreement of the Three Rivers and McKay Point records for a typical period in 1921 as well as the extent of daily fluctuation are shown in Fig. 1. The difference in discharge is due to intermediate diversions. At the dates where the river is rising the time difference between Three Rivers and McKay Point, a distance of 9 miles is only one to two hours; on other dates when the river is falling the difference in time is about seven hours. The extent of the daily fluctuations indicates the probability of error where records are based on single gage readings. The river rises for about six hours during the day and recedes during the other eighteen hours. These period correspond with the time of melting at the higher altitudes. The percentage fluctuations at McKay Point are larger than at Three Rivers indicating that there is no spreading out of the maximums or minimums in the stream channel between these two points.

Other comparisons were tried in order to check the Three Rivers records. The total annual discharge of the Kaweah River was compared with that of the Kings and Tule rivers. The variations in the ratio of run-off in different years are greater than the variations in the

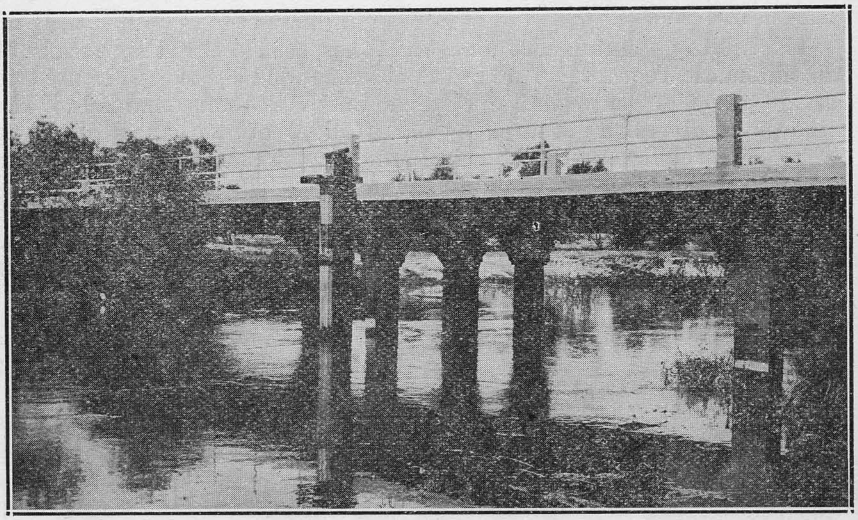

PLATE I, Figure B. Gaging Station on Cross Creek at Hanford Road Bridge.

years in question on the Kaweah River. Apparently the storms producing the larger portions of the precipitation vary in their distribution over these adjacent drainage areas in different years so that the relationship of the resulting run-off is not consistent.

A comparison of the sum of the records on the North, Middle and South forks with that at Three Rivers was also made. The records on the Middle Fork are kept by the power companies at their diversions. The South Fork record is not complete in recent years. While the records of these stations are based on gage readings only and can not be considered as dependable as the McKay Point record, they, in general, tend to support the McKay Point record in those months in which McKay Point differs from Three Rivers.

As these comparisons indicated that the record computed for the discharge at Three Rivers was more consistent than the Three Rivers record, the computed results have been used for the years 1918–19 and 1919–20. For 1920–21 the Three Rivers record was used as it agrees quite consistently with that computed from McKay Point except during March.

**Channel Losses in Kaweah River.**

In order to determine whether there is any channel seepage either above or below Three Rivers a series of measurements were made during the low water period in August and September, 1921. Measurements were made of each of the three forks and of the diversions and the records at Three Rivers and McKay Point for the same dates secured. The results are shown in the following table:

| | Upper measurement, second-feet | Lower measurement, second-feet | Diversions, second-feet | Losses or gain, second-feet |
|---|---|---|---|---|
| North Fork | 2.84 | 1.79 | 3.02 | +1.97 |
| South Fork | 4.82 | 1.0 | 2.92 | —0.90 |
| Middle Fork | ----------- | 43.30 | ----------- | ----------- |
| Total | ----------- | 46.20 | ----------- | ----------- |
| Kaweah River at Three Rivers Sta. | ----------- | 51.00 | ----------- | +4.80 |

The gain on North Fork is considered to be due to return flow from irrigation diversions. The loss on South Fork occurs in the coarse material in the lower portion of its length. Measurements up the Middle Fork were not made due to conditions of diversion for power. There is probably little, if any, loss except by seepage from the power flumes which may be lost before reaching the river.

From the junction of North and Middle Forks there appears to have been a gain of nearly five second-feet to the gaging station below Three Rivers, a distance of about four miles. In the nine miles between Three Rivers and McKay Point there was an indicated gain of seven second-feet. The extent to which these gains may continue throughout the year is not known. It is probable that they represent mainly ground seepage to the river channel from early season flood flow or diversion for irrigation rather than a continuous ground water movement. The conclusion appears warranted that there is at least no channel loss above McKay Point and that the flow at Three Rivers is the total run-off of the upper drainage area. The wells above McKay Point have in general given small yields, a further indication of lack of seepage.

## TULE RIVER.

There are two points of measurement whose records give the principal part of the run-off of the Tule River drainage area. These are the stations (1) on the main river above the mouth of the South Fork and (2) on the South Fork. The run-off of the small area below these stations is discussed with the other minor drainage areas.

**Main Tule River.**

The record of the main stream gives the run-off from 266 square miles of drainage area including the Middle and North Forks and their tributaries. The drainage area extends back to the divide of the Kern River drainage at elevations of over 9000 feet along most of the crest. The North Fork of Middle Fork extends northward to the east of North Fork and receives the drainage of much of this higher area. The mean annual run-off of the North Fork of the Middle Fork appears to be about 900 acre-feet per square mile, of the South Fork of the Middle Fork about 600 acre-feet per square mile and for the remainder including the North Fork about 275 acre-feet per square mile.

The record on the main stream is continuous since 1901. There are a few small diversions above the station but the record gives the water available for use below. Its accuracy is considered satisfactory. The records are based on daily gage heights. There are no continuous gage records available. The daily fluctuations due to snow melting are probably less on this stream than on the Kaweah. The annual discharges are given in Table 3.

**TABLE 3.**

**Runoff of Tule River Near Porterville, Above Mouth of South Fork. Drainage Area, 266 Square Miles. Record of U. S. Geological Survey.**

| Month | Discharge in total acre-feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1901 | 1901-02 | 1902-03 | 1903-04 | 1904-05 | 1905-06 | 1906-07 | 1907-08 | 1908-09 | 1909-10 |
| October | -------- | 1,783 | 1,476 | 1,045 | 3,382 | 775 | 2,370 | 2,830 | 1,920 | 2,740 |
| November | -------- | 2,559 | 2,975 | 1,428 | 1,785 | 2,523 | 2,900 | 3,150 | 2,030 | 5,270 |
| December | -------- | 3,074 | 3,812 | 1,722 | 2,275 | 5,792 | 5,970 | 6,520 | 2,720 | 36,600 |
| January | -------- | 2,767 | 15,618 | 1,845 | 2,914 | 30,700 | 14,300 | 7,130 | 55,000 | 21,100 |
| February | -------- | 8,830 | 9,608 | 6,960 | 4,215 | 11,100 | 15,800 | 15,200 | 49,800 | 10,000 |
| March | -------- | 22,259 | 15,864 | 17,401 | 14,140 | 84,200 | 21,800 | 18,200 | 32,600 | 13,300 |
| April | -------- | 33,977 | 26,598 | 16,602 | 12,200 | 45,900 | 45,500 | 10,600 | 45,200 | 13,600 |
| May | 25,702 | 21,090 | 22,013 | 16,110 | 19,250 | 66,400 | 20,800 | 10,100 | 45,000 | 9,470 |
| June | 14,281 | 11,306 | 9,402 | 4,403 | 8,688 | 57,800 | 15,600 | 4,750 | 34,300 | 3,180 |
| July | 3,751 | 2,644 | 2.337 | 1,045 | 2,023 | 22,300 | 5,060 | 1,230 | 10,100 | 1,110 |
| August | 1,168 | 1,291 | 1,045 | 553 | 603 | 5,180 | 2,260 | 633 | 3,300 | 406 |
| September | 1,012 | 893 | 833 | 1,190 | 488 | 2,820 | 1,780 | 1,100 | 2,300 | 631 |
| Totals | ·45,900 | 112,000 | 112,000 | 70,300 | 71,000 | 335,000 | 154,000 | 81,400 | 285,000 | 117,000 |

| Month | Discharge in total acre-feet | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1910-11 | 1911-12 | 1912-13 | 1913-14 | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 |
| October | 1,360 | 1,520 | 429 | 212 | 928 | 581 | 5,840 | 928 | 490 | 529 | 879 |
| November | 1,900 | 2,550 | 904 | 2,230 | 1,210 | 1,750 | 3,800 | 1,680 | 1,430 | 976 | 1,690 |
| December | 2,980 | 2,930 | 1,390 | 4,180 | 2,560 | 3,790 | 12,600 | 2,180 | 2,790 | 3,230 | 3,070 |
| January | 17,800 | 4,000 | 1,740 | 44,400 | 4,500 | 58,200 | 9,410 | 2,370 | 2,490 | 1,920 | 4,960 |
| February | 15,100 | 3,370 | 1,640 | 14,300 | 9,720 | 33,200 | 19,300 | 2,870 | 6,500 | 2,160 | 8,500 |
| March | 26,900 | 5,450 | 5,130 | 14,300 | 10,600 | 51,800 | 16,100 | 12,800 | 13,500 | 18,100 | 14,400 |
| April | 21,000 | 9,700 | 7,970 | 15,900 | 14,900 | 38,700 | 23,000 | 8,930 | 15,600 | 25,600 | 9,640 |
| May | 17,400 | 12,200 | 6,210 | 16,500 | 37,400 | 33,200 | 24,800 | 5,810 | 12,100 | 20,700 | 15,300 |
| June | 10,800 | 6,720 | 2,950 | 9,640 | 16,100 | 18,500 | 17,500 | 1,960 | 2,700 | 9,340 | 8,930 |
| July | 3,380 | 842 | 445 | 2,480 | 3,510 | 6,200 | 3,640 | 167 | 259 | 1,510 | 1,090 |
| August | 1,330 | 175 | 142 | 627 | 744 | 2,240 | 1,150 | 56 | 34 | 194 | 98 |
| September | 988 | 314 | 278 | 397 | 625 | 1,200 | 547 | 159 | 18 | 209 | 57 |
| Totals | 121,000 | 49,800 | 29,200 | 125,000 | 103,000 | 249,000 | 138,000 | 39,900 | 57,911 | 84,468 | 68,614 |

The mean annual discharge of the main river station since 1901 has been 120,000 acre-feet. This record does not cover the dry period between 1890 and 1900. As the rainfall records begin in 1889, the measured run-off since 1901 was plotted against the rainfall for each year and the indicated relationship used to estimate the probable run-off for 1889 to 1900. The rainfall for these earlier years averaged 88 per cent of the long time mean. The resulting estimates of run-off averaged 88,000 acre-feet per year for this earlier period.

For the full period, 1889 to 1921, the estimated and measured run-off indicates a mean annual discharge of 106,000 acre-feet per year for the area above the present gaging station on the main Tule River.

For the period of actual record the years of smallest discharge were 1912 and 1913 with a total of 50,000 and 29,000 acre-feet respectively or 47 and 27 per cent of the probable long time mean. In 1918 the discharge was 38 per cent of the long time mean. The largest measured discharge was in 1906 with 335,000 acre-feet or three times the long time mean. Two other years, 1909 and 1916, were 2½ and 2¼ times the mean. For the years 1889 to 1901 the estimates indicate a minimum discharge of 28,000 acre-feet in 1898 with no years exceeding 1.5 times the probable long time mean.

For the long time period the discharge at the gaging station on the main Tule River appears to be derived about as follows:

| Drainage area | Mean annual run-off, acre-feet | Per cent of total |
|---|---|---|
| South Fork of Middle Fork | 25,000 | 23 |
| North Fork of Middle Fork | 30,000 | 27 |
| Bear Creek | 5,000 | 5 |
| Remainder of drainage area | 46,000 | 45 |
| Totals | 106,000 | 100 |

**South Fork of the Tule River.**

The records on the South Fork of Tule River began in 1910. The record is not complete for all parts of the period since 1910. The discharges are given in Table 4 in which the missing records which have been supplied by estimates based on comparison with the record of the main Tule River are indicated.

For the eleven years of record the mean annual discharge has been 28,750 acre-feet. The maximum measured run-off has been 87,000 acre-feet in 1916 and the minimum 9040 acre-feet in 1913.

In order to estimate the run-off on the South Fork over a longer period than that covered by the record, the recorded discharges on the South Fork were plotted against the discharge of the main Tule River. From the relationship indicated the discharges for previous years were estimated by comparison with the measured or estimated discharges on the main Tule River.

For the period 1890 to 1921, the mean annual discharge of the South Fork of Tule River, as estimated on the above basis, appears to have been 29,000 acre-feet with variations from 8000 to 95,000 acre-feet in different years.

The gaging station on the South Fork is several miles above its entrance into the main stream. The gaging station on the main stream is also above the base of the hills. While the portion of the drainage area from which the run-off is not measured furnishes a relatively small part of the total discharge it has been estimated for purposes of completeness. The results are shown with those for all areas in Table 6. In minimum years the discharge is negligible; in wet years it is estimated that as much as 9000 acre-feet of run-off may occur with an average of about 2000 acre-feet per year. The estimate for this lower area was based on the same methods that were used for other small unmeasured areas as explained later.

TABLE 4.

**Runoff of South Fork of Tule River Near Porterville. Drainage Area, 76 Square Miles. Record of U. S. Geological Survey Except as Noted.**

| Month | Discharge in total acre-feet | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1910-11 | 1911-12 | 1912-13 | 1913-14 | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 |
| October | 302 | 440 | 285 | 132 | 326 | 264 | 1,680 | 330 | 470 | 311 | 430 |
| November | 780 | 509 | 546 | 584 | 405 | 738 | *750 | 550 | 750 | 370 | 893 |
| December | 916 | 719 | 555 | 1,760 | 818 | 2,340 | *1,000 | 607 | 1,030 | 2,210 | 1,540 |
| January | 3,210 | 615 | 941 | 15,300 | 1,440 | 21,600 | 2,800 | 715 | 756 | 568 | 1,840 |
| February | 2,850 | 555 | 944 | 4,670 | 2,850 | 12,500 | *4,000 | 1,524 | 1,790 | 863 | 2,780 |
| March | 6,760 | 1,640 | 1,650 | 4,090 | 3,190 | 18,800 | 5,200 | 3,204 | 4,480 | 6,390 | 4,610 |
| April | 4,560 | 4,150 | 1,830 | 5,360 | 4,320 | 13,000 | *5,000 | 2,012 | 4,590 | 9,340 | 3,270 |
| May | 2,860 | 3,740 | 1,040 | 4,110 | 14,300 | 9,900 | *3,500 | *1,200 | 3,140 | 3,830 | 3,330 |
| June | 1,480 | 1,830 | 684 | 1,570 | 4,250 | 4,630 | 3,720 | *500 | 940 | 1,970 | 2,150 |
| July | 481 | 595 | 303 | 658 | 1,380 | 1,920 | 1,340 | 114 | 233 | 726 | 615 |
| August | 196 | 210 | 112 | 151 | 435 | 849 | 586 | 46 | 133 | 322 | 242 |
| September | 162 | 158 | 152 | 165 | 256 | 496 | 270 | 209 | 135 | 417 | 210 |
| Totals | 24,600 | 15,200 | 9,040 | 38,000 | 34,000 | 87,000 | 29,846 | 11,011 | 18,447 | 27,317 | 21,910 |

*Records incomplete; discharge estimated by comparison with Main Tule River in connection with these investigations.

### Summary for Entire Tule River Drainage Area.

A summary of the run-off for the different parts of the Tule River drainage area gives a total estimated long time mean annual run-off of 137,000 acre-feet with a minimum of 36,000 acre-feet and a miximum of 439,000 acre-feet. For the thirty-two years covered by the records and estimates, there are three years in which the run-off exceeds twice the mean. The run-off in each of the last four years has been less than normal, the average for the four years being 59 per cent of normal. This is the longest period during the thirty-two years in which no year had a run-off at least equal to the mean.

### Run-off of Smaller Drainage Areas in Tulare County.

In addition to Kaweah and Tule rivers there are Deer and White creeks and various other small drainage areas which discharge their run-off into the valley portion of Tulare County. Except for Deer and White creeks the discharge of these streams has not been measured. In order to make an estimate of the total water supply of the area some basis of estimating the discharge of such drainage areas is required.

The method used has consisted of an estimate of the precipitation at different elevations on each drainage area with an estimate of the run-off resulting from such precipitation. The details of the method are discussed in Bulletin 9 of this office entitled "Water Resources of Kern River and Adjacent Streams and Their Utilization." The curves used for Tulare County are as shown in Figs. 2 and 3.

Most of the precipitation records available are for relative low elevations. Precipitation increases with elevation; the rate at which such increase occurs appears to be as indicated in Fig. 2, based on such records as are available.

The relationship of rainfall and run-off as shown in Fig. 3 is also based on such records as are available. The curves for drainage areas for which the discharge has been measured were developed by trial. The curves for unmeasured areas were then estimated by comparison of the character of the drainage areas.

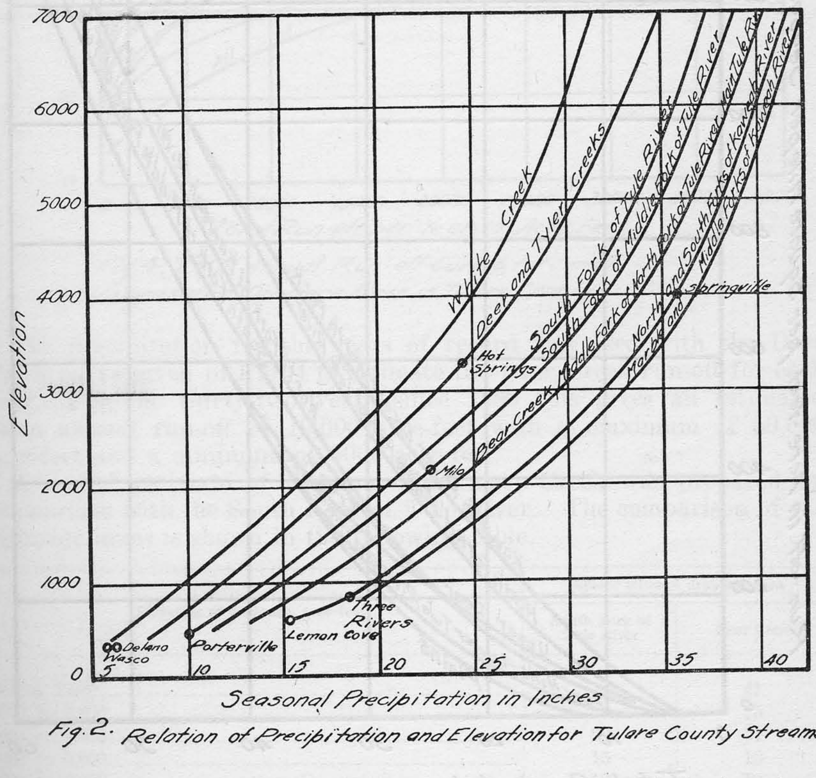


Fig. 2. Relation of Precipitation and Elevation for Tulare County Streams

While such a method of estimation can not be exact it is thought to represent the probable run-off within reasonable limits. The figures given are thought to be fully as large as the actual run-off.

**Deer Creek.**

There is a record for the upper 17 miles of drainage area at Hot Springs from 1911 to date, one for 15 square miles on Tyler Creek for 1911-13 and one for 1919 to date for 76 square miles of drainage as secured by Mr. Irving Althouse, engineer for the Terra Bella Irrigation District.

The Tyler Creek records are classed as poor by the U. S. Geological Survey. The Hot Springs record on Deer Creek is generally fairly consistent; the 1920-21 record, however, appears excessive in comparison with other adjacent streams. The elevation, rainfall, and run-off relationships were developed for Deer Creek above Hot Springs as shown in Figs. 2 and 3. These agree fairly well with the records. These curves were used for estimating the long time run-off of the remaining upper drainage area on Tyler Creek. For the drainage

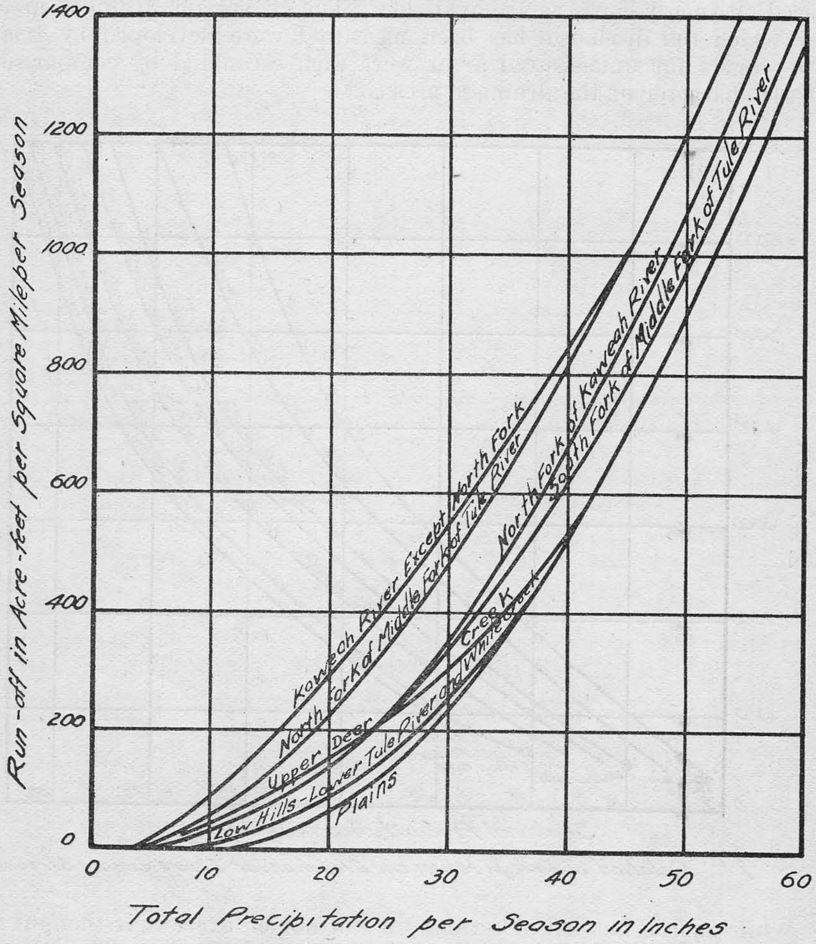


Fig. 3. Relation of Precipitation and Run-off for Tulare County Drainage Areas

area below Hot Springs the rainfall run-off records for 'plains' conditions was used. From the parts, the run-off of the total drainage area was computed giving the curve shown in Fig. 4.

The run-off curve for the entire Deer Creek drainage area given in Fig. 4 gives results averaging about 18 per cent greater for 1920 and

1921 than the measurements made by the Terra Bella Irrigation District. The conditions in both of these years were such as to produce probably less than the average run-off from the precipitation. The run-off curve used appears, however, to give results as great, if not somewhat greater, than would probably be shown by a long direct record of run-off.

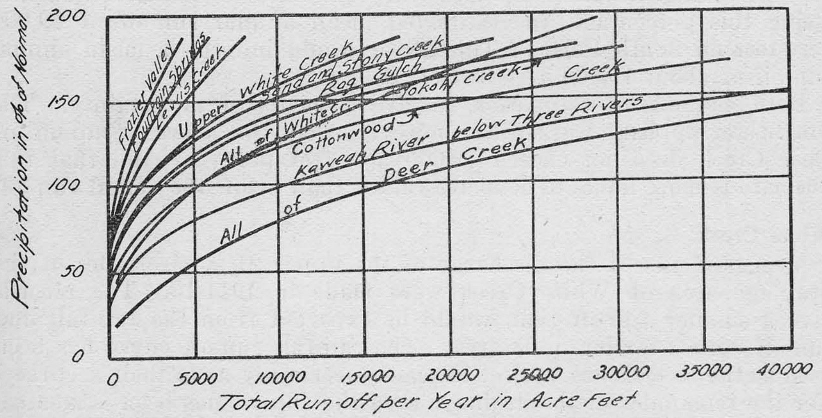


Fig. 4. Total Annual Run-off Curves for Small Unmeasured Drainage Areas in Tulare County

The precipitation for the years of record was used with the Deer Creek curve given in Fig. 4 to estimate the Deer Creek run-off for each year. For the thirty-two years since 1890 this gives an estimated mean annual run-off of 19,000 acre-feet with a maximum of 50,000 acre-feet and a minimum of 5000 acre-feet.

A second estimate of the run-off of Deer Creek was prepared by comparison with the South Fork of Tule River. The comparison of the drainage areas is shown in the following table.

| Elevation of drainage, acre-feet | Square miles of drainage area | |
|---|---|---|
| | South Fork of Tule River | Deer Creek |
| Below 2,000 | 4 | 41 |
| 2,000 to 3,000 | 8 | 15 |
| 3,000 to 4,000 | 20 | 21 |
| 4,000 to 5,000 | 15 | 12 |
| 5,000 to 6,000 | 12 | 10 |
| Over 6,000 | 17 | 11 |
| Totals | 76 | 110 |
| Total above 2,000 | 72 | 69 |

Some of the South Fork drainage area exceeds 8000 feet in altitude. While the total areas above 2000 feet elevation are closely similar, the South Fork has 44 square miles over 4000 feet elevation as compared with 33 square miles for Deer Creek. The rainfall curves, Fig. 2, indicate that the South Fork will receive about one-eighth more precipitation than Deer Creek due to its location farther north.

The recorded run-off of South Fork of Tule River for 1920 and 1921 is 27,300 and 21,900 acre-feet. The measured run-off of Deer Creek was 14,100 and 11,400 acre-feet for these years. This equals 52 per cent of the estimated run-off of South Fork in each of the two years. The percentage relationship may vary in years of excessive rainfall. Using this percentage, the estimated mean annual run-off of 29,000 acre-feet on South Fork of Tule River would indicate a mean annual run-off of about 15,000 acre-feet on Deer Creek.

Both methods of estimation involve elements of uncertainty. The conclusion appears warranted, however, that the average run-off of Deer Creek does not exceed 19,000 acre-feet per year and that this estimate is more liable to be above rather than below the actual run-off.

**White Creek.**

Measurements of the discharge of the upper 21 square miles of the drainage area of White Creek were made in 1911-13. The records give a smaller run-off than would be expected from the rainfall and run-off curves for low hills area. The rainfall run-off curve has been used as the records are subject to some uncertainty as to their accuracy. For the remainder of the drainage area the run-off has been estimated, using the rainfall run-off curve for the plains area. The resulting curves are shown in Figs. 2, 3 and 4.

The estimated mean annual run-off for the 77 square miles below the gaging station is 2500 acre-feet and that for the area above the gaging station is 3800 acre-feet, a total for the whole stream of 6300 acre-feet. All of this run-off can be considered as reaching the ground water as the flow is absorbed from the creek channel, the distance to which the flow reaches varying with the run-off in different years. The estimated total run-off varies from 1500 to 26,000 acre-feet in different years. The estimated average run-off for the five years 1917 to 1921 is 4000 acre-feet.

White Creek drains a narrow strip of area extending directly back to the divide of the Kern River drainage area. It does not extend along this divide to the same extent as Deer Creek and consequently has a smaller drainage area at the higher elevations. The run-off of White Creek appears to be less, relatively, than that of Deer Creek.

In 1921, the rains in May resulted in flow as far as the Southern Pacific Railroad south of Ducor, a discharge of 12 second-feet being used in irrigating grain at that point on May 23. The flow rapidly decreased and receded up the creek channel within a few days. The flow at the east line of township 27 east began early in May and continued at a general average of about four second-feet until the middle of June. About two miles further upstream the flow began early in April and continued to the end of June. In 1909 it is stated that water reached the east line of township 24 east. In 1919, the water is reported to have reached Sec. 7, T. 24 S., R. 26 E., and in 1920, Sec. 11, T. 24 S., R. 26 E. The channel in this portion of its length has been eroded into the older sediments and has not built a more recent delta until the areas further west are reached.

## RUN-OFF OF MINOR DRAINAGE AREAS IN TULARE COUNTY.

In this discussion are included the small streams and the portions of the main streams below the gaging stations. While small in amount and uncertain in occurrence some attempt to estimate quantitatively the run-off of these drainage areas appears to be desirable. Such an estimate is difficult to make due to the absence of direct records. The estimates given are those for the total quantity of water which would be expected to be discharged from each area. In some cases locations

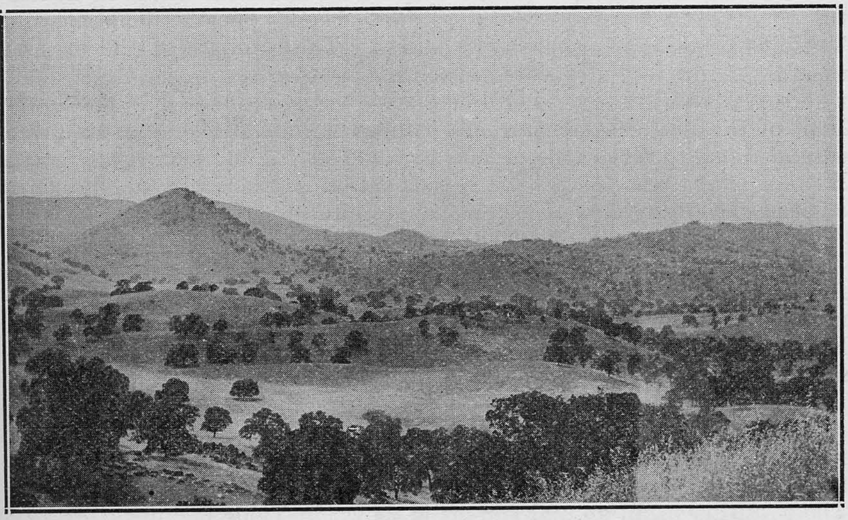

PLATE II, Figure A. General View of Drainage Area of Yokohl Creek.

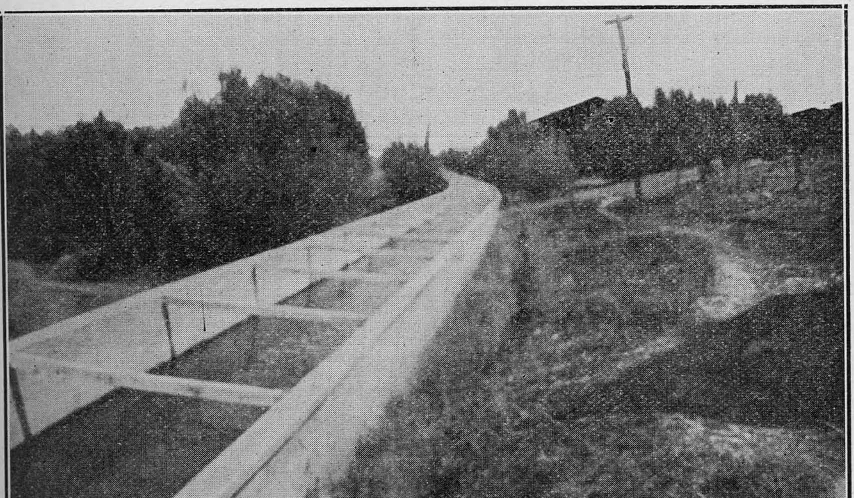

PLATE II, Figure B. Concrete Flume of Lindsay-Strathmore Irrigation District.

for measuring the quantities given probably would be difficult to find as the channels probably lose water within the drainage areas. The figures given are the total amount of water which it is estimated the drainage areas contribute to the ground water or to direct diversion. While there is no basis for testing the accuracy of the estimates it is thought that they are greater rather than less than the actual run-off.

The smaller drainage areas were taken from the 1919 Forest Service map of the Sequoia National Forest, having a scale of one-fourth inch to the mile. This map shows streams but not elevations. As far as the area covered permitted these were checked by the Kaweah and Tehipite U. S. G. S. quadrangle sheets. The estimate of the area in each thousand feet of elevation was made from the U. S. G. S. sheet where available and by general estimate for the remainder. The lower limit of the area contributing any run-off is indefinite, the areas given extend down to elevations of 500 to 600 feet for most of the streams. Run-off from areas below 2000 feet elevation is practically negligible in amount except in years of excessive precipitation.

The drainage areas are given in Table 5.

The estimated precipitation was taken for the different elevations from the precipitation and elevation curves shown in Fig. 2. The estimated run-off was taken from the rainfall run-off curves shown in Fig. 3. The 'plains' curve was used for the lower drainage areas modified somewhat to take into account local factors in the probable variation of rainfall with elevation. The curves showing the resulting relation between the estimated run-off and the rainfall in per cent of normal are shown in Fig. 4. These curves are used with the precipitation for each year to give the estimated total run-off for that year. The resulting mean annual run-off is shown in Table 6.

**TABLE 5.**

**Drainage Areas of Foot Hills Streams, Tulare County.**

| Stream | Drainage area in square miles | Elevation of drainage area |
|---|---|---|
| Sand and Storey creeks east of Orosi | 50 | All estimated as less than 2000 feet elevation. No map available. |
| Cottonwood Creek above Woodlake | 87 | Estimated as 57 square miles 2000 to 3000 feet; 10 square miles 3000 to 4000 feet. |
| Limekiln Creek | 87 | Estimated as 40 square miles under 2000 feet; 25 square miles 2000 to 3000 feet; 15 square miles 3000 to 4000 feet; 5 square miles 4000 to 5000 feet; and 2 square miles over 5000 feet. |
| Greasy Creek and Kaweah River on north side below Three Rivers | 15 | 8 square miles over 2000 feet elevation—maximum, 3500 feet. |
| Kaweah River on south side below Three Rivers including Horse Creek | 37 | Varies from 600 to 3000 feet; 15 square miles over 2000 feet. |
| Yokohl Creek | 52 | 27 square miles under 2000 feet; 12 square miles 2000 to 3000 feet; 8 square miles 3000 to 4000 feet; 5 square miles 4000 to 5000 feet. |
| Lewis Creek | 32 | 5 square miles over 2000 feet; rest down to 700 feet. |
| Frazier Valley | 15 | All under 2000 feet. |
| Tule River below Success and South Fork below gaging station | 50 | 10 square miles over 2000 feet. |
| Deer Creek below Terra Bella Irrigation district station | 27 | All under 2000 feet. |
| Fountain Springs area | 36 | All under 2000 feet. |
| Rag Gulch | 130 | 72 square miles under 2000 feet; 50 square miles 2000 to 3000 feet; 5 square miles 3000 to 4000 feet; 3 square miles over 4000 feet. |
| White Creek below gaging station | 77 | 49 square miles under 2000 feet; 25 square miles 2000 to 3000 feet; 3 square miles 3000 to 4000 feet. |

For all drainage areas shown the estimated mean annual run-off is 39,000 acre-feet for the 700 square miles included. Of this about one-third is into Kaweah River below the Three Rivers gaging station, the largest part of this coming from Limekiln Creek which has some drainage area of 6000 feet elevation in Grouse Meadows. The upper portions of the drainage area of Limekiln Creek should have a rate of run-off similar to areas of equal elevation on the North Fork of the Kaweah. Cottonwood Creek has a drainage area similar in size to that of Limekiln Creek but of lower average elevation. The general topography is somewhat less rugged and a smaller rate of run-off is to be expected. This is indicated by conditions in 1920-21 when Limekiln Creek flowed during the winter and during the rain in May, 1921, while no surface flow reached the lower portions of Cottonwood Creek during this period.

The other lower tributaries of the Kaweah River are small and of limited discharge, flowing only after fairly heavy storms.

Yokohl Creek, while it may be considered as a tributary to Kaweah River, enters the valley lands before reaching the river and is practically a separate stream. The upper portion of the drainage area is fairly rugged with some bare granite, the lower hills are rounded and there are bottom areas along the creek in which the flow may be largely absorbed. In some portions willows and grass indicate some ground water supply. The upper one-half of the drainage area probably supplies over three-fourths of the run-off. The total run-off appears to reach the ground water along its course or in the adjacent areas in the valley.

TABLE 6.

Estimated Run-off of Minor Drainage Areas in Tulare County.

| Drainage area | Drainage area, square miles | Estimated mean annual runoff total, acre-feet | Estimated mean annual runoff, acre-feet per square mile |
|---|---|---|---|
| Sand and Storey creeks | 50 | 3,000 | 60 |
| Cottonwood Creek | 87 | 7,000 | 80 |
| Kaweah River below gaging station, including Limekiln Creek | 142 | 13,000 | 92 |
| Yokohl Creek | 55 | 4,000 | 73 |
| Lewis Creek | 22 | 1,500 | 68 |
| Frazier Valley | 22 | 500 | 23 |
| Tule River below gaging stations | 57 | 2,000 | 35 |
| Dear Creek below gaging station | 27 | 800 | 30 |
| Fountain Springs | 36 | 1,000 | 28 |
| White Creek below gaging station | 77 | 2,500 | 32 |
| Rag Gulch | 130 | 3,500 | 27 |
| Totals | 705 | 38,800 | 55 |

Lewis Creek has a small drainage area, all of which is less than 3000 feet in elevation. There is a dam with wells on this creek, the water being taken to lower lands. The lands served are now a part of the Lindsay-Strathmore Irrigation District. Lewis Creek is reported to flow only following relatively heavy rains such as storms giving a precipitation of two inches or over.

Frazier Valley and Fountain Springs areas are broad, flat land from which the surface run-off is negligible in amount but in which there may be minor absorption in the channels of local washes.

The lower Tule River areas are largely on the South Fork below the gaging station. The estimate used indicates that such run-off is less than 2 per cent of that measured at the gaging stations.

Deer Creek below the gaging station is a low area which probably contributes run-off only at times of excessive precipitation. The average amount may be as estimated.

White Creek below the gaging station is a rolling area two-thirds of which is below 2000 feet elevation. An erratic run-off of about the amount given is to be expected.

Rag Gulch has a rather extensive rolling drainage area of generally low elevation. In many years its run-off does not reach the valley as surface flow. This drainage is the only definite area tributary to the lands along the Tulare-Kern County line and its uncertain and limited discharge indicates the lack of direct sources of ground water replenishment in this area.

## TOTAL WATER SUPPLY FROM DRAINAGE AREAS DISCHARGING INTO TULARE COUNTY.

The preceeding discussions of the run-off of each drainage area may be summarized as follows:

**Total Mean Annual Run-off of Drainage Areas Discharging Into Tulare County.**

| Streams from North to South | Acre-feet |
|---|---|
| Sand and Storey Creeks | 3,000 |
| Cottonwood Creek | 7,000 |
| Kaweah River, entire drainage area | 451,000 |
| Yokohl Creek | 4,000 |
| Lewis Creek | 1,500 |
| Frazier Valley | 500 |
| Tule River, entire drainage area | 137,000 |
| Deer Creek | 18,900 |
| Fountain Springs | 1,000 |
| White Creek | 6,300 |
| Rag Gulch | 3,500 |
| Total | 633,700 |

The total given, 634,000 acre-feet, represents the total water supply which, from the data now available, appears to be the mean annual water supply from these areas. The records are considered adequate to furnish a basis for determining with practical accuracy the actual run-off. It is not probable that longer periods of measurement will show mean discharges materially different from the figure given. The total represents the water which is available for use in the portions of Tulare County dependent on this supply for their irrigation. Not all of this discharge is now used or can be used due to variations in its amount in different years. It is not evenly distributed over the areas requiring irrigation. Its utilization depends on the detailed conditions for storing in reservoirs, diversion by canals, or absorption as ground water all of which vary with different streams. The utilization of these water supplies is discussed separately for the areas dependent on the separate sources of supply.

As later discussed the average surface outflow of the Kaweah River is estimated to be 70,000 acre-feet per year and of the Tule River 17,000 acre-feet per year. Deducting these amounts from the total inflow of 634,000 acre-feet gives a mean annual water supply under present conditions of development for the lands dependent on these water supplies of 547,000 acre-feet.

## SURFACE OUTFLOW FROM VALLEY AREAS.

The preceding discussions have covered the water supply entering the irrigable areas covered by this report. Not all of such flow is retained within the area. At times of flood a part of the run-off passes across the valley areas and enters Tulare Lake. The following discussion relates to the surface flow which passes across the valley areas. Questions regarding the escape from these areas of ground water supplies are discussed later in Chapter IV.

Of the streams entering the valley lands in Tulare County only Kaweah and Tule rivers contribute any material flow to Tulare Lake. While no direct records for Deer and White creeks are available for flood years the indirect data does not indicate that any such excess run-off reaches Tulare Lake. The records available on Kaweah and Tule River cover the seasons of 1916, 1917, 1920 and 1921.

### Outflow from Kaweah Delta.

Excess run-off from Kaweah River may reach Tulare Lake through two groups of channels. The flow of the river is divided at McKay Point between the St. Johns and Kaweah rivers. Water flowing through St. Johns River without being diverted enters Cross Creek near Goshen and finally reaches Tulare Lake. Water not diverted from the Kaweah River channels may reach Tulare Lake by either entering Cross Creek or by mingling with Tule River water in Elk Bayou. Outflow from the delta occurs more generally through Cross Creek than through Elk Bayou. The latter flow is usually small in amount except in years of excessive run-off.

Water reaching Cross Creek may be used by diversion into lower canals before reaching Tulare Lake. Such diversions, however, are outside the area covered by these investigations, and do not affect what is regarded as the delta of Kaweah River.

Records of the outflow of Kaweah and Tule rivers were kept in 1916 by the State Department of Engineering. The Kaweah River records were secured near the entrance of Cross Creek into Tulare Lake and do not include diversions from Cross Creek. The conditions for measurement were somewhat unfavorable. The records for the winter flow are incomplete. The records for Tule River were secured at the railroad crossing near Turnbull and are probably reasonably accurate. The actual records with the estimated division of the Tule River records between the two sources of its supply are given in Table 7.

TABLE 7.

**Records of Outflow of Kaweah and Tule Rivers in 1916, with Estimated Division of Flow Between Kaweah and Tule Rivers.**

| Months in 1916 | Total discharge of Cross Creek, acre-feet | Discharge of Kaweah River at Three Rivers, acre-feet | Total discharge to Tulare Lake through Tule River, acre-feet | Discharge of Main and South Fork of Tule River, acre-feet | Part of Tule River to Tulare Lake, estimated to have come from Elk Bayou, acre-feet | Total estimated outflow of Kaweah River, acre-feet | Per cent of Kaweah discharge reaching outflow channels | Per cent of Tule discharge reaching outflow channels | Total estimated discharge retained on Kaweah delta, acre-feet | Total estimated discharge retained on Tule delta, acre-feet |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 45,800 | 94,100 | 38,300 | 79,800 | ---------- | 45,800 | 49 | 48 | 48,000 | 41,500 |
| February | 29,000 | 61,600 | 34,500 | 45,700 | 7,500 | 36,500 | 59 | 59 | 25,000 | 18,700 |
| March | 50,800 | 108,000 | 53,100 | 70,600 | 8,100 | 58,900 | 55 | 64 | 49,000 | 25,600 |
| April | 27,600 | 127,000 | 4,860 | 51,700 | 2,400 | 30,000 | 24 | 5 | 97,000 | 49,200 |
| May | 26,000 | 145,000 | 3,000 | 43,100 | 3,000 | 29,000 | 20 | -------- | 116,000 | 43,100 |
| June | 22,800 | 131,000 | 270 | 23,130 | 300 | 23,100 | 18 | -------- | 108,000 | 23,100 |
| July | 10,500 | 59,000 | -------- | 8,130 | ---------- | 10,500 | 17 | -------- | 49,000 | 8,100 |
| Totals | 212,500 | 725,700 | 134,030 | 322,160 | 21,300 | 233,800 | 32 | 35 | 492,000 | 209,300 |

A comparison of these records for outflow from the Kaweah Delta in January with the inflow at Three Rivers shows that the outflow equals the inflow in excess of 1200 second-feet; that is, the inflow over 1200 second-feet on 14 days of the month is equal to the volume of the outflow. This is equivalent to saying that inflow up to 1200 second-feet was retained in January and that any excess passed across the delta. A similar comparison for February indicated that all inflow in excess of 450 second-feet appeared as outflow. The smaller amount retained in February can be accounted for by the heavy precipitation and January use satisfying the water requirements so that smaller diversions were made. For March the similar figures indicated that the outflow equaled the inflow in excess of 800 second-feet; for April, 1600 second-feet; for May, 1900 second-feet; for June, 1800 second-feet; and for July, 900 second-feet. The actual outflow during July is thought to have been delayed flow from June rather than direct outflow of July run-off.

The flow in Cross Creek at the bridge on the main Hanford road was measured by Mr. H. H. Holley during 1917. The record has been made available for use in this report. The measurements give directly the actual outflow from the Kaweah Delta below the Lakeside Canal. The records cover May and June. In May the discharge was 5000 acre-feet and in June 21,930 acre-feet. The outflow in May equalled the flow at Three Rivers in excess of 1800 second-feet, in June, in excess of 1750 second-feet. In 1917, the run-off was equal to about the average for the Kaweah River.

No direct records are available for 1918 and 1919. Indirect data indicates that there was little if any outflow in those years. The inflow was less than normal.

In 1920 water from Kings River was diverted into Cross Creek through the Lake Lands canal. A record of the diversions of the Corcoran District was secured under the direction of Mr. Max Enderlein. The difference between the Kings River diversion of the Lake Lands canal and of the diversions of the Corcoran District is considered to be Kaweah River water. On this basis in May the Kaweah River outflow would have been approximately equal to the flow at Three

Rivers in excess of 2400 second-feet. In June the outflow would have been equal to the flow at Three Rivers in excess of 1700 second-feet.

In 1921, beginning on January 11, a record was secured of the flow of Cross Creek at the Hanford road bridge. An automatic register was used and sufficient current meter gagings obtained to give a fairly dependable record. The discharge from January to April was due to local seepage, waste from irrigation or run-off from storms. The records of the diversion of the Lake Lands canal were obtained from Mr. Chas. L. Kaupke, water commissioner on Kings River. The full amount diverted has been deducted from the Cross Creek record to give the estimated Kaweah River outflow through Cross Creek. The losses in the Lake Lands canal between its head and Cross Creek are considered to be balanced by the inflow.

Diversion by the Lake Lands canal ended June 17. After this date the flow in Cross Creek was small and decreasing and represents local waste rather than discharge in Kaweah River in excess of the diversions.

TABLE 8.

**Records of Outflow of Kaweah Delta Through Cross Creek at Hanford Highway Bridge, Season of 1921.**

| Date | Rates of flow in second-feet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Discharge of Cross Creek | | | April | | May | | June | | | | Discharge of Cross Creek | |
| | Jan. | Feb. | Mar. | Cross Creek | Lake Lands Canal | Cross Creek | Lake Lands Canal | Cross Creek | Lake Lands Canal | Excess of Cross Creek over Lake Lands Canal | Kaweah River at Three Rivers | July | Aug. |
| 1 | ------ | 3.2 | 5.2 | 12.0 | ------ | 390 | 395 | 25 | 64 | -------- | 1,260 | 12.6 | 2.2 |
| 2 | ------ | 3.4 | 5.0 | 10.2 | ------ | 390 | 344 | 25 | 65 | -------- | 1,400 | 11.7 | 2.0 |
| 3 | ------ | 2.6 | 4.0 | 7.8 | ------ | 162 | 32 | 25 | 64 | -------- | 1,260 | 10.8 | 1.7 |
| 4 | ------ | 2.2 | 3.3 | 6.8 | ------ | 36.2 | 26 | 21 | 62 | -------- | 1,400 | 10.8 | 1.5 |
| 5 | ------ | 2.0 | 3.3 | 33.2 | ------ | 21.2 | 25 | 21 | 67 | -------- | 1,660 | 9.7 | 1.2 |
| 6 | ------ | 1.8 | 3.3 | 57.0 | ------ | 21 | 23 | 174 | 282 | -------- | 1,880 | 8.8 | 1.0 |
| 7 | ------ | 1.8 | 3.4 | 21.0 | ------ | 17.2 | 22 | 354 | 364 | -------- | 2,260 | 8.3 | ------ |
| 8 | ------ | 2.7 | 3.6 | 11.7 | ------ | 17.2 | 21 | 478 | 464 | 14 | 2,380 | 7.8 | ------ |
| 9 | ------ | 2.4 | 3.7 | 9.0 | ------ | 17 | 20 | 582 | 467 | 115 | 2,380 | 7.6 | ------ |
| 10 | ------ | 2.1 | 3.7 | 8.5 | ------ | 13.4 | 19 | 634 | 339 | 295 | 2,450 | 6.8 | ------ |
| 11 | 1.2 | 2.2 | 3.7 | 8.3 | ------ | 13.4 | 19 | 674 | *496 | 178 | 2,320 | 6.2 | ------ |
| 12 | 1.2 | 2.6 | 4.2 | 8.3 | ------ | 13.5 | 17 | 674 | *503 | 171 | 2,120 | 6.2 | ------ |
| 13 | 1.2 | 3.0 | 4.7 | 9.0 | ------ | 13.5 | 99 | 660 | *440 | 220 | 1,820 | 6.2 | ------ |
| 14 | 1 2 | 4.0 | 5.5 | 9.0 | ------ | 255 | 284 | *460 | 291 | 169 | 1,660 | 6.4 | ------ |
| 15 | 1.1 | 5.2 | 7.4 | 9.2 | ------ | 330 | *336 | *300 | 246 | 54 | 1,400 | 6.4 | ------ |
| 16 | 1.0 | 5.8 | 9.0 | 9.0 | ------ | 394 | *373 | *300 | 250 | 50 | 1,080 | 6.2 | ------ |
| 17 | 1.1 | 4.2 | 6.4 | 5.9 | ------ | 390 | *286 | *150 | 113 | 37 | 996 | 6.2 | ------ |
| 18 | 1.4 | 3.7 | 5.4 | 7.8 | ------ | 231 | 115 | *80 | 5 | 75 | 900 | 6.2 | ------ |
| 19 | 1.2 | 3.3 | 5.3 | 8.6 | ------ | 41 | 17 | *40 | 4 | 36 | 932 | 6.2 | ------ |
| 20 | 1.2 | 3.2 | 5.2 | 7.4 | ------ | 30.5 | 13 | *20 | 2 | 18 | 1,080 | 5.5 | dry |
| 21 | 2.0 | 3.2 | 5.4 | 7.2 | ------ | 30.5 | 12 | 20 | 1 | -------- | 1,200 | 4.8 | ------ |
| 22 | 3.7 | 3.1 | 5.8 | 5.0 | ------ | *30.5 | 14 | 22 | 1 | -------- | 1,290 | 4.0 | ------ |
| 23 | 3.7 | 3.3 | 6.4 | 3.8 | ------ | *30.5 | 14 | 28 | ------ | -------- | -------- | 3.6 | ------ |
| 24 | 2.8 | 6.6 | 6.4 | 3.6 | ------ | *30.5 | 15 | 33.5 | ------ | -------- | -------- | 5.5 | ------ |
| 25 | 2.5 | 7.6 | 6.6 | 3.6 | ------ | *30.5 | 14 | 27.2 | ------ | -------- | -------- | 3.5 | ------ |
| 26 | 2.0 | 7.8 | 6.6 | 4.1 | ------ | 30.5 | 14 | 20 | ------ | -------- | -------- | 3.4 | ------ |
| 27 | 1.8 | 7.4 | 6.6 | 3.6 | ------ | 36 | 15 | 15.1 | ------ | -------- | -------- | 3.2 | ------ |
| 28 | 1.8 | 6.2 | 6.4 | 3.2 | *52 | 101.6 | 126 | 13.2 | ------ | -------- | -------- | 3.0 | ------ |
| 29 | 3.6 | ------ | 6.4 | 3.2 | *111 | 318 | 245 | 12.6 | ------ | -------- | -------- | 2.6 | ------ |
| 30 | 4.2 | ------ | 7.8 | 30.5 | *179 | 294 | 151 | 12.6 | ------ | -------- | -------- | 2.4 | ------ |
| 31 | 3.6 | ------ | 12.3 | ------ | ------ | 80 | 65 | ------ | ------ | -------- | -------- | 2.4 | ------ |
| Total in acre-feet | 86 | 211 | 341 | 845 | 678 | 7,550 | 6,450 | 11700 | 8,930 | 2,770 | -------- | 390 | ------ |
| Assumed flow in Cross Creek from Kaweah River, in acre-feet | 86 | 211 | 341 | 167 | ------ | 1,100 | ------ | 2,770 | ------ | -------- | -------- | 390 | ------ |

Total discharge considered to come from Kaweah River for season, 5065 acre-feet.

*Record incomplete; figures used estimated.

The monthly summary for 1921 is shown in Table 8. The outflow from the Kaweah River was about equal to the flow at Three Rivers in excess of 1800 second-feet in May and in excess of 2050 second-feet in June.

Gaging stations were also established in 1921 for the measurement of any outflow from Elk Bayou and Tule River. The discharge from Elk Bayou varied from a very small amount up to a maximum of 2 second-feet during the period January 12 to August 1, 1921. No uncontrolled flood waters passed the station. The flow at the gaging station disappeared by seepage from one to three miles below the station. Statements secured from those adjacent to the channel indicate that no flood flow has occurred since 1917.

The water leaving the Kaweah Delta as surface flow represents a portion of the run-off of this stream not now diverted and consequently available for use by new canals except as subject to diversion rights below the points of measurement. The run-off of these streams which does not reach the points of outflow measurement represents some character of present use. The amount and conditions of the occurrence of outflow are important in relation to possible extensions of the use of these streams and an estimate of their amount in years other than those covered by direct records is desirable. Such an extension has been made by using the estimates of the rates of flow at Three Rivers which will produce outflow in the different months as obtained from the years for which records of outflow are available and considering that any flow at Three Rivers in excess of these quantities will appear at outflow.

A comparison of the daily discharges at Three Rivers and the outflow in 1916, 1917, 1920 and 1921 as previously given indicated that the outflow to be expected would be equal to the total flow at Three Rivers in excess of the amounts given in Table 9.

**TABLE 9.**

**Estimated Outflow from Kaweah Delta.**

| Months | Outflow to be expected equals the daily discharge of Kaweah River at Three Rivers in excess of the following amounts. | |
|---|---|---|
| | When previous month has had a discharge above normal, second-feet | When previous month has had a discharge not exceeding the normal, second-feet |
| January | ---- | 1,200 |
| February | 450 | 1,200 |
| March | 800 | 1,500 |
| April | 1,600 | 1,800 |
| May | 1,900 | 1,900 |
| June | 1,800 | 1,900 |
| July | 900 | all used |

The schedule given in Table 9 is not exact and was not exactly applied as floods of one or two days duration were not considered to result in outflow. The smaller amount retained on the Kaweah Delta after continued periods of above average run-off is to be expected, particularly during winter and spring months when the demands for use are more easily satisfied.

The daily discharges at Three Rivers were examined and the excesses above the amounts given in Table 9 computed. The results are given in Table 10. The average for the 18 year period is 72,000 acre-feet per year. For the same period the mean annual discharge at Three Rivers has been 455,000 acre-feet or the indicated mean annual net use of water on the Kaweah Delta has been 383,000 acre-feet.

TABLE 10.

**Estimated Outflow from Kaweah River in Years for which Discharge Record is Available at Three Rivers.**

| Season | Total discharge at Three Rivers, acre-feet | Estimated outflow total, acre-feet |
|---|---|---|
| 1903-04 | 373,000 | 28,000 |
| 1904-05 | 338,000 | 2,000 |
| 1905-06 | 1.090,000 | 550,000 |
| 1906-07 | 594,000 | 80,000 |
| 1907-08 | 253,000 | ------- |
| 1908-09 | 800,000 | 255,000 |
| 1909-10 | 410,000 | -------- |
| 1910-11 | 546,000 | 56,000 |
| 1911-12 | 207,000 | 4,000 |
| 1912-13 | 221,000 | -------- |
| 1913-14 | 486,000 | 33,000 |
| 1914-15 | 370,000 | 14,000 |
| 1915-16 | 762,000 | 234,000 |
| 1916-17 | 471,000 | 27,000 |
| 1917-18 | 230,000 | -------- |
| 1918-19 | 289,000 | -------- |
| 1919-20 | 372,000 | 9,000 |
| 1920-21 | 371,000 | 5,000 |
| Mean for period | 455,000 | 72,000 |

The character of the occurrence of this outflow indicates the difficulty of its use as the basis of a regulated irrigated supply. For the 18 years of record, in five years the estimate shows no outflow, in four years it was less than 10,000 acre-feet; in four years it was between 10,000 and 50,000 acre-feet; and in the five remaining years it was 56,000, 80,000, 234,000, 255,000 and 550,000 acre-feet. Of the total estimated outflow for the full 18 year period, 80 per cent occurred in the three years of largest run-off.

Estimates for the years 1889 to 1904 based on the estimated total discharge for those years, gave an estimated mean annual outflow for that period of 31,000 acre-feet. As previously given the estimated total annual discharge at Three Rivers for the earlier period is less than the measured discharge since 1903 and the outflow would also be less. For the full 32 year period the estimated mean annual outflow would be 55,000 acre-feet.

**Outflow from the Tule River.**

The records of water reaching Tulare Lake from Tule River are not as complete or definite as those for Kaweah River. The division of the flow measured in the lower Tule River in 1916 between its estimated source in Elk Bayou or Tule River has been given in Table 7. The run-off of Tule River in 1920 and 1921 was not sufficient to cause any measurable outflow.

On the basis of the 1916 data it has been assumed that the Tule Delta will retain 40,000 acre-feet of total run-off in the first winter month of large discharge and 20,000 acre feet in the second winter month of large flow. In March, following a winter of low run-off 40,000 acre-feet should be retained or 25,000 acre-feet following months of heavy flow. In April and May all discharge up to 50,000 acre-feet should be retained. No outflow after May is to be expected.

On the basis of the above generalizations the probable amounts of outflow occurring in each year since 1890 were estimated. Outflow probably occurred in 11 years in the 32-year period. In years when the total run-off of Tule River is less than 100,000 acre-feet no surface outflow in appreciable amounts would be expected. In years having discharges between 100,000 acre-feet and the mean annual discharge of 137,000 acre-feet the outflow would be limited. For years of excess discharge the outflow increases rapidly with the increase in total run-off of the river.

For the period of 32 years covered the estimated outflows are as follows:

| Year | Estimated outflow, acre-feet | Year | Estimated outflow, acre-feet |
|---|---|---|---|
| 1889-90 | 35,000 | 1910-11 | 8,000 |
| 1893-94 | 5,000 | 1913-14 | 18,000 |
| 1905-06 | 188,000 | 1914-15 | 2,000 |
| 1906-07 | 25,000 | 1915-16 | 113,000 |
| 1908-09 | 126,000 | 1916-17 | 7,000 |
| 1909-10 | 5,000 | | |

For the remaining years no outflow is estimated to have occurred. For the full period the mean annual outflow would be 17,000 acre-feet. Of the total estimated outflow, 80 per cent occurred in three years out of the 32 years. The wide variations in the amounts and the irregular occurrence of such outflows from Tule River indicates the difficulty of utilizing such portions of the Tule River run-off as the basis of any regulated dependable water supply.

Deducting the estimated mean annual outflow of 17,000 acre-feet from the estimated mean annual run-off of 137,000 acre-feet give a net mean annual supply of 120,000 acre-feet from Tulare River under existing conditions. This is the extent of the average annual water supply available by direct diversion or by pumping for the maintenance of the irrigated areas dependent on Tule River run-off for their water supply.

# PART II.

# UTILIZATION OF THE RUN-OFF OF KAWEAH RIVER.

## CHAPTER III.

# PRESENT UTILIZATION OF THE RUN-OFF OF KAWEAH RIVER.

### Canal Diversions from Kaweah River.

There are about 20 canals now diverting from Kaweah River. Of these, four, the Marks and Rice, Lemon Cove, Merryman and the Wutchumna divert above McKay Point. At McKay Point the flow of the river is divided between the St. Johns and Kaweah rivers. The areas served from the two channels are not distinct as some canals diverting from the St. Johns serve land lying south of the Keweah River and some canals receive water from both streams.

There are now in effect certain court decisions under which the rights of the different ditches have been decreed. The present diversion of the flow is the result of several decisions and the handling of the diversions is not as definite as that practiced on many streams. There is, however, a general basis on which the flow at different stages and seasons is divided.

Of the ditches diverting above McKay Point all except the Wutchumna divert on the south side of the river. The Lemon Cove canal serves an area of citrus groves near Lemon Cove. The Merryman ditch extends to the vicinity of Exeter; much of the land served also receives additional water from wells. The Wutchumna ditch serves areas on the north side of the St. Johns River near Woodlake and along Cottonwood Creek and also has a branch which crosses the St. Johns River to serve scattered areas in the vicinity of Visalia.

At McKay Point a concrete division wier has been built which controls the division of the flow between the St. Johns and Kaweah rivers. The flow is divided equally between the two channels until, in the late summer, the flow falls to 80 second-feet when the entire flow is turned down the Kaweah. Later in the season when the flow has increased to 80 second-feet it is again divided equally.

The division of the flow in the two channels between the various ditches varies with the stage of the stream. A general schedule is followed under which the different ditches divert. The Peoples Consolidated Ditch diverts both for its own use and also for conveyance to the Elk Bayou ditch the flow to which the latter may be entitled.

No effort has been made to determine the details of the rights or practices governing the diversions of the various ditches. All available data relating to actual diversions has been studied. The purpose of these investigations has been the study of the water resources and the extent to which their use may be feasible rather than a study of the particular titles that may have been acquired to any portions of such water supplies. No detailed attention has been given to the matters directly at issue in the litigation now in progress between the lower ditches and the Lindsay-Strathmore Irrigation District. The data collected by both parties to this litigation relating to the general Kaweah River Delta has been made available and has been of great value in these investigations. No study of the effect of the pumping by the Lindsay-Strathmore District on the flow of the Kaweah River in the vicinity of the area pumped has been made as the controversy was regarded as one over the title to the use of a portion of the available water supplies rather than one involving the total extent of such supplies.

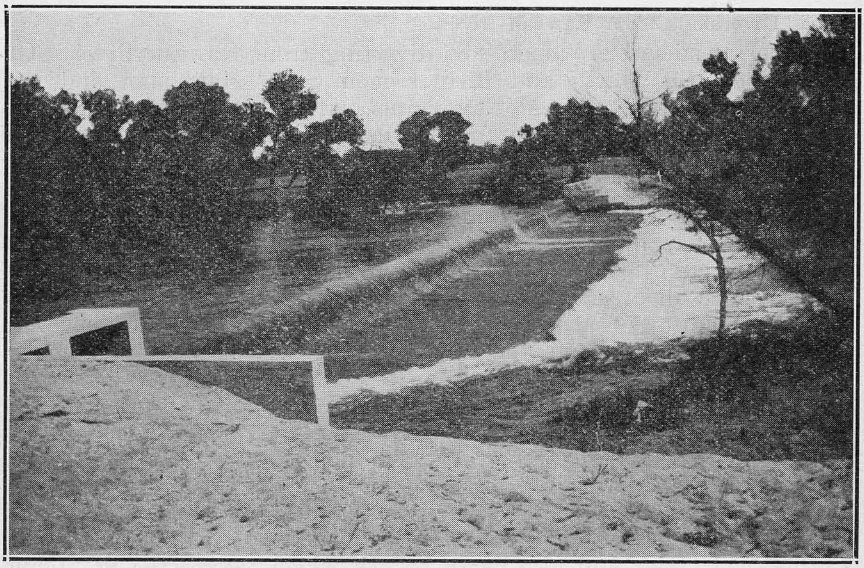

PLATE III, Figure A. Diversion Weir of Tulare Irrigation District.

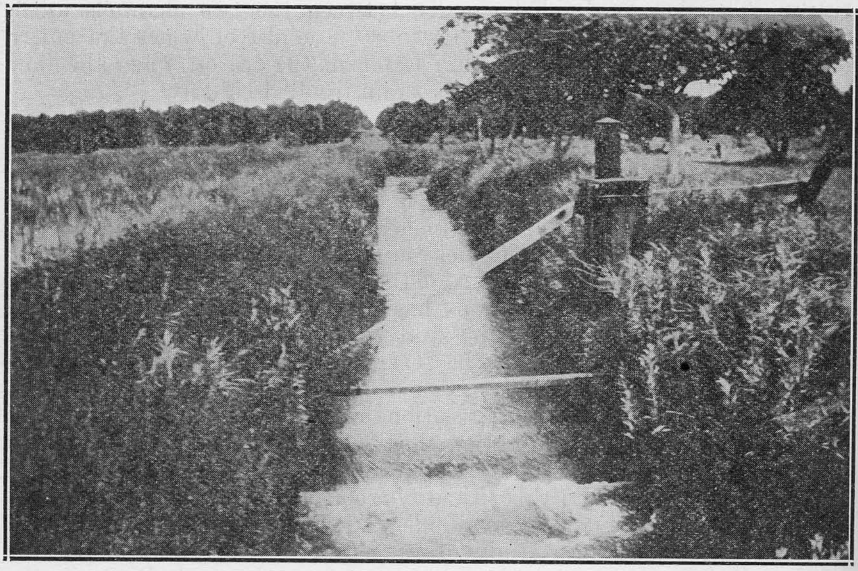

PLATE III, Figure B. Gaging Station on Jennings Ditch.

The records of canal diversions available cover the seasons of 1917, 1920 and 1921. Both parties to the present litigation made measurements of the diversions during a portion of 1917. More extensive measurements have been made by Mr. H. H. Holley for the plaintiffs during 1920 and 1921 the results of which have been made available. The records are shown in Tables 11, 12 and 13.

**TABLE 11.**

**Diversion Records of Kaweah River Ditches in 1917. Mean of Records of Plaintiffs and Defendants in Suit of Tulare Irrigation District et al. vs. Lindsay-Strathmore Irrigation District.**

| Ditch | Total acre-feet | | | | | |
|---|---|---|---|---|---|---|
| | April | May | June | July | Aug. | Total |
| Peoples Consolidated | 14,200 | 18,750 | 23,100 | 8,350 | 2,500 | 66,900 |
| Farmers | 5,400 | 8,300 | 8,100 | 2,200 | 100 | 24,100 |
| Evans | 1,700 | 1,850 | 1,950 | 1,250 | 450 | 7,200 |
| Fleming | 600 | 700 | 600 | 450 | 300 | 2,650 |
| Persian | 2,100 | 2,850 | 2,350 | 1,600 | 400 | 9,300 |
| Oakes | 600 | 750 | 650 | 400 | 200 | 2,600 |
| Watson | 1,450 | 1,500 | 1,450 | 1,100 | 750 | 6,250 |
| Tulare Irrigation Company | 3,250 | 4,650 | 3,700 | 2,350 | | 13,950 |
| Tulare Irrigation District | 12,100 | 25,800 | 22,100 | 2,300 | | 62,300 |
| Jennings | 700 | 700 | 700 | 500 | | 2,600 |
| Matthews | 1,000 | 1,200 | 1,100 | 1,150 | 250 | 4,700 |
| Modoc | 2,700 | 2,550 | 2,400 | 1,900 | | 9,550 |
| Uphill | 1,500 | 1,100 | 1,400 | 1,100 | | 5,100 |
| Packwood | 900 | 6,750 | 8,400 | 100 | | 16,150 |
| Lakeside | 9,050 | 12,100 | 12,600 | 3,300 | | 37,050 |
| Totals | 57,250 | 89,550 | 90,600 | 28,050 | 4,950 | 270,400 |
| Plaintiffs' record of river at McKay Point | 70,780 | 92,910 | 111,770 | 28,940 | 6,980 | 311,380 |
| Cross Creek outflow | | 5,000 | 21,930 | | | 26,930 |
| Indicated unmeasured diversions and river channel seepage | 13,530 | —1,640 | —760 | 890 | 2,030 | 14,050 |

**TABLE 12.**

**Diversion Records for Kaweah River Ditches for 1920. Records of H. H. Holley.**

| Ditch | Total acre-feet diverted | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mar. | April | May | June | July | Aug. | Total |
| Diversions above McKay Point— | | | | | | | |
| Marks and Rice | *123 | *238 | *246 | *238 | *246 | *246 | 1,337 |
| Lemon Cove | *215 | *415 | *430 | *415 | *430 | *430 | 2,335 |
| Merryman | *185 | *535 | *645 | *685 | *555 | *545 | 1,350 |
| Wutchumna | 3,550 | 5,020 | 5,900 | 6,950 | 2,960 | 990 | 25,370 |
| Totals | 4,073 | 6,208 | 7,221 | 8,288 | 4,191 | 2,211 | 32,192 |
| Diversions below McKay Point— | | | | | | | |
| Peoples Consolidated | 8,450 | 10,760 | 22,660 | 16,330 | 6,180 | 1,310 | 65,690 |
| Farmers | 1,680 | 7,350 | 10,310 | 7,320 | 190 | ------- | 26,850 |
| Evans | 1,180 | 1,290 | 1,640 | 1,330 | 1,080 | 90 | 6,610 |
| Fleming | 240 | 730 | 760 | 580 | 450 | 20 | 2,780 |
| Persian | 130 | 1,150 | 1,470 | 1,350 | 320 | ------- | 4,420 |
| Oakes | 30 | 300 | 820 | 540 | 340 | 10 | 2,040 |
| Watson | 1,170 | 1,300 | 1,630 | 1,330 | 1,080 | 90 | 6,600 |
| Tulare Irrigation Company | 340 | 1,830 | 3,660 | 3,400 | 420 | ------- | 9,650 |
| Tulare Irrigation District | 1,200 | 4,100 | 16,400 | 11,690 | ------- | ------- | 33,390 |
| Jennings | 190 | 1,060 | 1,400 | 1,400 | 630 | ------- | 4,680 |
| Matthews | 1,010 | 1,200 | 1,450 | 1,320 | 850 | ------- | 5,830 |
| Modoc | 1,230 | 2,670 | 2,930 | 2,200 | 960 | ------- | 9,990 |
| Uphill | 210 | 970 | 1,600 | 1,220 | 400 | ------- | 4,400 |
| Packwood | 760 | 3,280 | 2,520 | ------- | ------- | ------- | 6,560 |
| Lakeside | 1,450 | 9,670 | 19,750 | 14,210 | 480 | ------- | 45,560 |
| Goshen | ------- | *700 | *1,100 | *700 | ------- | ------- | 2,500 |
| Totals | 19,270 | 48,360 | 90,100 | 64,920 | 13,380 | 1,520 | 237,550 |
| Indicated unmeasured diversions— | | | | | | | |
| Cross Creek outflow and river channel seepage | 14,500 | 18,420 | 19,260 | 13,030 | 4,700 | 1,850 | 71,760 |
| Kaweah River at Three Rivers | 33,770 | 66,780 | 109,360 | 77,950 | 18,080 | 3,370 | 309,310 |

*Estimated from incomplete records.

## TABLE 13.

**Diversion Records for Kaweah Ditches in 1921. Records of H. H. Holley.**

| Ditch | Total acre-feet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Total |
| Diversions above McKay Point— | | | | | | | | | | | | | |
| Marks and Rice | *180 | *90 | 0 | 0 | 0 | *180 | *180 | *180 | *180 | *180 | *180 | *180 | 1,530 |
| Lemon Cove | *430 | *215 | 0 | 0 | 0 | *90 | *416 | *430 | *416 | *430 | *430 | *416 | 3,273 |
| Merryman | *590 | *240 | 0 | 0 | 0 | 175 | *566 | 635 | 665 | 584 | 571 | 565 | 4,591 |
| Wutchumna | 1,950 | 340 | 0 | 42 | 845 | 2,520 | 5,740 | 6,210 | 5,225 | 2.370 | 409 | 81 | 25,732 |
| Totals | 3,150 | 885 | 0 | 42 | 845 | 2,965 | 6,902 | 7,455 | 6,486 | 3,564 | 1,590 | 1,242 | 35,126 |
| Diversions below McKay Point— | | | | | | | | | | | | | |
| Peoples Consolidated | 0 | 1,211 | 2,720 | 3.876 | 6,006 | 9,413 | 9,117 | 13,785 | 14,000 | 4,813 | 1,489 | 979 | 67,409 |
| Farmers | 0 | 20 | 0 | 108 | 40 | 1,522 | 2,920 | 7,495 | 7,369 | 425 | 0 | 0 | 19,899 |
| Evans | 0 | 275 | 496 | 812 | 905 | 1,357 | 969 | 1,359 | 1,312 | 1,440 | 115 | ------- | 9,040 |
| Fleming | 7 | 9 | 214 | 279 | 139 | 83 | 503 | 800 | 648 | 787 | 72 | ------- | 3,541 |
| Persian | 25 | 850 | 126 | 893 | 1,271 | 1,372 | 836 | 2,589 | 2,664 | 823 | ------- | ------- | 11,449 |
| Oakes | ------- | ------- | ------- | 226 | 288 | 448 | 582 | 624 | 499 | 403 | 25 | ------- | 3,095 |
| Watson | ------- | 275 | 496 | 813 | 905 | 1,357 | 969 | 1,359 | 1,312 | 1,440 | 126 | ------- | 9,052 |
| Tulare Irrigation Company | ------- | ------- | ------- | ------- | ------- | 2,636 | 2,330 | 3,519 | 3,646 | 570 | ------- | ------- | 12,701 |
| Tulare Irrigation District | ------- | ------- | ------- | ------- | ------- | 477 | 1,477 | 13,332 | 13,100 | 195 | ------- | ------- | 28,581 |
| Jennings | ------- | ------- | ------- | ------- | 59 | 735 | 963 | 1,244 | 1,387 | 490 | ------- | ------- | 4,878 |
| Matthews | ------- | ------- | 84 | 334 | 508 | 780 | 972 | 1.180 | 1.128 | 673 | ------- | ------- | 5,659 |
| Modoc | ------- | ------- | ------- | ------- | ------- | 1,222 | 2,670 | 2,935 | 2,202 | 962 | ------- | ------- | 9,991 |
| Uphill | ------- | ------- | ------- | ------- | 240 | 878 | 1,129 | 1,311 | 1,472 | 340 | ------- | ------- | 5,370 |
| Packwood | ------- | ------- | ------- | ------- | ------- | ------- | ------- | 2,900 | 4,080 | ------- | ------- | ------- | 6,980 |
| Lakeside | ------- | ------- | ------- | 247 | 1,537 | 9,030 | 7,240 | 19,835 | 16,920 | 1,215 | ------- | ------- | 56,024 |
| Goshen | ------- | ------- | ------- | ------- | ------- | ------- | ------- | *1,500 | *1,500 | ------- | ------- | ------- | 3,000 |
| Sweeney | ------- | ------- | ------- | ------- | ------- | ------- | *240 | *250 | *250 | 158 | ------- | ------- | 898 |
| Hamilton | ------- | ------- | ------- | *350 | *300 | *350 | *360 | *375 | *375 | 363 | 222 | ------- | 2,695 |
| Wutchumna-Barton Cut | ------- | ------- | ------- | ------- | ------- | ------- | *1,000 | *2,000 | *2,000 | 250 | ------- | ------- | 5,250 |
| Totals | 32 | 2,640 | 4,136 | 7,938 | 12,198 | 31,660 | 34,277 | 78,392 | 75,864 | 15,347 | 2,049 | 979 | 265,512 |
| Discharge at McKay Point | 3,110 | 6,490 | 9,120 | 15,100 | 21,460 | 41,954 | 43,932 | 81,989 | 79,216 | 17,709 | 2,553 | 1,608 | 324,241 |
| Indicated unmeasured diversions, Cross Creek outflow and river channel seepage | 3,078 | 3,850 | 4,984 | 7,162 | 9,262 | 10,294 | 9,655 | 3,597 | 3,352 | 2,362 | 504 | 629 | 58,729 |

*Estimated from occasional measurements.

The records of both parties for 1917 were based on staff gage readings and current meter ratings. The records for 1920 and 1921 are based mainly on continuous gage height records of automatic registers. As the flow of the Kaweah River fluctuates materially during the day during the summer months as previously discussed, records of diversion based on continuous gage height records should be more dependable than those based on one or two daily readings. The run-off in 1917 was about normal, that for 1920 and 1921 was somewhat below normal. The diversions by the various canals will vary with the nature and extent of the flow in the river particularly for those ditches having later rights. The schedule under which diversions are made is not sufficiently definite to enable the diversions of the different ditches in other years to be estimated on the basis of the flow in the stream and the priority of each ditch and no estimates for other years have been attempted.

The flow of Kaweah River at McKay Point is either diverted by canals, percolates from the river channels or escapes from the Kaweah Delta through Cross Creek or other outlet channels. The records for the three years 1917, 1920 and 1921 are sufficient to enable the total canal diversions and the outflow to be determined with fair completeness. The difference between the sum of these items and the total supply is considered to represent seepage from the stream channels.

The available diversion records by months for 1917 are summarized in Table 11, those for 1920 in Table 12 and those for 1921 in Table 13. The 1917 records do not indicate any large amount of unaccounted for flow. The difference between the sum of the measured canal diversions and Cross Creek outflow for the five months covered by the records is 14,050 acre-feet or 4.5 per cent of the total flow at McKay Point. This smaller percolation in 1917 might be expected as the year previous had been one of large run-off and the ground water elevations adjacent to the stream channels were higher in 1917 than in 1920 or 1921. The 1917 diversions records are also probably less accurate than those for 1920 and 1921.

The 1920 diversion records indicate a larger channel seepage than those for 1917. If the outflow of Cross Creek for 1920 of about 9000 acre-feet is deducted, the remaining unaccounted for flow amounts to 20 per cent of the discharge at McKay Point. Any difference in channel seepage that may have been caused by the pumping by the Lindsay-Strathmore Irrigation District during the months covered by the canal diversion records would be included in the above unaccounted for flow.

The records for 1920–1921 cover the full run-off year. The unaccounted for flow in Table 13 is about 59,000 acre-feet. The outflow through Cross Creek for this period was 5000 acre-feet and the amount pumped for use within the Lindsay-Strathmore District was about 13,500 acre-feet. If the water used by the district is all assumed to have come from the flow at McKay Point during the period of record the remaining net unaccounted for supply becomes 40,500 acre-feet or 12 per cent of the total at McKay Point.

As both of the years in which more complete diversion records are available were ones of similar but less than normal run-off, the channel seepage to be expected in years of excess run-off can not be estimated on the basis of the data available. It is probable that the actual amount of such channel seepage would increase with an increase in the amount of run-off but that the percentage of seepage would decrease. The available records indicate that there is a material addition to the ground water from such channel percolation. As the records were secured at the points of diversion of the St. Johns and Kaweah rivers or adjacent channels only the seepage from such channels are included in the figures given.

**Maximum Rate of Diversion by Canals from Kaweah River.**

The run-off in 1920 and 1921 being less than normal the total diversions for those years are also less than for years of larger run-off. There were periods in the irrigation season of both years, however, when water was passing the lowest diversion. At such times it may be assumed that the diversion requirements of the various canals were fully satisfied. The conditions of total discharge under which outflow from the Kaweah Delta will occur have previously been discussed in detail.

**TABLE 14.**

**Maximum Rates of Diversion by Kaweah River Ditches.**

| Ditch | Maximum weekly average diversion in 1917, second-feet | Maximum weekly average diversion in 1920, second-feet | Maximum weekly average diversion in 1921, second-feet |
|---|---|---|---|
| Ditches diverting above McKay Point— | | | |
| Marks and Rice[2] | ---------- | 3 | 3 |
| Lemon Cove[2] | ---------- | 7 | 7 |
| Merryman[2] | ---------- | 11 | 11 |
| Wutchumna[2] | ---------- | 117 | 101 |
| Totals | ---------- | 138 | 122 |
| Ditches diverting below McKay Point— | | | |
| Hamilton[1] | 6 | 6 | 6 |
| Enlow[1] | 4 | 4 | 4 |
| Lindsay-Strathmore Irrigation District | ---------- | 48 | 48 |
| Peoples Consolidated | 502 | 517 | 362 |
| Farmers | 172 | 221 | 191 |
| Evans | 35 | 30 | 30 |
| Fleming | 11 | 16 | 15 |
| Persian | 41 | 37 | 73 |
| Oakes | 14 | 17 | 12 |
| Watson | 26 | 30 | 30 |
| Tulare Irrigation Company | 67 | 67 | 71 |
| Tulare Irrigation District | 429 | 391 | 357 |
| Jennings | 12 | 24 | 23 |
| Matthews | 29 | 31 | 26 |
| Modoc | 43 | 58 | 55 |
| Uphill | 36 | 31 | 26 |
| Packwood | 163 | 89 | 139 |
| Goshen[2] | 25 | 25 | 25 |
| Lakeside | 282 | 362 | 374 |
| Wutchumna-Barton cut | 33 | [1]33 | [1]33 |
| Totals | 1,930 | 2,037 | 1,900 |

[1]No direct records; figures given are estimates.
[2]Based on estimated monthly means.

The diversion records for each ditch were examined and the maximums assembled in Table 14. The weekly means have been used rather than the maximums for any single day. The total discharge of the Lindsay-Strathmore Irrigation District is included in Table 14 although it is taken from ground water adjacent to the stream and does not affect the flow of the river by the amount pumped. Table 14 indicates that a total diversion of about 1950 second-feet below McKay Point and 2080 second-feet below Three Rivers will meet the simultaneous maximum rates of diversion by these ditches. As all ditches will not actually be diverting at their maximum rate simultaneously somewhat smaller total diversions at any time will meet the total diversion needs. The previous discussion of outflow shows that a discharge of over 1900 second-feet at Three Rivers, if maintained, will result in outflow from the Kaweah Delta indicating that this rate of flow supplies the normal diversions plus the channel seepage.

### Areas Irrigated by Kaweah River Ditches.

Various classifications of the lands irrigated by the different ditches diverting from the Kaweah River have been made by the parties to the litigation over the pumping by the Lindsay-Strathmore Irrigation District. These classifications have resulted in a stipulation between the parties regarding the areas irrigated under several of the ditches.

No attempt was made in connection with these investigations to canvass in the field the areas supplied by each ditch. Some areas partially served by ditches were included in the areas canvassed for pumping. The various classifications made by the parties to the litigation were made available and were compared. Where material differences were found sufficient investigations were made to enable a conclusion to be reached. The extent of the areas served was also checked with the officers of the different ditches. The resulting figures used for the areas served agree with those stipulated for the ditches covered by the stipulation and represent the results of the data collected in this investigation as to the other ditches. The results are shown in Table 15 and on Map 1.

TABLE 15.

**Areas Served by Ditches Diverting from Kaweah River.**

| Ditch | Area in acres of | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Alfalfa | Orchard and vines | Field crops | Wild pasture | Total | Receiving supplemental water by pumping |
| Ditches diverting above McKay Point— | | | | | | |
| Marks and Rice | ---------- | 129 | ---------- | ---------- | 129 | ---------- |
| Lemon Cove | ---------- | 1,100 | ---------- | ---------- | 1,100 | ---------- |
| Merryman | ---------- | 1,680 | ---------- | ---------- | 1,680 | 1,680 |
| Wutchumna[3] | 870 | 5,602 | 814 | 160 | 7,446 | 4,253 |
| Totals | 870 | 8,511 | 814 | 160 | 10,355 | 5,933 |
| Ditches diverting below McKay Point— | | | | | | |
| Hamilton | 15 | 50 | 115 | 270 | 450 | ---------- |
| Long's Canal | ---------- | 160 | 300 | 1,140 | 1,600 | ---------- |
| Enlow | 130 | 6 | 40 | 364 | 540 | ---------- |
| Lindsay-Strathmore Irrigation District | ---------- | 9,370 | ---------- | ---------- | [2]9,370 | ---------- |
| *Peoples Consolidated | 4,088 | 4,445 | 4,265 | 1,771 | 14,569 | 4,127 |
| *Elk Bayou | 4,150 | 250 | 776 | 461 | 5,637 | 1,784 |
| *Farmers | 2,850 | 1,378 | 2,840 | 297 | 7,635 | 3,394 |
| Evans[1] | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| *Fleming | 372 | 408 | 84 | 150 | 1,014 | 448 |
| Persian[1] | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| *Oakes | 216 | 237 | 287 | 282 | 1,022 | 63 |
| Watson[1] | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| Evans-Persian-Watson[1] | 4,300 | 2,150 | 6,470 | 120 | 13,040 | 2,538 |
| *Tulare Irrigation Company | 1,588 | 942 | 279 | 475 | 3,284 | 2,191 |
| *Tulare Irrigation District | 7,905 | 602 | 2,823 | 869 | 12,199 | 2,771 |
| Jennings | 300 | 100 | 230 | ---------- | 630 | 26 |
| *Matthews | 692 | 14 | 192 | 30 | 928 | 280 |
| *Modoc | 2,000 | 84 | 850 | 656 | 3,590 | 611 |
| *Uphill | 1,148 | 124 | 107 | 494 | 1,873 | 723 |
| *Packwood | 1,469 | 536 | 916 | 79 | 3,000 | 2,626 |
| *Goshen | 720 | 2 | 545 | 600 | 1,867 | 609 |
| Lakeside | 11,000 | 340 | 6,360 | 2,050 | 19,750 | 3,668 |
| Totals | 42,943 | 21,198 | 27,514 | 10,108 | 101,728 | 25,859 |

*Ditches for which areas given have been agreed upon by stipulation between parties to the pending litigation.
[1]Area of Watson, Persian and Evans ditches combined.
[2]Area irrigated in 1920; gross area in district about 15,000 acres.
[3]Lands served by Wutchumna ditch on north side of river only. About 20 per cent of the use on this system is for variable areas on the south side of the river for which data is not available.

The area supplied by ditches diverting from the Kaweah River is not definite as it varies from year to year with the extent of the run-off. Many areas use ditch water when available supplemented by water pumped from wells for periods when the ditch supply is deficient. The figures given in Table 15 are thought to represent, as closely as conditions will permit a classification to be made, the area generally served by ditches from the Kaweah River. The actual service given will vary from a complete supply during the full season to one irrigation in years of unfavorable run-off. Not all of the area given is irrigated in many seasons.

The Peoples Consolidated Ditch received water over a longer season than most other ditches diverting from the Kaweah River. The ground water is higher than in many other areas.

The Elk Bayou receives its water by diversion through the Peoples Consolidated Ditch. The area covered by this system was canvassed in 1920 for pumping use and data also collected on the ditch irrigation for that season. The canvass gave a total area irrigated by ditches in 1920 of 4170 acres. The acreage agreed upon in the stipulation of 5637 acres represents the area prepared to receive ditch irrigation when the water supply is available.

The areas irrigated under the Watson, Evans and Persian ditches overlap to a considerable extent, some lands receiving water from more than one of these ditches. The areas under the three ditches have been combined in Table 15.

The acreage irrigated in any year in the Tulare Irrigation District varies more widely than under most of the other ditches as the water rights for this system are among the later priorities on the river. An area of 3540 acres was found to have received some irrigation from the canal system in this district during 1920; the larger part of this area also received supplemental pumping supplies.

Ground water conditions affect the area irrigated from the Uphill and Modoc ditches, the ground water being relatively high in some parts of the area served.

The Packwood and Goshen ditches receive water after the larger part of the other ditches are supplied and in consequence the area served is more variable from year to year. Supplemental pumping is also used to a greater extent than under many of the other ditches.

The Lakeside Ditch serves an area which is to the west of Cross Creek and is considered to be outside of the area of the Kaweah Delta which is dependent for its ground water supply on the Kaweah River. The ground water conditions in the area supplied by the Lakeside Ditch are the result of its own diversions and of the use of Kings River waters on adjacent areas rather than of the use under other canals diverting from the Kaweah area. The Lakeside Ditch is one of the larger Kaweah canals and receives a considerable proportion of the water diverted from the Kaweah River.

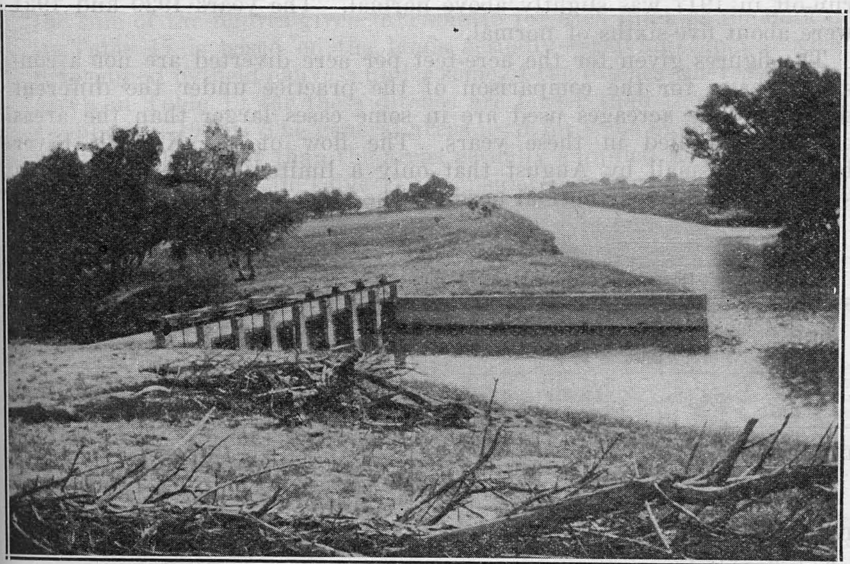

PLATE IV, Figure A. Waste Gate on Lakeside Canal near the Diversion from Cross Creek.

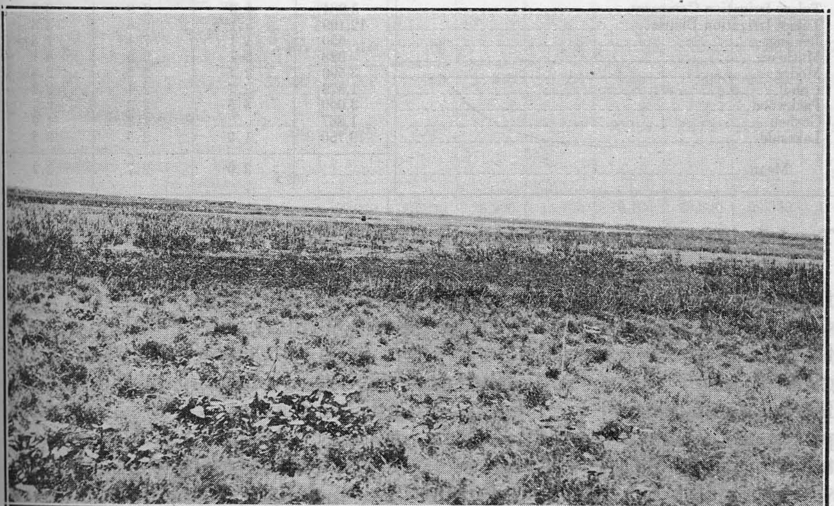

PLATE IV, Figure B. Pasture Irrigation under the Lakeside Canal.

**Duty of Water Under Ditches.**

The data previously given for the diversions and the areas irrigated for the various ditches is assembled in Table 16 in terms of the rate of use of water per acre irrigated. The figures given represent diversions, the amounts delivered to the farms would be less than the figures given by the amount of the conveyance losses, which for at least some of the ditches may be relatively high. Of the years shown in Table 16, the run-off in 1917 was slightly above normal. The years 1920 and 1921 were about five-sixths of normal.

The figures given for the acre-feet per acre diverted are not a consistent basis for the comparison of the practice under the different ditches as the acreages used are in some cases larger than the areas actually supplied in these years. The flow of the Kaweah River becomes so small by August that only a limited area can receive a supply equal to their normal needs in the later part of the season.

**TABLE 16.**

**Diversions in Acre-feet per Acre of Ditches Diverting from Kaweah River.**

| Ditch | Area supplied by ditch, acres | Average acre-feet per acre supplied, diverted during season of— | | |
|---|---|---|---|---|
| | | Apr. to Aug., 1917 | Mar. to Aug., 1920 | Oct. 1920 to Sept., 1921 |
| Ditches diverting above McKay Point— | | | | |
| Lemon Cove | 1,100 | ---------- | 2.1 | 3.0 |
| Merryman | 1,680 | ---------- | 1.9 | 2.7 |
| Wutchumna | 7,446 | ---------- | 3.4 | 3.5 |
| Ditches diverting below McKay Point— | | | | |
| Lindsay-Strathmore | 9,370 | ---------- | 1.6 | 1.5 |
| Peoples Consolidated | 14,569 | } 3.3 | 3.2 | 3.3 |
| Elk Bayou | 5,637 | | | |
| Farmers | 7,365 | 3.3 | 3.6 | 2.7 |
| Evans-Watson-Persian | 13,040 | 1.7 | 1.4 | 2.3 |
| Fleming | 1,014 | 2.6 | 2.7 | 3.5 |
| Oakes | 1,022 | 2.6 | 2.0 | 3.0 |
| Tulare Irrigation Company | 3,284 | 4.3 | 2.9 | 3.9 |
| Tulare Irrigation District | 12,199 | 5.1 | 2.8 | 2.8 |
| Jennings | 630 | 4.1 | 7.4 | 7.8 |
| Mathews | 928 | 5.1 | 6.3 | 6.1 |
| Modoc | 3,590 | 2.7 | 2.8 | 2.8 |
| Uphill | 1,873 | 2.7 | 2.4 | 2.9 |
| Packwood | 3,000 | 5.5 | 2.2 | 2.3 |
| Goshen | 1,867 | ---------- | 1.3 | 1.6 |
| Lakeside | 19,750 | 1.9 | 2.3 | 2.8 |
| Mean | ---------- | 3.0 | 2.7 | 2.9 |

## Total Irrigated Areas Dependent on Kaweah River for Their Water Supply.

The areas now irrigated which are dependent on the Kaweah River for such water supply as they may receive are larger than the areas served by ditches diverting from the river due to the additional areas for which pumping is practiced. The extent of the area whose underground water supply is dependent on water originating in the Kaweah River is not distinct but blends into adjacent areas. However, for the purposes of the study of the water resources and their use it is essential to delimit the area considered to be dependent on each source of water supply. This has been done as outlined on Map 2. The determination of the limits of each area has been based on the data collected regarding the ground water and its use as discussed in detail later.

From the canvass of the areas served entirely by each pumping plant made in these investigations and the data on use under ditches, the total irrigated areas dependent on Kaweah River as given in Table 17 were determined. The location of the areas is shown on Map 1.

The areas given in Table 17 represent the lands receiving a more or less complete irrigation supply in 1920. The sum of the figures given for areas supplied by ditches only and by ditch and pump are less than the sum of the figures given in Table 15 for each ditch as the data used in Table 17 is based on the lands actually receiving canal service as determined by field canvass under some of the ditches whereas the areas given in Table 15 for these ditches are larger than the areas actually supplied in 1920. The general areas used for some of the other ditches are probably larger than the areas actually supplied in 1920. For the year given the data in Table 17 is considered to represent fairly closely

TABLE 17.

**Summary of Areas Irrigated in 1920 Which Are Considered to be Dependent on the Run-off of Kaweah River for Their Water Supply.**

| Area | Crop—acres | | | | | Character of water supply—area in acres | | | Total area in acres |
|---|---|---|---|---|---|---|---|---|---|
| | Orchard and vines | Alfalfa | Corn | Grain | Miscel-laneous, including pasture | By ditch only | By ditch and pump | By pump only | |
| Main area of Kaweah Delta covered by canals diverting for lands below Venice Hills | 25,800 | 29,900 | 13,800 | 22,500 | 11,300 | 47,000 | 18,900 | 37,400 | 103,300 |
| Areas covered by canals diverting for lands mainly above Venice Hills | 16,800 | 800 | 300 | 600 | 800 | 2,700 | 6,900 | 9,700 | 19,300 |
| Area of lower Kaweah Delta outside of areas covered by canals | 1,500 | 7,500 | 2,700 | 2,800 | 1,400 | *900 | *100 | 14,900 | 15,900 |
| Area west of Lindsay-Strathmore Irrigation District toward which ground water slopes from the Kaweah Delta | 6,400 | 700 | 100 | -------- | 100 | -------- | -------- | 7,300 | 7,300 |
| Total of above areas | 50,500 | 38,900 | 16,900 | 25,900 | 13,600 | 50,600 | 25,900 | 69,300 | 145,800 |
| Area irrigated by Lakeside Ditch | 300 | 11,000 | 6,400 | -------- | 2,100 | 16,100 | 3,700 | -------- | 19,800 |
| Area irrigated by Lindsay-Strathmore Irrigation District | 9,400 | -------- | -------- | -------- | -------- | 9,400 | -------- | -------- | 9,400 |
| Total | 60,200 | 49,900 | 23,300 | 25,900 | 15,700 | 76,100 | 29,600 | 69,300 | 175,000 |

*Includes area east of Cross Creek.

the total cropped area receiving irrigation with water originating in the run-off of Kaweah River. The supply for the full area shown was not complete as some lands dependent on canal irrigation alone receive deficient service during the latter part of the season. The data relating to canal areas was collected in 1920, that relating to pumping in 1920 and 1921. The areas are later used as representing the lands irrigated in 1920 and 1921 as the increase in 1921 was relatively small.

For purposes of study of the relations of recharge and draft on the ground water of the Kaweah Delta, the total area has been divided into four parts as shown on Map 2. The first of these includes all of the lands served by canals diverting for lands lying below Venice Hills. The outer boundaries extend beyond the areas usually served. This area includes all lands which can be expected to receive canal irrigation in any year by existing ditches and includes much land for which no canal system is now available. About 55 per cent of the gross area receives irrigation from some source of supply, about one-half of the area irrigated receiving only canal service.

The second area includes the areas covered by canals diverting mainly for service above Venice Hills. It extends to Exeter on the south side of the river including the areas above the Peoples Ditch. On the north side of the river it covers the area along Cottonwood Creek served by the Wutchumna Ditch and adjacent lands.

The third area covers those lands whose ground water is considered to be dependent on Kaweah River run-off for its replenishment but which does not receive any direct irrigation by canals. This division covers the area extending westerly from the main canal area to Cross Creek and southerly to the area dependent on Tule River.

The fourth area includes the part of lands lying between the main deltas of Kaweah and Tule rivers toward which the ground water slopes from the Kaweah Delta. The present slopes may be the result of artificial conditions of pumping draft as well as of natural conditions. This area extends easterly to the Lindsay-Strathmore Irrigation District and the upper canal area and southerly until the slope toward the Tule Delta is reached.

These four divisions have been selected mainly for convenience in the study of ground water conditions. It is obvious that the boundaries used for any such classification can not be exact and that the differences in such factors as canal use, pumping draft and ground water fluctuations will tend to blend or merge along the boundaries selected. For convenience the boundaries have been made to follow section lines in most instances. The areas served by the Lakeside Ditch and the Lindsay-Strathmore Irrigation District are not included. Although these two systems receive Kaweah River water they are considered as being outside the Kaweah Delta and not affected by general ground water movement within the delta.

The area supplied by the Lakeside Ditch included about 3700 acres which received supplemental pumping. There is also some supplemental pumping within the Lindsay-Strathmore Irrigation District for which no direct data is available but which is understood to have been of small amount in 1920.

The mean annual run-off of the Kaweah River has been previously estimated as 451,000 acre-feet of which an average of 55,000 acre-feet passes across the Kaweah Delta without diversion or absorption, leaving a net mean annual water supply of 396,000 acre-feet for the irrigation of lands dependent on this source of supply. The figures given in Table 17 indicate that there is now developed an acre of irrigated land for every 2.3 acre-feet of mean annual available water supply for irrigation. Deducting 45,000 acre-feet as the average diversion of the Lakeside Ditch and 15,000 acre-feet for the diversion of the Lindsay-Strathmore Irrigation District leaves an average supply of 336,000 acre-feet for the 146,000 acres now supplied on the Kaweah Delta or an average of 2.3 acre-feet per acre.

#### Subirrigated Areas.

In addition to the areas to which irrigation is applied from canals or by pumping there are some areas on which there is moisture drawn from the high ground water by capillary action. These subirrigated areas were classified by the Lindsay-Strathmore Irrigation District in 1917. This classification has been adjusted to the conditions of 1920 by comparison with the lowering of the ground water from 1917 to 1920. Only land is included in this classification which has not been included in the area receiving surface irrigation. There are areas receiving surface irrigation in which the ground water is sufficiently high to result in loss of moisture from the surface by direct draft by plants on the ground water.

On the above basis it is estimated that in 1920 there were 1500 acres of cropped land and 1500 acres of pasture subirrigated under ditches and not credited as surface irrigated, and that in addition there were subirrigated areas along stream channels and not under any ditch system of 900 acres of crops and 4600 acres of pastures giving a total area of such subirrigated land of 8500 acres. Adding this area to the 175,000 acres surface irrigated gives a total cropped area dependent on the Kaweah River of 183,500 acres for which the average water supply available would be 2.2 acre-feet per acre.

**Rate of Increase In Area Irrigated by Kaweath River Run-off.**

The figures given represent the areas supplied during the period covered by these investigations. There are no complete data available on the rate of increase in the area supplied in past seasons. Such information as could be secured is given in the following discussion.

The reports of the U. S. Census give some comparative data. The report of the irrigation census for Tulare County as a whole is as follows:

| Item | Results for year 1909 | Results for year 1919 | Ratio of results for 1919 to those for 1909 |
|---|---|---|---|
| Area irrigated, acres | 265,404 | 398,662 | 1.5 |
| Flowing wells, number | 79 | 23 | ---------- |
| Flowing wells, capacity gallons per hour | 35,513 | 7,173 | ---------- |
| Pumped wells, number | 794 | 4,515 | 5.8 |
| Pumped wells, capacity gallons per hour | 237,420 | 1,776,335 | 7.5 |
| Pumping plants, number | 739 | 3,758 | 5.1 |
| Pumping plants, capacity gallons per hour | 244,318 | 2,331,179 | 9.5 |

While this data covers Tulare County as a whole it is probable that the relative increase in the Kaweah River areas is similar to that for the whole county.

For 1919, the census reports for the Kaweah River area, three flowing wells, 2136 pumped wells with a capacity of 842,000 gallons per minute, and 1734 pumping plants with a general average lift of 41 feet. Similar data segregated by streams was not given for 1909. The total capacity of the pumped wells in 1919 is 1870 second-feet, a rate of flow exceeded by the Kaweah River only during relatively short periods during the year and closely equal to the maximum simultaneous canal diversions of all canals diverting from the Kaweah River.

These figures indicate a marked decrease in flowing wells during the ten-year period covered. The area in which artesian wells may be secured is now much smaller than formerly. For pumping wells the data indicates an increase of over 500 per cent in number and of about

800 per cent in capacity. The areas supplied by pumping plants are not given separately for each county. It would appear that the increase in area served by pumps has been about 500 per cent from 1909 to 1919 for the county as a whole.

Data given in the report of the California Conservation Commission for 1912 gives the area served by pumping plants in Tulare County in 1909 as 37,942 acres and in 1912 as 75,320 acres or an increase of 100 per cent in this three-year period. The total area served partly or entirely by pumping plants in the parts of the county covered in these investigations for 1921 is 159,200 acres. This figure does not include areas in the northern part of the county supplied from Kings River sources. The figures are not available on which to base an estimate of the relative rate of increase in the different parts of the county since 1912. On the basis of general data, however, it is considered that the ratio of increase on the Kaweah area has been at least as great as for the areas in the southern portion of the county.

In the canvass of pumping plants the date of installation was secured. A summary of the relative number of plants for various years follows. The plants canvassed in the main canal area did not include those supplying supplemental pumping to lands under several of the ditches and the data for this area is less complete than for the others.

RELATIVE NUMBER OF PUMPING PLANTS OPERATING IN DIFFERENT YEARS IN PER CENT OF THE NUMBER OPERATING IN 1921.

| Year | Area along foothills above main canal areas | Within main canal area | On lower portion of Kaweah Delta outside of canal area |
|---|---|---|---|
| 1921 | 100 | 100 | 100 |
| 1920 | 93 | 91 | 97 |
| 1919 | 84 | 76 | 90 |
| 1918 | 82 | 64 | 85 |
| 1917 | 81 | 57 | 75 |
| 1916 | 78 | 51 | 66 |
| 1912 | 60 | 15 | 30 |

The ratio of new development since 1912 has been smaller in the area along the foothills than in the other portions of the delta. The increase in the last three years has been largely in areas north of the river. The figures given exclude the area now in the Lindsay-Strathmore Irrigation District.

For the outer area the development during the past three years has been less rapid than during the preceding years. The increase in the total area of general crops from 1920 to 1921 was relatively small although much changing of crops on the same areas occurred.

The conclusions presented in the proceding table are in general agreement with the statements of pump dealers as to relative number of plants installed in different years.

The figures given have been used in estimating the pumping draft in years prior to 1921.

## CHAPTER IV.

# USE OF GROUND WATER IN AREA DEPENDENT ON KAWEAH RIVER RUN-OFF.

### INTRODUCTION.

The study of the use of ground water can be approached in the same manner as a study of the use by surface diversion. The supply available in the case of ground water is the sum of the various elements which contribute to the replenishment of the ground water. The draft by pumping corresponds to the diversion by canals of the surface flow. The accumulated ground water supply is comparable to storage; if the draft exceeds the incoming supply a decrease in the storage will result and the ground water will fall. A refilling of the ground water storage can only occur when the replenishment exceeds the draft. It is obvious that over a period of years the total inflow must equal the sum of the elements of outflow if the ground water levels are to be maintained.

The separate elements involved in a ground water study are more difficult to measure due to their inaccessibility but the principles of supply and use do not differ from those involved in surface irrigation by canals. The study of the use of ground water on the Kaweah River area has been approached by considering the elements of replenishment, the extent of the use or draft by pumping, the probability of escape of ground water by general outward movement and the resulting balance of use and replenishment as indicated by the rise or fall of the ground water.

It is not possible to measure the elements of inflow to the ground water on the Kaweah Delta. The records of run-off furnish an adequate basis for estimating the total mean annual water supply but the proportion of this which reaches the ground water can not be determined by direct measurement. Seepage from river channels and from canals can be considered as practically all reaching the water table. Measurements of canal seepage can also be made. Total losses from irrigation due to deep percolation can only be approximated at best.

The elements of draft also can not be definitely measured. The pumping plants were canvassed and data on the amount of water pumped obtained. Such records while probably fairly dependable as a whole are not accurate as to details and can not be made so without an extent of measurement of the discharge of each plant which is beyond the scope of practical investigation.

Fairly complete records of the fluctations of the ground water on the Kaweah Delta are available since early in 1917. These records cover all of the delta except the westerly portions lying beyond the areas served by canals. The more complete records are those of the Lindsay-Strathmore Irrigation District which have been made available for use in these investigations. In order to cover the full area considered to be dependent on the Kaweah River for such ground water supplies as it might receive additional observations have been made since July, 1920, covering the area as far westerly as Cross Creek. Additional records within the area of the Corcoran Irrigation District were also secured through the cooperation of this district. Sufficient records were obtained westerly from Cross Creek and northward to the Kings River ridge to determine the direction of slope of the ground water in these areas. Data relating to the ground water south and west of Hanford was made available by Mr. Max Enderlein, civil engineer of Hanford.

### Elements of Inflow or Recharge of Ground Water.

The records of canal diversions in 1917 (Table 11) account for practically the entire river flow during the summer months. Similar records more carefully taken in 1920 and 1921 (Tables 12 and 13) indicate a channel seepage of about 15 per cent of the run-off. In years of larger total run-off the percentage of seepage from stream channels and overflowed areas will vary with the conditions of run-off.

Evidence was presented in the trial of the *Tulare District et al.* vs. *Lindsay-Strathmore Irrigation District* during 1917 on the number of irrigations usually given to lands supplied by the ditches. This data, taken in connection with the average diversions per acre indicate that the average amount of water applied at each irrigation from the canals may be as large as one acre-foot per acre. Such rates of use will result in percolation losses which will reach the ground water. That such losses occur and that they may materially affect ground water levels is indicated by the rise of wells in the vicinity of irrigated areas during the period of irrigation.

### Estimated Draft on Ground Water.

The pumping on the area supplied from Kaweah River was canvassed to secure data on the amount of draft on the ground water. It is not feasible to secure an accurate measurement of such draft due to the large number of plants operating. An accurate measurement of the total amounts pumped would not give the net draft on the ground water as a portion of the pumped water, where the use is excessive, will return to the ground water by percolation.

The areas of each crop irrigated by pumping, the number of irrigations given and the average depth of each application were used as one basis of estimating the total draft. The periods of operation, the power consumption, the efficiency of the plant and the lift were also used as a basis of estimate. The efficiency of a number of plants was tested to furnish an average efficiency for the different types of plants used. From all of the data obtained estimates of the average use for the different crops in the different parts of the area were made which were applied to the areas of each crop.

Where both ditch and pumping supplies are used on any area the proportion of the supply secured by pumping was estimated based on the number of irrigations given from each supply and the general character of the water supply and service under each ditch.

The areas outside of the main canal areas were canvassed directly for the purposes of these investigations. The areas of supplemental pumping for lands served by canals were secured largely from the results of the investigations of the Lindsay-Strathmore Irrigation District.

Tests of 53 centrifugal pumping plants resulted in an average over all efficiency for the plants of 38.6 per cent which is equivalent to a power consumption of 2.66 kilowatt hours per acre-foot of water lifted one foot in height. The plants tested were using centrifugal pumps varying in size from two inches to eight inches, the larger proportion being from three to five inches. The efficiency tended to vary somewhat with the size increasing with the larger plants. This tendency was irregular and not large in amount and the average efficiency given was used for plants of this type.

The irrigation practice under pumping plants was found to vary for the different portions of the area and for the different crops.

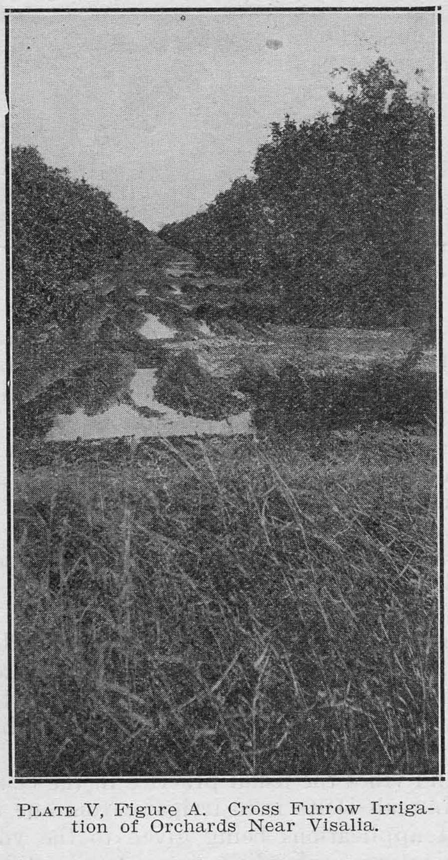

PLATE V, Figure A. Cross Furrow Irrigation of Orchards Near Visalia.

Alfalfa is irrigated in border checks 40 to 60 feet in width and 300 to 1200 feet in length, the larger checks being used on the heavier soils. The practice varies from five irrigations per season of an average depth of about 0.7 feet on the more retentive soils to 12 irrigations of an average depth of about 0.3 feet on the heavier soils. The results for 53 farms serving a total area of alfalfa of 4080 acres for which data on the water used was obtained gave an average amount pumped of 3.4 acre-feet per acre. The usual season extends from March to September, inclusive.

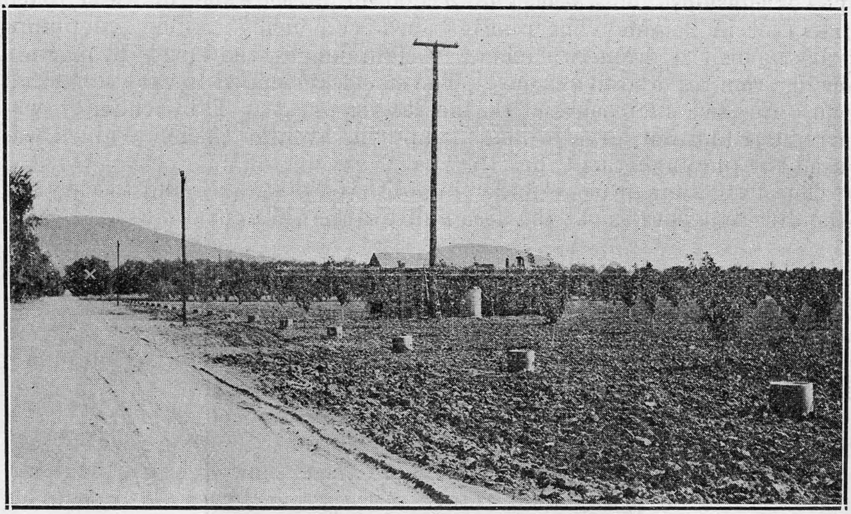

PLATE V, Figure B. Pumping Plant and Concrete Pipe Distribution System for Orchard near Exeter.

Corn, such as Egyptian or milo maize, is grown as an independent crop and also following grain. It is given from one to four irrigations, the average being three. The average use on 17 areas totaling 545 acres was found to be 1.25 acre-feet per acre.

The practice regarding the irrigation of grain varies with the precipitation for each season. Usually an irrigation is given in the Fall before seeding with an additional irrigation in the Spring. With a large rainfall at either season one or both of these irrigations may be omitted. The average is probably one irrigation per season. On seven areas totaling 516 acres given one irrigation the average amount pumped was 0.7 acre-feet per acre.

Cotton and rice were grown to some extent in 1920; the acreage in these crops in 1921 was materially reduced. For cotton an average of about four irrigations of 0.5 acre-feet per acre was typical. The use for the small area in rice was relatively large; no direct data on the amount used was obtained.

For orchards and vines the usual practice in the central and western portions of the Kaweah Delta is to irrigate from one to five times, the larger number of applications being given to the younger trees and vines. Three irrigations, extending from April to September, would be typical of the average practice. Data on twenty orchards and vineyards, totaling 1061 acres, indicated an average depth of pumping of 2.15 acre-feet per acre in this area.

For the citrus plantings on the higher lands lying in the vicinity of Exeter and Lindsay and also on the north side of the river, where the heavier soils underlain by hardpan occur, more frequent irrigations are required as only a limited amount of water can be made to enter the soil at each application. Usual practice would be represented by an irrigation each month for six to eight months with an average of seven irrigations. The season of irrigation varies somewhat with the varieties grown; some winter irrigation of Valencias may be practiced if the rainfall is deficient. March to October, inclusive, would represent the general season of use, however. Data on 38 areas in citrus crops, covering 1400 acres, gave an average use of 2.6 acre-feet per acre. The delivery for similar crops on similar soils within the Lindsay-Strathmore Irrigation District has averaged about 1.6 acre-feet per acre. It appears that those owners having pumping plants from which larger supplies may be secured are actually applying to their orchards about 2.5 acre-feet per acre.

The figures given represent the estimated total draft on the ground water for the different crops. When pumped, such water is subject to loss by seepage in farm ditches and by percolation through the soil in irrigating. As the average care in handling water under the pumping plants is better than that used in general irrigation from the ditches diverting from the river with a smaller average depth applied at each irrigation the return to the ground water from pumping should be relatively less than the losses from ditch irrigation. For the higher areas of heavier soil very little return to the ground water is probable. For much of the deciduous orchards and vineyards cement pipe is used for distribution with a resulting reduction in conveyance losses.

It is not feasible to estimate definitely the proportion of the total draft which may return to the ground water. Under average conditions of the use of pumped water a relatively small return would be expected but such average use includes areas on which the use is excessive and from which losses will occur. The drafts, as estimated for each crop and area, have been reduced by 10 per cent for the upper areas, 20 per cent for the pumping within the main canal served areas and 15 per cent for the outer areas to give the estimated net draft. These reductions are arbitrary and, while possibly fairly representative of average conditions, will vary materially in individual cases. They are considered to include both percolation losses and any over estimate of the gross draft.

The summary of the estimated total net draft is shown in Table 18. The figures given show an estimated total net pumping draft for 1921 of 162,000 acre-feet which was equal to 44 per cent of the run-off of that year and 41 per cent of the mean annual available run-off. The average draft per acre irrigated is smallest in those areas where pumping is used to supplement canal use. The pumping by the Lindsay-Strathmore Irrigation District and by small plants within the area served by the Lakeside Ditch are not included in the figures shown in Table 18.

The relatively heavy draft per acre of gross area in the area west of the Lindsay-Strathmore Irrigation District is noticeable in comparison with the draft in the other areas.

### Possible Sources of Loss from Kaweah Delta Ground Water Storage.

The efficiency of the Kaweah Delta as a reservoir for the storage of ground water depends, like any other reservoir either surface or under-

TABLE 18.

**Total Estimated Pumping Draft from Ground Water by Small Pumping Plants in Areas Dependent on Kaweah River for their Ground Water Supply.**

| Area | Acres irrigated | | Total estimated net draft from ground water, acre-feet | Gross area in acres | Average draft in acre-feet per acre irrigated | Average draft in acre-feet per acre of gross area |
|---|---|---|---|---|---|---|
| | By ditch and pump | By pump only | | | | |
| Main area of Kaweah Delta covered by canals diverting for lands below Venice Hills | 18,900 | 37,400 | 85,000 | 190,000 | 1.5 | 0.45 |
| Area covered by canals diverting mainly for lands above Venice Hills | 6,900 | 9,700 | 27,000 | 60,000 | 1.6 | 0.45 |
| Area of lower Kaweah Delta outside of areas covered by canals | 100 | 14,900 | 31,000 | 95,000 | 2.1 | 0.30 |
| Area west of Lindsay-Strathmore Irrigation District toward which the ground water slopes from the Kaweah Delta | ---------- | 7,300 | 19,000 | 20,000 | 2.6 | 0.85 |
| Totals | 25,900 | 69,300 | 162,000 | 365,000 | 1.7 | 0.45 |

ground, on its water tightness. If it is a closed basin in which ground water may be retained until withdrawn by pumping, such ground water storage may represent the most effective and economical means of utilizing the available water supply. If it consists of a sloping body of water moving steadily, even if slowly, toward some underground outlet it can not be expected to be efficient in retaining the run-off of years of more than normal supply for use in following seasons of deficient flow. An effort has been made to investigate, as thoroughly as the scope of these investigations has permitted, the conditions relating to the water tightness of the Kaweah Delta.

The general direction and rate of slope of the ground water is shown by the ground water contours on Map 2. The ground water movement is, like other flow, in the direction of the greatest slope which is at right angles to the direction of the contours. The general direction of the slope on the Kaweah Delta is toward the southwest. The change in direction of the contours north of Cottonwood Creek as the area served by Kings River is reached indicates the division of the areas dependent on Kaweah and Kings rivers. The contours west of Cross Creek show that the ground water slopes nearly south in this area with the contours following the general direction of the margin of Tulare Lake, indicating both a direction of movement toward Tulare Lake instead of to the north and across the lower Kings River Delta and a source of supply from Kings River rather than from Kaweah River.

On Map 2 are also shown portions of the contours representing deeper wells which in some instances formerly were artesian or flowing. The water rises in such deeper wells to elevations about 10 feet higher than that in adjacent shallow wells, indicating that the amount of pressure in the deeper wells is in excess of that in the shallow wells. The direction of slope of the deeper ground water closely parallels that of the shallow wells indicating that any movement in such deeper strata will also be toward the southwest rather than toward the northwest along the main San Joaquin Valley trough.

### Ground Water Conditions Along Kings River Ridge.

In addition readings were secured on deeper wells north of the Kings River Ridge. In the vicinity of Riverdale the ground water elevations were found to vary from about 215 to 230 feet with an increase in elevation toward the east along the Kings River Ridge. Surface water on the Kings River Ridge, near Hardwick, has an elevation of about 240 feet; no deeper wells were found in this vicinity. The water in the deeper wells in the Kaweah Delta vary in elevation from about 250 feet near Tulare to about 200 feet near Corcoran, with the slope definitely to the southwest. The deeper wells north of the Kings River Ridge appear to obtain their supply and pressure from sources of loss along the Kings River and to have a direction of slope similar to that of the surface waters which is both to the north and to the south away from the ridge. The elevation of the water in the deeper wells along Fresno Slough is such that but little, if any, fall would be available to cause movement from the deeper strata on the westerly portions of the Kaweah Delta even if continuous strata existed under the Kings River Ridge through which such movement might take place. The conclusion appears to be warranted that the Kings River Ridge is a barrier to the movement northward of any ground waters originating on the Kaweah Delta and also probably for ground waters originating from any areas south of Kings River.

If any ground water movement occurred outward from the Kaweah Delta such water would eventually have to reach an outlet. If such movement is toward the basin of Tulare Lake and does not escape northward it would have to appear within the basin. Tulare Lake is considered to be a sealed area, its lowering when no inflow occurs is at a rate represented by evaporation from its surface, its becoming dry indicates lack of seepage inflow. While water from Kaweah Delta may reach the deeper strata under Tulare Lake, it is considered that it is held there without natural outlet and accumulates pressure until natural relief is obtained through the filling of areas on the delta so that surface losses occur or until artificial relief through wells is secured.

### Ground Water Fluctuations on Kaweah Delta During Winter Months.

During the summer months the fluctuations of the wells represent the combined effect of inflow, draft and possible outflow so that the effect of any one factor can not be distinguished. During the winter months, however, both inflow and draft are at a minimum and the effect of any outflow may be more definitely observed. During the years covered by the well records the winter run-off has been generally smaller than normal so that the effect of any natural outflow of ground waters should be more readily discernible.

An examination of the well records indicated that the downward trend, due to late summer pumping, ended generally by November 1. Little use by pumping occurs before February 1. The well records were studied and the fluctuations for each season from November 1 to February 1 computed. The rise or fall of each well for each winter since 1917 was plotted at the location of the well and the average fluctuations for each area determined. The resulting balancing of the amount of rise and fall, together with the stream flow and rainfall, are shown in Table 19. Table 19 indicates a net rise for the area as a whole

TABLE 19.

**Summary of Changes in Ground Water from November 1 to February 1, Expressed in Total Equivalent Soil Volume in Acre-feet of Rise or Fall.**

| Area | Nov. 1, 1917 to Feb. 1, 1918 | Nov. 1, 1918 to Feb. 1, 1919 | Nov. 1, 1919 to Feb. 1, 1920 | Nov. 1, 1920 to Feb. 1, 1921 | Nov. 1, 1921 to Feb. 1, 1922 |
|---|---|---|---|---|---|
| Main area of Kaweah Delta covered by canals diverting for lands above and below Venice Hills | —39,000 | [1]+15,000 | —23,000 | +83,000 | ---------- |
| Area of lower Kaweah Delta outside of areas covered by canals | [2]+20,000 | [2]+20,000 | [2]+20,000 | +26,000 | +74,000 |
| Area west of Lindsay-Strathmore Irrigation District toward which ground water slopes from the Kaweah Delta | +62,000 | +54,000 | +57,000 | +69,000 | ---------- |
| Total | +43,000 | +89,000 | +54,000 | +178,000 | ---------- |
| Stream flow, Kaweah River, Nov. 1 to Feb. 1, acre-feet | 10,100 | 23,800 | 17,900 | 34,800 | 36,550 |
| Rainfall at Visalia, Nov. 1 to Feb. 1, in inches | 0.49 | 3.65 | 1.98 | 4.66 | 6.39 |

[1]Estimated; well records incomplete for this period.
[2]Estimated; well records for this area began in 1920.

during each winter of the period of record. The conclusion appears warranted that there is no movement of ground water outward from the Kaweah Delta as the well fluctuations and use during these months will account for the inflow. During years of light run-off there is a lowering of the ground water in the upper portions of the delta. In both years covered by the actual records there was a rise of the ground water in the lower delta. The ground water contours indicate a total fall of about 100 feet in the ground water elevation from the vicinity of Visalia to the western end of the canal served area. Under the influence of this slope there appears to be a movement of ground water outward from the upper portions of the Kaweah Delta. In years of small winter run-off this outward movement appears to exceed the inflow with a consequent lowering of the ground water in the upper delta. In years of greater run-off the inflow exceeds the outer movement and an actual rise of the ground water occurs during the winter months in the upper delta. In all years of record there is an actual rise in the outer areas. The records cover four seasons for the area west of the Lindsay-Strathmore Irrigation District. Only two seasons records are available for the westerly outer area; both show a rise of the ground water. These were years of larger winter run-off than the three preceding winters. There was less rise in the more westerly wells for which records are available for the winter of 1917-18 than for 1920-21. Somewhat less movement of ground water outward on the delta would be expected in 1917-18 than in 1920-21 as the ground water on the upper delta was lower relative to that on the outer delta with a consequent flatter slope to the ground water.

The data shown in Table 19 have also been plotted in Fig. 5. A fairly consistent relationship between the winter run-off and the

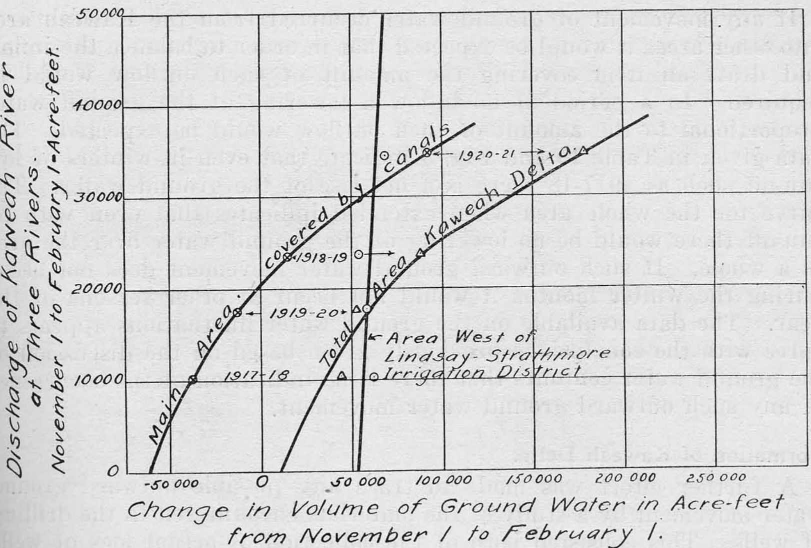


Fig. 5. Relation of Fluctuations of Ground Water in Kaweah Delta to Run-off during the Winter Months.

ground water fluctuations in the main portions of the Kaweah Delta is shown. A winter discharge of about 20,000 acre-feet appears to be required in order to maintain the ground water during the three months on the upper delta. This discharge would not all reach the ground water due to diversion for winter irrigation. There would also be some winter draft by pumping which might amount to 8000 to 10,000 acre-feet.

The rise of the ground water in the area west of the Lindsay-Strathmore Irrigation District appears to be independent of the winter flow in the Kaweah River. Such movement occurs under the general influence of the ground water slope from the adjacent area within the areas covered by canals and the extent of variation of such slope in years of different amounts of run-off does not appear to materially affect the amount of such movement.

The data available for the western area of the lower Kaweah Delta do not cover a sufficient period to enable a similar relation to be plotted on Fig. 5.

The rise in the outer area during the winter of 1921-22 was greater than during the winter of 1920-21. The run-off was similar in the two seasons. The rainfall was heavier in the second season and may have resulted in some direct additions to the ground water as it came in well concentrated storms. For the entire Kaweah area the total fluctuations appear to vary fairly consistently with the run-off. The curve shown on Fig. 5 is subject to the uncertainty involved in the estimated fluctuations of the lower delta for the seasons for which direct records are not available.

If any movement of ground water occurred from the Kaweah area into other areas it would be expected that in order to balance the inflow and draft an item covering the amount of such outflow would be required. In a period of no inflow a lowering of the ground water proportional to the amount of such outflow would be expected. The data given in Table 19 and Fig. 5 indicate that even in winters of low run-off such as 1917-18 there is a net rise of the ground water. The curve for the whole area when extended indicates that even with no run-off there would be no lowering of the ground water over the area as a whole. If such outward ground water movement does not occur during the winter months it would not occur at other seasons of the year. The data available on the ground water fluctuations appears to agree with the conclusions previously given based on the discussion of the ground water contours that there is no indication of the occurrence of any such outward ground water movement.

**Formation of Kaweah Delta.**

A further effort was made to trace any possible outward ground water movement by a study of the materials encountered in the drilling of wells. This consisted both of the collection of actual logs of wells where available and of discussion of general conditions with those engaged in well drilling. The conditions under which the various materials forming the Kaweah Delta have been deposited are too complex to enable any definite structure to be developed from such data. In general the first artesian strata is found after passing through a layer of blue clay at depths which vary from about 350 feet near Tulare to 500 feet at points five or six miles further west. Below these depths alternating strata of sands and blue clays are found. The slope of the upper blue clay strata is somewhat steeper than that of the present ground surface. These strata may have some relationship to the clays occurring in the hog wallow areas near the upper edge of the valley, the difference in color being due to differences in conditions affecting oxidation. A well in the courthouse yard at Visalia is reported to have struck a tight red and yellow clay at a depth of 275 feet. Present stream channels in the upper portion of the valley area are cut down into the underlying heavier formation and afford a means of access of water to any pervious strata of such formations. The depths given to the first heavy clay strata may indicate the thickness of the recent valley alluvium or delta deposits.

There is no difficulty in securing ground water supplies from wells anywhere in the main areas of the Kaweah Delta and the wells are usually relatively shallow, few exceeding 200 feet in depth. In the outer portions of the delta the water bearing strata are less frequent and deeper. West of a line approximately following the Santa Fe Railroad from Corcoran to Hanford, the yield of shallow wells is small and deeper wells, usually artesian, are used. It appears that the upper water bearing strata tend to pinch out in this area and the only available supplies are from the lower areas containing water under artesian pressure. Flowing wells could formerly be obtained over a much larger area than at present; some wells flow only during the winter season now that formerly flowed continuously. The source of the water in these deeper strata appears to be the Kaweah Delta until the general body of underground water underlying the valley trough is reached where the source may be the mingled supply from all streams tributary to the Tulare Lake Basin.

In Water Supply Paper 398 of the U. S. Geological Survey the quality of the water obtained from different depths in wells in this vicinity is discussed with conclusions that appear to agree with the general statements made above. Wells in the areas formerly covered by Tulare Lake, where the formations consist of deposits from the lake including the saline deposits due to evaporation, are stated to yield water high in sulphates. Those deeper wells in the same areas which draw their supply from sediments derived from the east side streams and deposited under the lake bed fill secure water of good quality. The eastern boundary of the area affected by lake residues is shown as running from Earlimart through Angiola, Corcoran, Guernsey and Lemoore. Data given regarding the depth of the lake deposits result in the conclusions that the thickness varies from a negligible amount near Corcoran and Guernsey to 400 feet or more at a distance of six to eight miles west of Corcoran. The conclusion is also reached that ground waters from the east and the west side sources do not mingle to any large extent and that wells to the west of the middle of the lake would probably encounter the sulphate waters derived from west side sources at all depths.

The lake bed deposits being of generally finer materials than those deposited by the streams in building up their deltas are less freely water yielding and the difference in both quality and quantity account for the use of deeper wells in the area where the lake bed fills overlap the direct stream deposits. This difference in the conditions under which the materials have been deposited appears to account for the differences in wells in this area. The abruptness of the change in the conditions affecting surface wells has caused the line of change to be referred to locally as being a possible "fault line." Apparently no such assumption is needed to explain the conditions existing here.

The data available on the character of the formations and the quality of the water obtained appear to still further support the conclusion that no general outward movement of ground water from the Kaweah Delta occurs. The tightening of the surface strata on the western portion of the delta would limit, if not entirely prevent, any such movement in these strata. The change in quality of the water in the deeper strata indicates that movement of the sulphate free water from the Kaweah Delta has not progressed beyond the areas adjacent to the delta.

## GROUND WATER FLUCTUATIONS.

The general ground water fluctuations for any period indicate the balance between the elements of replenishments and of draft for that period. The data on ground water from which the fluctuations can be studied on the Kaweah area consists of records beginning early in 1917 over the upper and main canal areas and maintained to date by parties to the pending litigation resulting from the pumping by the Lindsay-Strathmore Irrigation District, data given in Water Supply Paper

398 of the U. S. Geological Survey on depths to ground water in 1905, general information on conditions in past years and records extending over the outer portions of the Kaweah Delta from July, 1920, to February, 1922, secured in the course of these investigations. The records of the Lindsay-Strathmore Irrigation District have been used for the areas covered. Those pertaining to the area immediately adjacent to the area of pumping by the district have not been included in the discussion which follows.

### Ground Water Fluctuations 1917 to 1921.

The records of wells indicate that the lowering due to pumping ceases in the late fall and that a rise due to the lessening of draft and the recharge begins. A study of the well records indicated that this change in the ground water elevations occurs generally about November 1 and this date has been used as the division of the ground water year. As the records did not begin until early in 1917 a separate year from March 1, 1917, to March 1, 1918, is used for that season.

These well readings cover all of the Kaweah Delta except the outer portion on the west and southwest. The records of about 200 wells were available for each of the years. About 80 wells were observed for the outer area of the delta in these investigations from July, 1920, to February, 1922. The probable fluctuation of these wells for the other years was estimated by comparison with adjacent wells for which records covering long periods were available.

The change of elevation in each well for each year was plotted on maps showing the location of each well and contours showing equal changes of rise or fall were drawn from which the average changes shown in Table 20 were determined. Map 3 gives the results for 1920–21.

TABLE 20.

Summary of Average Lowering of Ground Water, in Feet, in Kaweah Delta Areas, 1917 to 1921.

| Area | Average lowering for period in feet | | | | | |
|---|---|---|---|---|---|---|
| | Mar., 1917 to Mar., 1918 | Nov. 1, 1917 to Nov. 1, 1918 | Nov. 1, 1918 to Nov. 1, 1919 | Nov. 1, 1919 to Nov. 1, 1920 | Nov. 1, 1920 to Nov. 1, 1921 | Nov. 1, 1917 to Nov. 1, 1921 |
| Main area of Kaweah Delta covered by canals diverting for lands below Venice Hills | 2.5 | 2.5 | 2.1 | 0.1 | 0.8 | 5.5 |
| Areas covered by canals diverting for lands mainly above Venice Hills | 0.8 | 0.9 | 0.9 | 0.2 | 0.8 | 2.8 |
| Area of lower Kaweah Delta outside of areas covered by canals | *2.3 | *3.2 | *2.7 | *1.3 | 1.8 | 9.0 |
| Area west of Lindsay-Strathmore Irrigation District toward which ground water slopes from the Kaweah Delta | 1.5 | 2.2 | 2.1 | 0.8 | 1.3 | 6.4 |
| Mean | 1.9 | 2.2 | 2.0 | 0.4 | 1.0 | 5.6 |
| Total run-off of Kaweah River—acre-feet | 391,500 | 237,000 | 281,500 | 377,500 | 373,500 | 317,500 |
| Estimated total pumping draft—acre-feet | 109,000 | 124,000 | 133,000 | 142,000 | 162,000 | ---------- |
| Rainfall at Visalia—inches | 5.21 | 8.07 | 8.85 | 9.32 | 8.56 | ---------- |

*Estimated.

The summations of the lowering of the water table in different years are not altogether consistent. It would be expected that the total lowering would be greatest in years of least rainfall and run-off and of greatest draft. The results in general vary with the amount of run-off except for 1920 when the lowering was less than that in 1921 although the run-off in the two years was practically the same.

Although the total run-off in 1920 and in 1921 was closely the same, its distribution by months differed. In 1920, 50 per cent of the run-off occurred in May and June and 7 per cent during November to February inclusive. In 1921, the run-off was more evenly distributed; only 28 per cent occurred during May and June and 16 per cent in November to February. The more even run-off in 1921 resulted to some extent in a larger proportion of the supply being diverted by the older ditches for areas near the upper portion of the delta with less water reaching the outer canal areas. In 1920 the rainfall in the area was somewhat greater than in 1921. In March, 1920, the rainfall was 3.74 inches at Visalia and in March, 1921, 1.36 inches with some resulting earlier pumping in 1921 than in 1920. In the early part of 1920 there were some restrictions placed on power for pumping due to the shortage of supply which had some effect in lessening the draft at that time.

For the mean of 1920 and 1921 with a net available water supply of 369,000 acre-feet per year an area of 183,500 acres of cropped or subirrigated land was supplied with a resulting average lowering of the ground water of 0.7 feet over an area of 365,000 acres or a total draining of 255,000 acre-feet of soil volume. If the ground water had remained stationary a net average use of about 2.0 acre-feet per acre would have been indicated. The lowering is difficult to estimate as the quantities of water represented by changes in ground water elevations are variable. If the loss in ground water storage due to the lowering is estimated to represent an average of one-tenth of the volume of the soil drained, a ground water depletion of 25,000 acre-feet is indicated.

The mean annual gross run-off of the Kaweah River has been estimated to be 451,000 acre-feet of which an average of 55,000 acre-feet is not retained on the Kaweah Delta, leaving an average net available supply of 396,000 acre-feet. The difference between the net available supply in 1920 and 1921 and the mean is 27,000 acre-feet.

The above comparisons indicate that the present draft on the Kaweah River run-off is closely equal to the mean annual net available supply. An increase in use under existing conditions would be expected to result in a lowering of the average ground water elevations.

The conclusion that present use is about equal to the available supply does not mean that all of the present use can be maintained without further lowering of the ground water as the supply and use in the different portions of the area are not balanced. In some portions due to canal diversions and light pumping the ground water has risen since the deficient years of 1918 and 1919, in other areas of small canal use or heavy pumping there has been a continual lowering of the ground water which can only be expected to continue even in years of large run-off under existing conditions of diversion. The conditions affecting the different portions of the area are discussed in detail later.

## Change in Ground Water Since 1905.

In Water Supply Paper 398 of the U. S. Geological Survey, "Ground Water in the San Joaquin Valley, California," readings of wells in Tulare County with the owner's name, the section, township and range of the location and the depth of water are given. The report states that the records were obtained during the period from 1905 to 1907; the work in Tulare County is referred to as of 1905. While the seasons of 1904 and 1905 were somewhat below normal in run-off, the pumping draft on the outer portion of the delta was relatively small at that time and the water table was probably relatively high.

An effort was made to find the wells read in 1905 in order to determine the changes in ground water elevation since that year. Such comparisons were made for 97 wells scattered from the vicinity of Visalia to the area which was artesian in 1905. The readings were secured in 1920. The comparisons have been reduced to the changes from 1905 to 1917 by comparison with the well records for the same areas for the period 1917 to 1920.

The results are as follows:

| Area | Number of wells found | Average lowering, 1905 to 1917 | Average lowering, 1917 to 1921 |
|---|---|---|---|
| T. 18 S., R.s 23 and 24 E., in vicinity of Visalia | 31 | 4.0 | 1.1 |
| T. 19 S., R.s 23-25 E., extending from Visalia to Tulare | 33 | 1.3 | 7.0 |
| T. 20 S., R.s 23 to 25 E., extending from Tulare toward Corcoran | 33 | 3.0 | 10.8 |

The first group of wells are located generally within the canal served area and show more drop from 1905 to 1917 than for the period 1917 to 1921. In the second area the canal service is less extensive and more irregular in amount with a consequent larger development of pumping draft in recent years. This is indicated by the drop of 7.0 feet in the last four years as compared to 1.3 feet for the previous twelve years. For the third area there is little canal service and pumping began relatively somewhat earlier; however, the drop per year has been about ten times as large for the past four years as for the previous ten years. Not all of this difference should be considered to be due to the relative draft during the two periods as the last four years have been ones of less than average run-off.

## Variations in Conditions of Water Supply and Use in Different Parts of Kaweah Delta.

The available data regarding water supply, diversions, areas served, pumping draft and ground water fluctuations for the Kaweah Delta as a whole has been presented and discussed with the conclusion that for the total area of the Kaweah Delta the present rate of water consumption very closely equals the mean annual net available water supply or that the present total irrigation development is as large as can be maintained with the water supply under existing conditions without a continuous lowering of the ground water in some parts of the delta over any period of years. This conclusion is limited to present conditions existing in this area both as to the amount of the net available annual water supply and the character of its use. It has also been concluded that while the above condition is correct as an average for the area as a whole, present development is not distributed over the delta in proportion to the locally available sources of water supply and that continued and serious lowering of the ground water is occurring and can only be expected to continue to occur in certain portions of the area if present conditions are maintained.

There is frequent discussion of the relative advantages of position in securing a permanent ground water supply between those located near the upper end of a delta as compared with those located at the lower or outer edges. The ground water occurs in the delta on a slope from the upper end outward to the lower edges and the argument is advanced that as pumping becomes heavy the ground water in storage in the delta will tend to become depleted and consequently to assume a flatter slope with a greater lowering at the upper end of the delta than at the outer. This would result in a more rapid increase in the lift on the upper end with a more quickly felt necessity of reducing pumping due to increases in costs. This basis of reasoning has not been supported by the experience on the delta of Kaweah River to date. The maximum lowering has occurred in those areas near the outer and lower edges of the delta wherever heavy pumping has been practiced with little local canal service while areas near the upper portion of the delta where replenishment mainly occurs by percolation from the stream channel and canal use have maintained their ground water levels.

A similar advantage in position appears to be inherent to such locations near the source of the ground water supply that exists on a canal where those located near the head of the canal have a material advantage in securing water in times of scarcity over those on the lower portion. Should a flattening of the ground water slope in the Kaweah Delta occur due to a large lowering of the ground water in the upper portion of the delta the amount of ground water reaching the outer portions would be reduced as both the area of cross section and the slope under which such movement occurred would be reduced.

The lowering of the ground water around the edges of the Kaweah Delta is resulting in increasing the ground water slope toward those areas and some increase in the ground water movement is to be expected. It is extremely doubtful, however, if such increased ground water movement will be sufficient to furnish the supply now being drawn from at least some of these outer areas until the total increase in lift has become so great that pumping will be restricted by the resulting costs. The present total fall of the ground water from the upper end of the delta to Goshen, Tulare or Lindsay is about 100 feet. The velocity of ground water is generally considered to vary about directly with the slope. To double the velocity would require that the slope or fall be doubled or a lowering of the ground water of 100 feet at the points mentioned would probably be required before double the present ground water movement to these outer areas might be expected to take place.

The conditions in the separate portions of the general areas previously discussed vary. The following discussion presents the conclusions reached in these investigations for the local areas within the general divisions of the delta.

**Main Area Covered by Canals.**

On Map 1 the areas served by the larger number of the Kaweah ditches are shown. On Map 3 the net ground water fluctuations for 1920–1921 are given. The area served by those ditches having generally the earlier priority of right to the use of Kaweah River has maintained its ground water elevations during the past two years of somewhat less than normal run-off.

There was an area of 135,000 acres covering the lands within which the 1921 canal irrigation on the delta was applied, out of the total area of 190,000 acres previously classed as the general area within which canal irrigation may be applied, for which the ground water averaged in 1921 to remain at the same elevation, the local rises balancing other local lowering. The pumping draft in this area averaged 0.3 acre-feet per acre of gross area. For the conditions existing in 1921 the inflow to the ground water balanced the rate of local pumping draft and the ground water movement into the outer parts of the delta. In the same area in 1919–20 there was an average rise of the ground water of 0.25 feet. For the period of 1917–1921 the portion of the area in the vicinity of Visalia has had no ground water lowering; about one-half of the area has lowered less than two feet and the outer portions have lowered as much as five feet. This area includes the areas north of the St. Johns River served by the Matthews and Uphill ditches and in general the area between St. Johns River and the eastern boundary of the lands served by the Peoples Ditch and extending to the southwest to about the line of the Southern Pacific Railroad from Tulare to Goshen. There was in general some rise in the ground water in the upper portions of this area in 1921 and some lowering in the lower portions. In this area there were 43,700 acres reported as receiving canal service only, 14,800 acres receiving both ditch and pump service, and 14,500 acres receiving pumped water only, a total area of 73,000 acres or slightly over 40 per cent of the total irrigated area dependent on Kaweah River.

The run-off in 1920–21 was 93 per cent of the estimated mean annual net available supply under existing conditions, the actual shortage being 27,000 acre-feet. With present conditions of use it would appear that this area can be expected to maintain its ground water elevations with some lowering in dry years and recovery in excess years. An increase in pumping draft particularly at the upper end of this area would not be expected to result in material ground water lowering within the area itself but will serve to intercept some ground waters now moving to the outer areas and increase the rate of lowering there. Due to the high ground water in some parts of the upper area there is now loss of moisture from subirrigated areas in excess of beneficial needs. An increase in draft in these areas with a lowering of the ground water would result in the salvage of such losses.

To maintain not only the average ground water elevation over this area as a whole but also in its parts, the distribution of a larger proportion of the run-off for surface irrigation in the areas more distant from the river than occurred in 1921 will be required. Such increase in canal use in the outer areas would serve both to reduce the draft and to increase the replenishment in those local areas.

The remaining 55,000 acres of the area previously classed as the main canal served area lying west of the Southern Pacific Railroad and extending from Goshen to the Tule River has been included in the main canal area as shown on Map 2 due to the fact that in years of excess run-off portions of this area may receive canal service principally from the Packwood, Tulare Irrigation District and Elk Bayou systems. In 1920 and 1921 the lands irrigated in this area were relatively small. The ground lowered over all of this area, the amounts being in general proportion to the extent of the local draft. The average lowering was 2.6 feet with a maximum lowering of about five feet. For the period 1917 to 1921 the total lowering has varied from five to twenty feet being largest in the area of heavy pumping west of Tulare.

In the eastern half of T. 20 S., R. 23 E. in which there was very little canal irrigation in 1921 but where the pumping draft averaged 1.3 acre-feet per acre of gross area there was an average lowering of four feet for the year. The rate of draft is four times the average rate for the area which held its ground water elevations in 1920–21. This heavy rate of draft without direct canal irrigation within the area can only be expected to result in a relatively rapid lowering of the ground water. The diversion of larger amounts of canal water into this area or the lessening of the draft by more careful use of the water pumped will be required if the present development is to be maintained.

In the western portions T. 20 S., R. 24 E. not included in the canal area maintaining its ground water in 1921, there was an average draft of 0.8 acre-feet per acre of gross area and an average lowering of 2.6 feet in the ground water. Conditions in this area differ from those in the eastern part of T. 20 S., R. 23 E. only in degree. The average pumping draft is somewhat less and the canal irrigation slightly greater with a consequent less lowering of the ground water. The balance for 1921 is a material lowering however, and present development can only be maintained without permanent ground water lowering by the use of larger amounts of canal irrigation than have been used in recent years. The permanence of present rates of pumping in this area will depend on the extent to which canal water may be brought into this area in years of more than normal run-off.

In the southwestern part of T. 19 S., R. 24 E. an average draft of 0.6 acre-feet per acre of gross area resulted in an average ground water lowering of 2.7 feet in 1921. In the southeastern part of T. 19 S., R. 24 E. where some canal irrigation was received an average draft of 0.9 acre-feet per acre of gross area resulted in an average lowering of 0.7 feet in 1921. Since 1917 the average lowering in the southwestern part of this township has been about 15 feet as compared with 10 feet in the southeastern portion. These differences illustrate the effect of the additional canal use in the southeastern part of the township where a heavier draft is maintained with less lowering than in the adjacent southwestern portion.

The differences in the conditions of draft and replenishment in the different parts of these areas is further illustrated by the hydrographs of typical wells shown in Figs. 6 to 8. The location of each well is shown on Map 2.

The character of the fluctuation of ground water at any point reflects the conditions affecting the well. The wells used are ones which are not subject to heavy draft and consequently reflect average changes for the vicinity rather than the local effects of single plants. A well whose hydrograph shows little change during the year in general indicates a limited recharge or a location at considerable distance from any direct source of supply. Wells adjacent to streams or canal use generally show a marked rise at the period of flow in such channels or of use under the canal. A lowering during the later season when run-off has diminished and the draft is a maximum is to be expected.

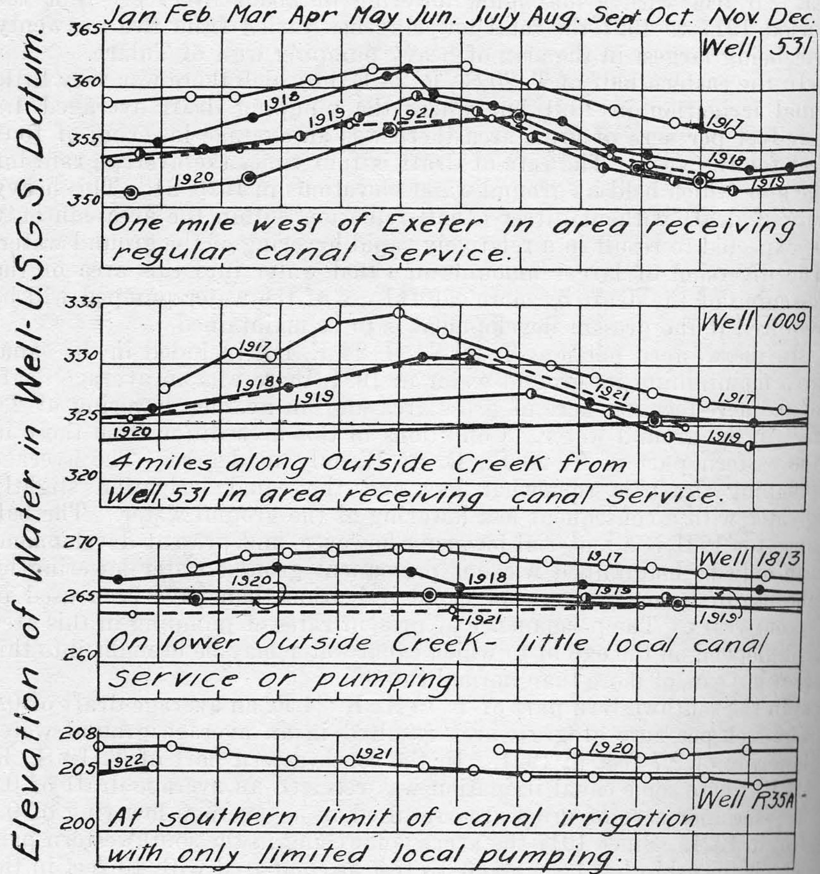


Fig. 6. Hydrographs of Typical Wells extending along the course of Outside Creek.

In Fig. 6 the hydrographs of four wells extending along the general direction of Outside Creek are shown. Well 531 is located one mile west of Exeter in the area served by the Consolidated Peoples Ditch. The hydrograph shows the rise each year during the period of large run-off in May and June with the lowering in the late summer during the period of draft, the rise beginning about November 1. Since 1918 the lowering of this well from year to year has not been regular and little marked drop is shown. The high elevations of 1917 following the excess run-off of 1916 have not been regained however.

Well 1009 is located about four miles along the course of Outside Creek from well 531. The records are not as complete but no pronounced tendency toward lowering is shown. This well is within the area receiving regular canal service. Well 1813 is located at the lower end of the irrigated area under the Peoples and Farmers ditches and adjacent to Outside Creek. There is little local pumping. There is little recharge shown during the periods of flow in Outside Creek with a continual lowering for each year covered by the record.

Well R35 is located at the southwestern limit of canal irrigation from Kaweah River in an area where practically no canal water was received in 1920 and 1921 and where there was only limited pumping in its vicinity. A continual drop of about two feet per year is shown without any periods of definite rise.

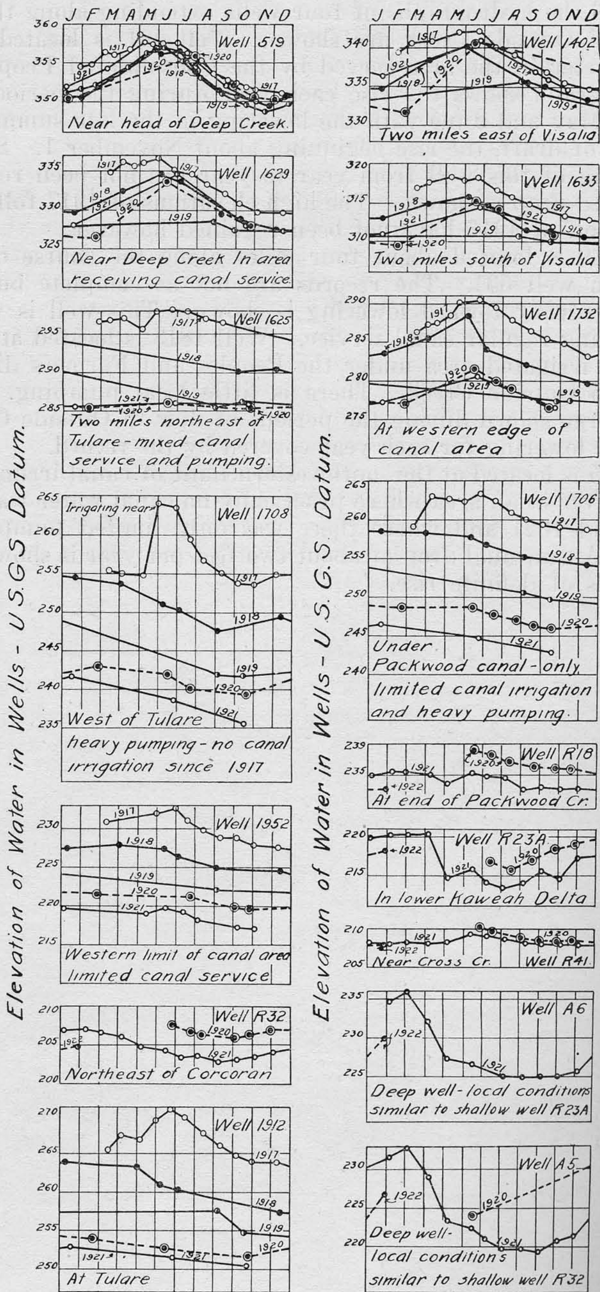


Fig. 7. Hydrographs of Typical Wells in lines radiating across Kaweah Delta along Deep and Packwood Creeks.

In Fig. 7 wells 519 to 1912 are located along the general direction of Deep Creek. Well 519 is located in the upper portion of the delta and shows the effect of local stream flow and irrigation. This well in 1921 had practically recovered the 1917 elevations. Well 1629 is also within the canal areas receiving regular service and has recovered since 1919. Well 1625 is located two miles northeast of Tulare in an area receiving irregular canal service and of fairly heavy pumping. A marked lowering from 1917 to 1919 is shown with very small changes since 1919. Well 1708 is located west of Tulare in an area of heavy pumping where no canal service has been received since 1917. The quick response to irrigation in 1917 and the continual lowering since 1917 are noticeable in this well. Unless water for irrigation from canals is brought to this area with fair regularity a continual lowering is to be anticipated.

Well 1952 is located about one-half way between Tulare and Corcoran in an area considered within the main Kaweah Delta but where very little canal service is received. A marked and continuous lowering is shown. Well R32 is located outside the canal area in the lower delta and shows a steady lowering due to pumping. Well 1912 is located at Tulare and like well 1708 reflects the effect of canal irrigation in 1917 and the lack of such replenishment since 1917.

Well 1402 in Fig. 7 is located two miles east of Visalia near Packwood Creek. It has nearly maintained the 1917 elevation due to its location in the area of regular canal irrigation. Well 1633 is located two miles south of Visalia under conditions similar to well 1402 except that adjacent canal irrigation is not as extensive. Well 1732 is located four miles west of well 1633 at the western edge of canal irrigation. The lowering in the two dry years of 1918 and 1919 is noticeable. Since 1919 the replenishment has balanced the draft. There is an area of heavy pumping to the west of this well. Well 1706 is located in the area of the Packwood Canal where canal service has been very limited since 1917 and where pumping is heavy. An average drop of about four feet per year is shown. Well R18 is located at the west limit of the area which is understood to ever receive canal irrigation and where no canal water has been used since prior to 1920. A continual drop with no recovery is shown.

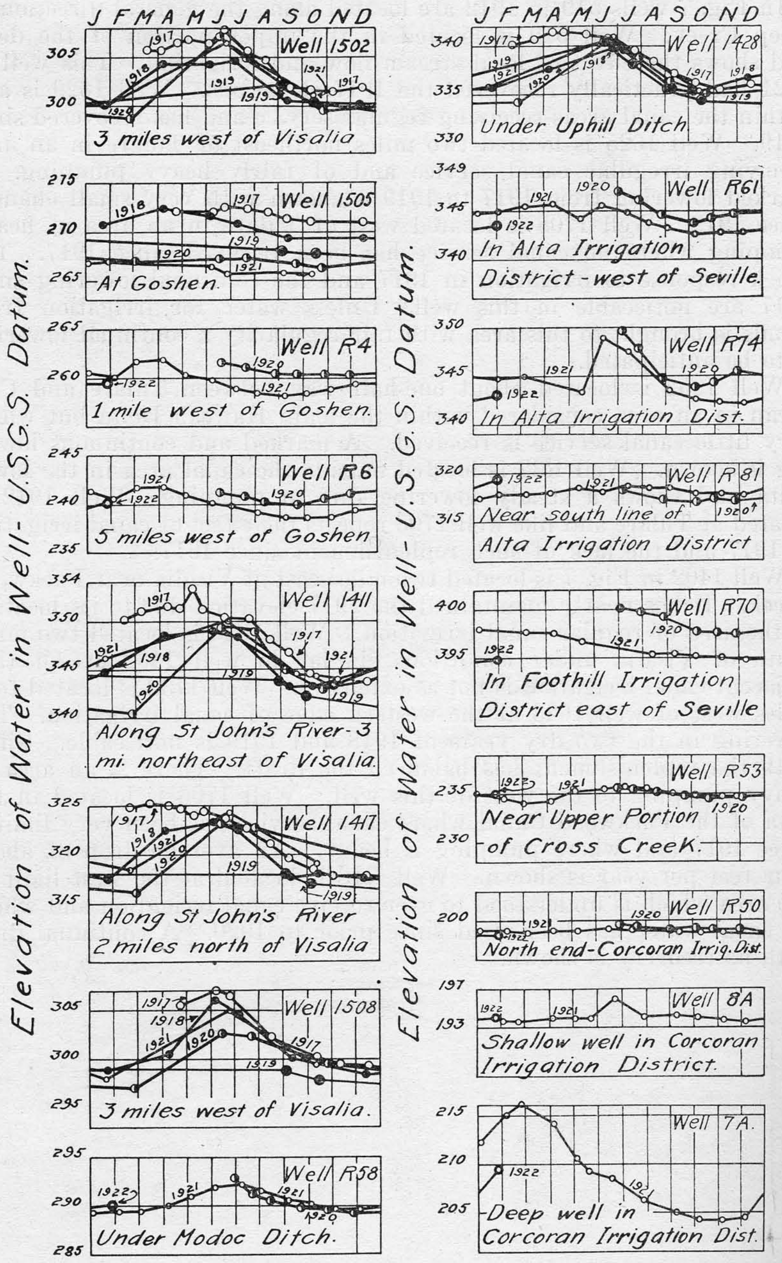


Fig 8. Hydrographs of Typical Wells in Northern Part of Kaweah Delta and in Adjacent Areas to the North and West.

In Fig. 8 are shown hydrographs of wells in the northern part of Kaweah Delta. Well 1502 is three miles west of Visalia under the Watson Ditch. A definite annual rise during the period of high flow in the Kaweah and a recovery of the 1917 elevations are shown. Well 1505 is at Goshen. There is limited canal use in the vicinity and more pumping than near well 1502. The difference in the form of the annual cycles is noticeable. Well 1505 shows a continual lowering. Well R4 is one mile west of Goshen and shows more lowering in 1921 than well 1505.

Wells 1411 and 1417 in Fig. 8 are along the course of St. Johns River under the Matthews Ditch and shows similar fluctuations. Well R58 is farther west and shows a less marked summer rise with no lowering. Well 1428 is under the Uphill Ditch north of St. Johns River, its hydrograph being similar to those nearer the river.

**Lower and Western Part of Kaweah Delta.**

In the area extending west from the main canal area to Cross Creek and south to Tule River there is no direct canal irrigation except for a small area adjacent to Cross Creek. The pumping draft varies with the different parts of the area. The averages draft and lowering for the different parts of this area in 1921 are as follows:

| Area | Average pumping draft in acre-feet per acre of gross area | Average lowering of ground water, feet |
|---|---|---|
| T. 18 S., R. 23 E. | 0.5 | 1.2 |
| T. 19 S., R. 23 E. | 0.5 | 1.3 |
| T. 20 S., R. 23 E. | 0.9 | 3.2 |
| T. 21 S., R. 23 E. | 0.2 | 1.7 |
| T.s 19, 20 and 21 S., R. 22 E. | 0.1 | 0.6 |

These figures show a consistent relationship of draft and lowering except for T. 21 S., R. 23 E. The draft in this township is relatively light but its distance from any direct sources of replenishment results in a larger lowering in proportion to the draft than in other areas. The rate of draft in the western part of T. 20 S., R. 23 E. as given above is about two-thirds that in the eastern part as given previously with a lowering in the western part equal to 80 per cent that in the eastern. The western part is more sensitive to draft apparently due to its greater distance from direct sources of supply.

The areas in range 22 east have a low rate of draft, the development being scattered. Even this rate of use resulted in a lowering in 1921,

The fluctuations of typical wells in this area are shown in Figs. 7 and 8. Well R23A, Fig. 7, is in an area of heavy local pumping where the summer lowering has been only partly recovered during the winter months. Well R41 is adjacent to Cross Creek and shows some effect from the June flow through Cross Creek. There is no pumping within over one mile of this well and little lowering is shown.

Well A6 is a deep well under similar local conditions to well R23A. Well A5 is also a deep well under conditions similar to shallow well R32. Both of these deep wells show a wider fluctuation during the year with a marked recovery of pressure in the winter. A net loss is shown for each year however.

Well R6, Fig. 8, is five miles west of Goshen and shows some rise in the spring of 1921 which may be caused by the Lakeside Ditch flow in Cross Creek. The well is at the western edge of present pumping.

## UPPER CANAL AREAS.

The area considered under the above heading is shown on Map 2. The division lines are not definite but the area includes the lands whose ground water appears to be derived from the Kaweah River above Venice Hills or from canals diverting from the upper portions of the river. The Marks and Rice, the Lemon Cove and the Merryman ditches divert on the south side of the river. The Wutchumna Ditch diverts on the north side. Longs Canal and the Enlow and the Hamilton ditches divert below McKay Point for lands along the stream channels. The diversion records are given with the records of all canals.

Near the St. Johns and Kaweah channels the area irrigated by canals is partly subirrigated. Little pumping is practiced in these lower lands for local use. The pumping plants of the Lindsay-Strathmore Irrigation District are located in this area, the water pumped being taken to the lands whose natural source of ground waters is mainly Lewis Creek.

For the lands lying in the northwestern part of this area and partly served by the Wutchumna Ditch the ground water contours indicate a direction of movement from above Venice Hills between the hills and Cottonwood Creek. The extent of replenishment in relation to the draft during the past four years has resulted in an average lowering of 3.6 feet in the ground water. There has been a relatively larger increase in the area supplied by pumps in some parts of this area during the past year than in other parts of the upper area. The lowering during the past four years has been greatest in the portion of the area in the southwestern part of township 17 south, range 26 east.

As the Wutchumna is one of the older rights on Kaweah River its diversions vary to a less extent from year to year than those of canals of later rights. The lowering of wells in this area during the past four years and particularly during 1921 appears to indicate that the movement of general ground waters from the Kaweah River and possibly from Cottonwood Creek together with such additions to ground water as may result from the use of Wutchumna Ditch water have not been sufficient to maintain the present draft without a continued lowering of the wells. Additional development by pumping in this area would be expected to result in a continued lowering of the water table with eventual difficulties due to greater lifts and additional cost of obtaining the required supplies unless additional canal diversions into the area are made.

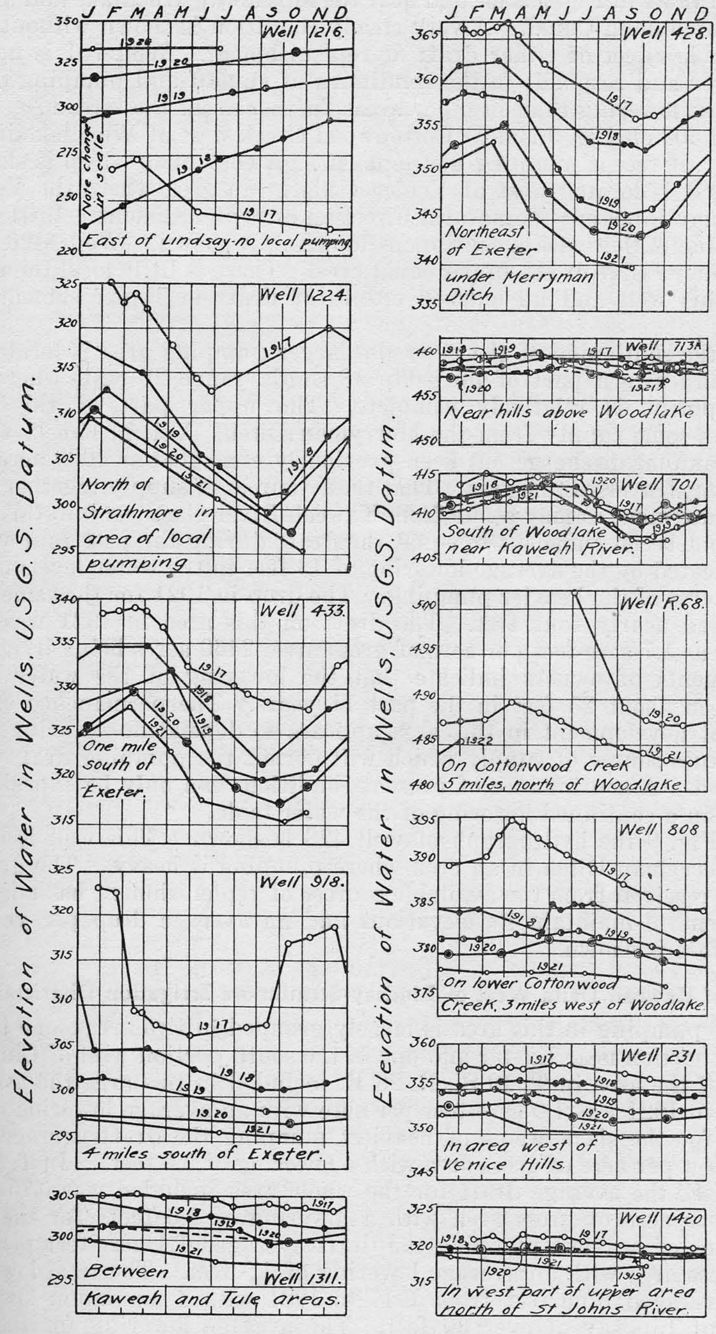


Fig. 9. Hydrographs of Typical Wells in Upper Kaweah River Areas.

Well 713A in Fig. 9 is located near the hills above Woodlake and under the Wutchumna Canal. A very steady condition is shown without any noticeable effect of either draft or replenishment. Well 701 is nearer the river and responds to the conditions of run-off and pumping draft with less lowering than in other areas further from the stream.

Well 808 on Fig. 9 is near Cottonwood Creek west of Woodlake in the vicinity of recent pumping development. A continuous drop is shown. Well 231 is located west of Venice Hills in an area where the Venice Hills may intercept the natural direction of replenishment. Little seasonal fluctuation with a continuous lowering is shown. Well 1420 is at the western edge of the upper canal area. There is little local pumping near this well and no marked effects of draft or replenishment are shown.

On the south side of the river the larger pumping area is located in the southeastern part of township 18 south, range 26 east, where the development is relatively complete. The upper part of this area receives some supply from the Merryman Ditch. Yokohl Creek, whose mean annual discharge has been previously estimated at 4000 acre-feet per year, traverses this area. That these sources of supply together with such movement as may occur from Kaweah River channels into this area have not beeen sufficient to equal the draft during the past four years, is indicated by the average lowering of 13 feet in the water levels under 3000 acres of the heavier pumping. The drop in 1921 for the same area averaged nearly four feet. The draft on this area in 1921 was estimated as 1.7 acre-feet per acre of gross area, 2460 acres being irrigated. Statements of owners indicate that the lowering of the water table has been about 25 feet in the past 11 years. The permanence of the present development in this area appears to depend on securing some substitute source of supply which will permit the pumping draft to be reduced. A continuance of present conditions can only be expected to result in a continued lowering of the water table.

In Fig. 9 the hydrograph of well 428 is shown. This well is below the Merryman Ditch in an area where pumping is heavy. The ground water received from the available sources of replenishment has not been sufficient to maintain its elevations and an average drop per year of four feet is shown.

### Area of Kaweah Delta West of Lindsay-Strathmore Irrigation District.

The pumping in this area is largely grouped in two areas, one in the north portion near Exeter and one in the south portion west of Lindsay. For all the area in T. 19 S., R. 26 E. included in this area the average draft in 1921 was 1.0 acre-feet per acre with an average lowering of 2.0 feet; for the six sections of heaviest pumping the draft averaged 1.6 acre-feet per acre of gross area with a lowering of 2.2 feet. In T. 20 S., R. 26 E. the average draft for the whole area included was 0.75 acre-feet per acre of gross area with a lowering of 1.6 feet; for the nine sections of heaviest pumping the draft averaged 1.4 acre-feet per acre of gross area with an average lowering of 1.9 feet. The total lowering has averaged nine feet from 1917 to 1921 with a maximum lowering west of Lindsay of over 30 feet. The average lowering for the two years 1920 and 1921 was 1.5 feet per year as compared with an average annual lowering of 3.0 feet for the two previous years. In 1920 and

1921 the run-off of Kaweah River has been larger than in 1918 and 1919 with a resulting larger amount of irrigation on adjacent areas on the Kaweah Delta, the draft may have decreased somewhat due to lessened discharge of pumps on the larger lifts or due to more careful use of water and the increase of slope into the area from the vicinity of Outside Creek may have resulted in some increased ground water movement into the area. The data on rise of the ground water in this area during the winter months (Table 19) shows little increase in such rise in 1921. The decrease in the rate of lowering has been much greater in the northern portion of this area than in the southern. In 1920 and 1921 the average lowering in T. 19 S., R. 26 E. was 1.5 feet and in 1918 and 1919, 3.6 feet. In T. 20 S., R. 26 E. the average lowering in 1920 and 1921 was 1.5 feet and in 1918 and 1919, 2.4 feet. The area around Exeter appears to receive more direct effects from run-off than the area west of Lindsay. As 1920 and 1921 had a run-off equal to over 90 per cent of the mean annual net available supply a continued lowering of the ground water in these areas is to be expected under existing conditions.

In Fig. 9 hydrographs of typical wells in the area between Exeter and Lindsay are shown. Well 433 is south of Exeter in an area of heavy pumping with some use under the Merryman Canal to the east and under the Peoples Ditch to the west. The summer draft prevents any summer rise showing if one occurs. A winter recovery is shown with a steady lowering in each year.

Well 918 is located four miles south of Exeter at the southern edge of the heavy pumping. A continuous lowering is also shown by this well. Well 1311 is west of Lindsay in an area distant from any source of supply. As the local pumping is less than in other parts of this area the lowering while continuous has been less in amount than in wells 433 and 918.

## AREAS ADJACENT TO KAWEAH DELTA.

### Areas Along the Foothills North of Kaweah River Areas.

Well readings were secured as far north as the north line of township 17 south in the area of the Alta and the Foothill irrigation districts. The areas to the south boundaries of these two districts are considered to be dependent on Kings River for their water supply. Kings River water is now obtained by the Alta district and the ground water contours indicate the source of supply of the ground water within the district is from the northward. The areas within the Foothill district adjacent to the Kaweah areas are dependent on their very limited local drainage from the hills behind them. As such areas are making efforts to secure a water supply from Kings River no detail study of their local supply has been made. It would appear, however, that any such local source of supply must be very limited and sufficient for only a very limited area.

Well R61, Fig. 8, is in the Alta Irrigation District and west of Seville. A continual lowering each year is shown. Well R74 is also in the Alta district and reflects more definitely the effect of irrigation from the Alta canals. Well R81 is on the south line of the Alta district and south of Cottonwood Creek. A small but steady rise is shown.

Well R70, Fig. 8, is located in the Foothill Irrigation District near the edge of the valley. A continual lowering due to pumping is shown.

**Cottonwood Creek Area.**

Pumping for local irrigation is practiced along Cottonwood Creek for several miles above Woodlake. The division of the areas dependent on Cottonwood Creek from the area dependent on Kaweah River for its ground water supply has been taken somewhat arbitrarily as the north line of Secs. 25 and 26, T. 17 S., R. 26 E. There is some area south of this line in which the ground water may be derived from either or both sources.

The canvass of pumping plants was carried into Sec. 27, T. 16 S., R. 26 E. A total area of 3372 acres of orchard and vines was found to be irrigated from wells drawing on Cottonwood Creek ground water. Data obtained on the discharge of the plants and the time of operation indicates uses in some cases exceeding three acre-feet per acre. Assuming an average draft of 2.5 acre-feet per acre gives a total draft of 8450 acre-feet per year. Other areas above those covered by the field canvass on which some water may be used are not included in the figures given.

The estimated mean annual discharge of Cottonwood Creek has been given previously as 7000 acre-feet. Neither this estimate of run-off or that of the present draft can be regarded as being of sufficient accuracy to warrant reaching a definite conclusion on the extent to which present draft may exceed the average recharge. Much the greater portion of the run-off of Cottonwood Creek is absorbed within this area. Both the nature of the formation and the ground water contours indicate that this area has no other source of supply except Cottonwood Creek.

That the present draft is relatively heavy in this area is also indicated by the fluctuations of the wells. The statements of owners indicate that the water table has fallen from 15 to 25 feet in the past eight years, the larger part of this drop occurring since 1918 and being more marked in 1921.

The only direct well readings available are for three wells observed in these investigations. For those in the main valley the drop from 1920 to 1921 was about four feet. The hydrograph of one of these wells, R68, is given in Fig. 9. The run-off of the creek for the four seasons, 1918 to 1921, was probably about one-half of normal, so that such lowering may be due to deficiency in supply rather than to excess of draft. The rate of draft is in excess of one acre-foot per acre of total area of creek fill which exceeds the rate of draft for those portions of the Kaweah Delta on which ground water elevations are being maintained.

The above discussion, while indefinite as to numerical items, indicates that caution should be used in increasing the draft on the ground water in the areas which depend on Cottonwood Creek for their recharge until the ability of such ground water to recover has been actually demonstrated by experience in years of large run-off.

**Lewis Creek Area.**

This area includes the lands along the edge of the hills between the deltas of Kaweah and Tule rivers whose only directly tributary run-off is that of Lewis Creek and adjacent minor areas. Nearly all of the land is included within the boundaries of the Lindsay-Strathmore Irrigation District which receives its water supply by pumping from areas adjacent to Kaweah River. There are some lands not included in the district which depend entirely on pumping and some lands within the district pump from their own wells to supplement the district supply.

Prior to the organization of the irrigation district the pumping within this area resulted in a lowering of the water table to a point where the quality of water obtained from many wells became unsuited for use in irrigation. Since the beginning of delivery of water by the district many wells have recovered a large part of the previous drop, other wells where local pumping has continued have fluctuated with the extent of such pumping. The experience with pumping prior to 1918 definitely demonstrates that the locally available ground water supplies are entirely inadequate for the needs of the present planted area and that the maintenance of the existing bearing orchards requires an outside source of water supply.

The boundaries of this area as discussed here were determined from the ground water contour map, Map 2. Lands under which the existing ground water slopes are from the hills rather than from either Kaweah or Tule River sources were included. The area which would have been included in a similar classification based on the ground water contours as they probably existed before any pumping was practiced would have extended further to the west as the effect of the maximum lowering of the ground water of 60 feet or more in this vicinity has been to change the natural slope and direction of the ground water contours and to create an artificial slope centering in the area of greatest lowering in the vicinity of Lindsay.

The estimated mean annual run-off of Lewis Creek as previously given is 1500 acre-feet. The actual run-off varies widely in different years and may be almost negligible in amount in years of small precipitation.

The data available on the water used within this area are shown in Table 21. The figures for the Lindsay-Strathmore district were supplied by the district. The data for areas outside the district were secured in the canvass of these areas made in these investigations. The estimated draft is computed as an average of 2.5 acre-feet per acre based on the estimated average pumping draft for orchards. This is larger than the water supplied per acre by the Lindsay-Strathmore district. Where obtainable some owners within the district are supplementing the supply received from the district with additional pumping from wells.

Both the nature of the construction of the district's canal system and the records of delivery indicate a very small seepage loss from the canal system. In irrigation on the soils within the district much difficulty is experienced in securing adequate depth of moisture penetration and percolation loss would be expected to be a minimum. The present draft over this area appears to exceed the total probable recharge. The

TABLE 21.

Data Relating to Use of Water in Lewis Creek Area.

| | 1918 | 1919 | 1920 | 1921 |
|---|---|---|---|---|
| Data for lands within Lindsay-Strathmore Irrigation District: | | | | |
| Acres irrigated | 7,904 | 9,300 | 9,371 | 9,400 |
| Total acre-feet pumped | 13,680 | 15,246 | 15,122 | [1]13,567 |
| Total acre-feet sold | 13,157 | 14,684 | 14,329 | ---------- |
| Conveyance loss, acre-feet | 523 | 562 | 793 | ---------- |
| Conveyance loss, per cent | 3.8 | 2.7 | 5.2 | ---------- |
| Average acre-feet per acre sold | 1.67 | 1.58 | 1.53 | ---------- |
| Data for lands not included within boundaries of Lindsay-Strathmore Irrigation District: | | | | |
| Area irrigated, acres | ---------- | ---------- | ---------- | 1,485 |
| Estimated pumping draft total, acre-feet | ---------- | ---------- | ---------- | 3,700 |

NOTE—Supplemental pumping for lands within the Lindsay-Strathmore Irrigation District is not included as data on the area served and amount pumped is not available.

[1]Water returned to Kaweah River is not included.

well records within the area indicate a general rise within the area served by the district during the last four years since the pumping draft has been reduced by the use of outside sources of supply and a lowering on the parts of the area continuing heavy local pumping.

Wells 1216 and 1224 in Fig. 9 are typical of the variations shown by wells in this area. Well 1216 is east of Lindsay in the area supplied by the district. A continual rise since 1917 is shown. Well 1224 is located north of Strathmore outside of the district in an area of local pumping and shows a heavy summer draw down with an average lowering of about three feet per year.

## Lakeside Ditch Area.

The area served by the Lakeside Ditch lies west of Cross Creek and is not a part of the Kaweah Delta. The water diverted by this system is considered to have no effect on the ground water of the delta. The area served is adjacent and to some extent overlaps that served by ditches diverting from Kings River. The ground water is relatively high and the soil conditions less favorable as a whole than those on the Kaweah Delta.

The records of diversions show that the Lakeside Ditch secured about one-seventh of the total diversions from the Kaweah River for the period covered by the records in 1917 and about one-fifth in 1920 and 1921. The average diversion appears to be about 45,000 acre-feet per year. This water accomplished less useful results than that diverted on other parts of the Kaweah Delta as it is used in an area having an excess present ground water supply and is not available for replenishment of ground water on the Kaweah Delta. Any means which would result in the transfer of all or part of the water now diverted by the Lakeside Ditch for use on areas on the Kaweah Delta where development has exceeded the ground water supplies would increase the beneficial results obtained from the Kaweah River run-off. A larger use of pumping within the Lakeside Ditch area would permit the transfer of at least part of the present use without reduction in the area now irrigated. Such pumping might also be of benefit by lowering the ground water in those areas under the Lakeside Ditch where it is now too high.

Well R53 in Fig. 8 is located just east of Cross Creek across from the area served by the Lakeside Ditch. There is some summer rise due to flow in Cross Creek or the adjacent irrigation. There is very little local pumping near this well.

**Corcoran Irrigation District.**

The Corcoran Irrigation District receives water through the Lake Lands Canal which diverts from Kings River and uses Cross Creek for a portion of its length. This use of the Lake Lands Canal began in 1918. Fluctuations of wells within the Corcoran district are illustrated by Well R50, Fig. 8, which shows very little change at any time during 1921. Well C8A in Fig. 8 is a shallow well which shows some response to the district's canal use in June, 1921. Well C7 is a deep well near Well C8A. Its very different cycle and the lowering from February, 1921, to February, 1922, are noticeable in comparison with the shallow well C8A.

Conditions in this area do not appear favorable for securing dependable or adequate ground water supplies from shallow wells. Larger yields might be secured from deeper wells but the sensitiveness of such strata to pumping either locally or to the east and the large cost of such deep wells make extensive development of such sources appear hazardous. The area is probably still within what might be considered to be the Kaweah Delta but represents those portions previously discussed in connection with the formation of the delta where the more shallow water strata become less pervious.

## CHAPTER V.

# KAWEAH RIVER STORAGE SITES.

Present uses from Kaweah River will largely control any possible storage on this stream. Any storage affecting the run-off to an extent which would affect or interfere with present diversions would involve adjustments with such present uses.

The study of the extent and feasibility of storage has been approached first from the point of view of its feasibility without consideration of present developments and second from the point of view of existing uses. The first point of view is that which would govern if there were no present uses to be considered and if the use of the available water supply could be approached as a new development to be planned for the maximum use of the water resources. It represents a somewhat ideal type of development, any falling short of this ideal measures the disadvantage of present development in restricting the attainment of such ideal. The second point of view represents the additional developments which it may be feasible to make without injury to present uses.

### AVAILABLE STORAGE SITES.

To regulate the run-off of a stream for irrigation, a reservoir site should be located so as to receive the run-off of practically all of the drainage area. In addition it should be water tight and of reasonable construction cost. The drainage area of the Kaweah River is generally rugged; except for small areas at the top of the drainage the grades of the streams are steep and without basins available for use as reservoirs. The mountain meadows in the upper portions may be sufficient to furnish storage for their local drainage areas but the total extent of such storage available is entirely inadequate to control the stream as a whole. Any site above Three Rivers could control only the fork on which it might be situated.

The only reservoir site meeting the requirements for full control of the stream is the one known locally as the Ward or the Homer's Grade site, the dam site of which is located about three miles below Three Rivers. Practically the entire run-off of the drainage area passes through this site. The foundation at the dam site is of good quality. The capacity which can be stored is adequate for the practical regulation of the stream. All elements except cost are favorable.

A survey of this site to a capacity of 65,000 acre-feet was made by H. H. Holley in 1908; the maps and reports have been made available in these investigations. In 1917 a survey was made to a capacity of 340,000 acre-feet under the supervision of G. B. Sturgeon, consulting engineer. The maps of this survey have also been made available. The results of these surveys are shown on Map 5. The area and capacity curves are shown in Fig. 10. The two surveys are in practical agreement in the portion covered by both. The survey by

Mr. Sturgeon covers sufficient storage capacity for any feasible development on this stream.

The formation at the dam site is granitic, rock being exposed on parts of both sides and apparently at relatively small depth in the stream channels. No borings have been made and the actual depth of stripping which would be required is in consequence uncertain. The amounts used in the estimates are thought to be adequate and probably in excess of the amount which would actually have to be used.

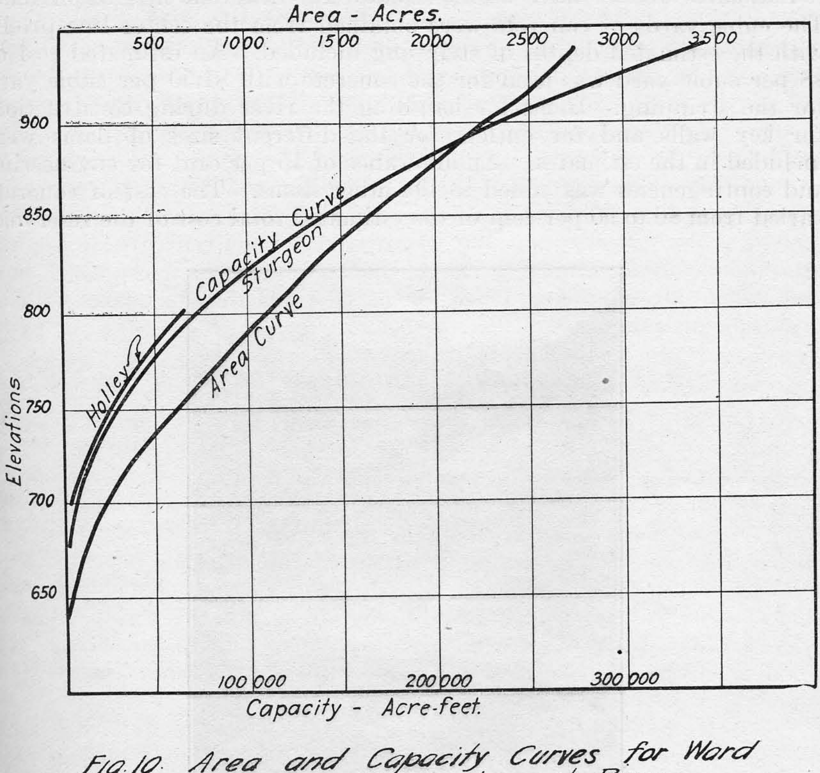


Fig. 10. Area and Capacity Curves for Ward Reservoir Site on Kaweah River.

On the north side of the river channel the exposed rock dips sharply at the river's edge. On the south side some nearly level ledge appears to cross the river at small depths. There is very little overburden on the north slope; the amount on the south slope, while larger, is relatively small, rock being exposed at intervals on the slope.

The type of dam which might be built at this site will depend on the height to be used. For capacities in excess of 100,000 acre-feet the length of crest exceeds 1400 feet and the height 150 feet so that a straight gravity section masonry dam is considered preferable. For smaller capacities there might be some saving in cost from the use of arch type dams. The spillway would be located at the dam either by direct discharge over a portion of the crest for heights up to 150 or possibly 200 feet and for greater heights by a side channel at either end of the dam in which the surplus flow would be carried sufficiently far away from the dam to be returned to the river without damage to the dam itself.

The reservoir site is principally unused land of relatively low value. The cost of acquiring such lands has been included in the estimates of cost. The paved highway now passing through the site would require relocation; cost of such changes is also included.

Estimates of cost have been prepared for different heights of dam. The cubic yards of concrete were obtained from the center line profile with the estimated depths of stripping included. An estimated cost of $8 per cubic yard was used for the concrete with $1.50 per cubic yard for the stripping. Items for handling the river during construction, for key walls and for outlets for the different sizes of dams were included in the estimates. An allowance of 15 per cent for engineering and contingencies was added to the other items. The cost of concrete varied from 80 to 90 per cent of the estimated total cost of the reservoir.

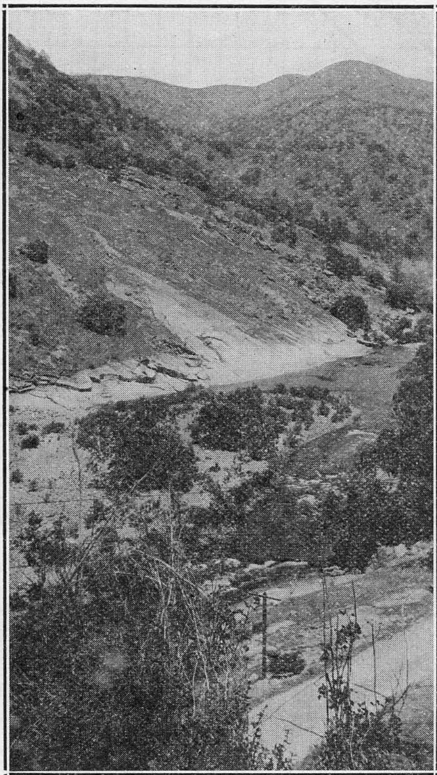

PLATE VI, Figure A. General View of North End of Dam Site at Ward Reservoir Site on Kaweah River.

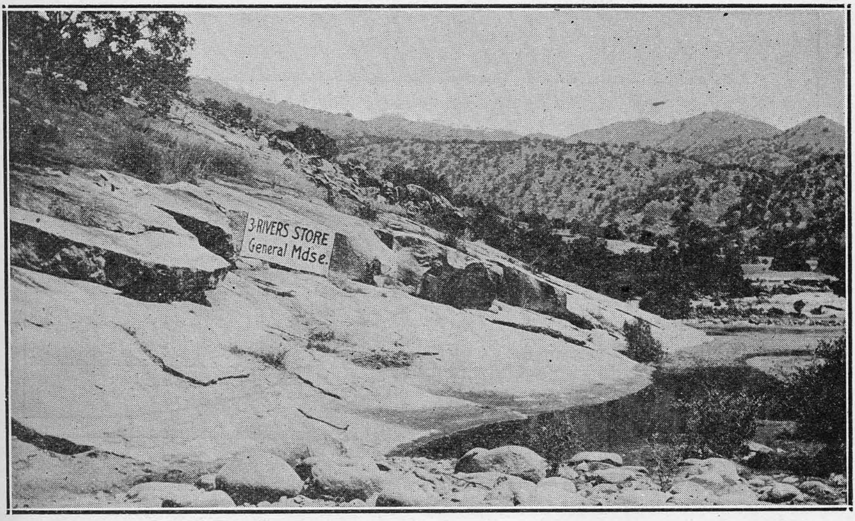


PLATE VI, Figure B. Detail View of Character of Rock on North End of Dam Site at Ward Reservoir Site on Kaweah River.

Estimates of total cost were made for six capacities varying from 15,000 to 300,000 acre-feet. The results were plotted against the capacities and the resulting curve (Fig. 11) used to estimate the cost for other capacities. The estimated cost per acre-foot of total capacity is also shown in Fig. 11.

Fig. 11 indicates that even with 300,000 acre-feet capacity the average cost per acre-foot would be $40 and that for capacities of 100,000 to 200,000 acre-feet costs of $50 per acre-foot are to be expected. Below a capacity of 100,000 acre-feet the cost per acre-foot increases rapidly. The estimated costs are thought to be sufficiently high to cover probable actual costs. The actual cost might be somewhat lower than the estimate if the amount of stripping required is smaller than that estimated or if the concrete can be placed for less than $8 per cubic yard.

The estimated costs per acre-foot of capacity are higher for this site than for the available sites on either the Kings or Kern rivers. The dam site here is similar to that on Kern River at Isabella but the reservoir is narrower and steeper so that much higher dams are required for the same capacity on the Kaweah River.

#### Economical Size of Storage.

The extent to which a reservoir can be utilized depends on its capacity in relation to the run-off of the stream. A reservoir of small capacity can be filled each year and 100 per cent service secured. A large reservoir may be filled only in years of excessive run-off and the use of the water stored may be extended over the following season. For such large reservoirs the average amount of storage used per year may be only a small part of the total capacity. The extent to which it may be economical to construct a reservoir on any stream depends on the cost of construction and the extent of use obtained.

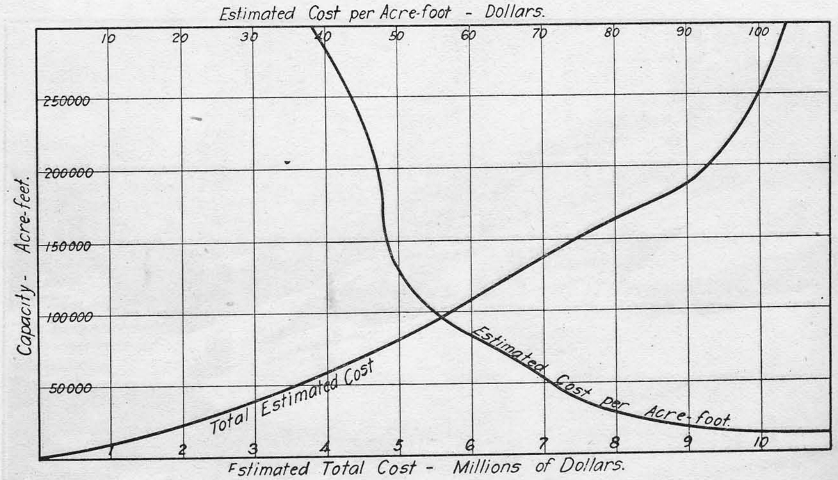


Fig. 11. Curves showing relation of estimated costs to capacity for Ward Reservoir Site on Kaweah River.

The mean annual discharge of the Kaweah River is about 450,000 acre-feet. To secure a regulated supply of this amount would require a storage capacity sufficient to enable the flow of excess years to be carried forward for dry years. A sufficient amount of storage to fully regulate the entire flow in all years would obviously cost in excess of the benefits derived. Trials of different rates of use and the shortages that would result with different storage capacities were made and the conclusion reached that the largest feasible development would consist of a regulated supply totaling 375,000 acre-feet per year or five-sixths of the mean annual run-off.

The extent of storage required to support any given water supply will depend on the difference between the actual run-off in any month and the requirement in that month. The proportion of the total annual supply needed for irrigation in any month depends on the crops and climate. The distribution of the use throughout the year, usually called the seasonal use, has been estimated as follows:

**Seasonal Use.**

Present seasonal use in diversions from the Kaweah and Tule rivers is of little guidance as to desired use as the canals are controlled by conditions of run-off rather than of demand.

On the Kaweah River, the proportion of future crops is subject to much uncertainty. The present tendency is toward trees and vines, these crops having increased materially in recent years. Of 50,000 acres served by pumps canvassed in 1920, 20 per cent were orchard, 40 per cent alfalfa and 40 per cent grain, corn and miscellaneous. This covers the outer and lower portion of the area where the proportion of orchard would be expected to be less than the average. For all lands served from Kaweah River it has been assumed that 40 per cent will be orchards and vines, 35 per cent alfalfa and 25 per cent grain or summer crops.

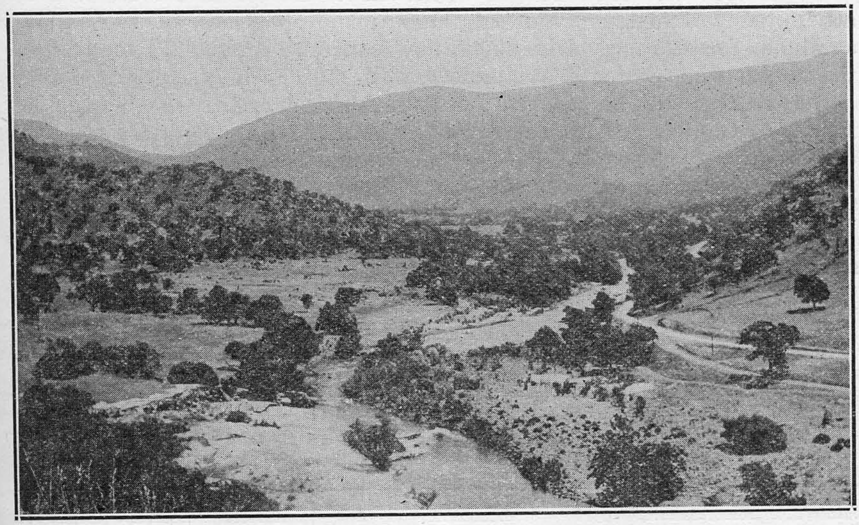

PLATE VII, Figure A. General View of Ward Reservoir Site on Kaweah River.

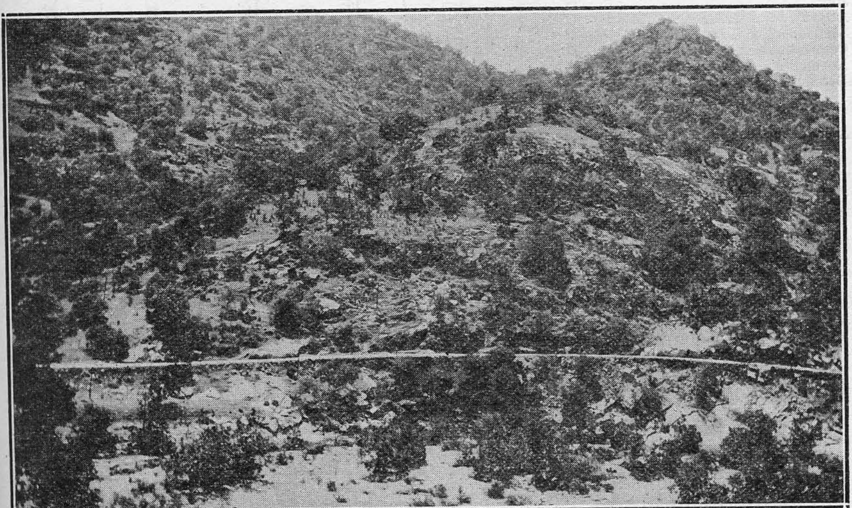

PLATE VII, Figure B. South End of Dam Site at Ward Reservoir Site on Kaweah River.

The proportion of the use for each of these types of crops in each month has been estimated by comparison with the data given in Bulletin 9 of this department on seasonal use in Kern County which is largely applicable here and by the seasonal use under pumping plants in Tulare County where the draft in each month is representative of the demand. The Kaweah Delta data used and the conclusions drawn are shown in Table 22.

The length of season during which direct irrigation service will be attempted will materially affect the water supply both of use and as available for storage. Diversions now continue during all months of the season when water is available. With storage it is considered that better results will be secured by confining the use to the months of March to October. Any excess flow in other months could be used by diversion but will be of rare occurrence with any large storage capacity. Such a limitation of season would largely eliminate grain as an irrigated crop.

TABLE 22.

**Seasonal Use on Kaweah Delta. Actual Use under Pumping Plants and Estimated Use Adjusted to Regulation of the River by Storage.**

| Month | Per cent of total use for the season, occurring in each month | | | | | |
|---|---|---|---|---|---|---|
| | Kaweah Delta pumping plants | | | | | Estimated seasonal use adapted to storage |
| | From 32 pumps serving alfalfa | From 13 pumps serving deciduous orchards and vines | From 26 pumps serving citrus | From 22 pumps serving mixed crops | Weighted mean for all crops | |
| January | 1 | ------------ | 1 | ------------ | ------------ | ------------ |
| February | 1 | 1 | 2 | ------------ | 1 | ------------ |
| March | 2 | 2 | 2 | 1 | 2 | 5 |
| April | 6 | 3 | 9 | 4 | 6 | 10 |
| May | 12 | 15 | 14 | 15 | 14 | 20 |
| June | 15 | 21 | 12 | 16 | 16 | 20 |
| July | 17 | 20 | 14 | 17 | 17 | 18 |
| August | 17 | 17 | 14 | 17 | 16 | 14 |
| September | 14 | 12 | 12 | 14 | 14 | 10 |
| October | 11 | 8 | 9 | 11 | 10 | 3 |
| November | 4 | 1 | 7 | 4 | 4 | ------------ |
| December | ------------ | ------------ | 4 | 1 | ------------ | ------------ |
| Totals | 100 | 100 | 100 | 100 | 100 | 100 |

TABLE 23.

**Estimated Maximum Rate of Use from Kaweah River Run-off Which Can Be Supported by Storage.**

| Month | Per cent of total use for season | Total acre-feet | Mean second-feet during month |
|---|---|---|---|
| March | 5 | 20,000 | 325 |
| April | 10 | 40,000 | 675 |
| May | 20 | 75,000 | 1,225 |
| June | 20 | 75,000 | 1,250 |
| July | 18 | 70,000 | 1,150 |
| August | 14 | 50,000 | 800 |
| September | 10 | 35,000 | 600 |
| October | 3 | 10,000 | 160 |
| Totals | 100 | 375,000 | ------- |

The final column in Table 22 shows the estimated requirement finally used. The use in April to June is increased and that in the late season decreased so as to give more use of direct flow with a smaller storage requirement. The estimated mean used would furnish an entirely adequate distribution of supply for this area.

The preliminary study of storage indicated that there would be average shortages of 34,000 acre-feet per year in an attempted supply of 405,000 acre-feet with 200,000 acre-feet of storage. Reducing the attempted supply to 375,000 acre-feet would result in a corresponding reduction in shortages in about one-half of the years. For final figures a use adjusted by months as above with a total for the season of 375,000 acre-feet has been used. The results are shown in Table 23.

**Use of Storage.**

The run-off records since 1903 were used to estimate the extent to which the regulated supply of 375,000 acre-feet could be supported by different amounts of storage. The run-off for each month was compared with the demand, the excess of run-off over demand being available for storage and the deficiency being required from storage. All flow from November to February, inclusive, was considered as available for storage. Different reservoir capacities were then tried, the supply available for storage being considered as placed in the reservoir until its capacity was reached, the excess over its capacity being considered as unused water. The demands for storage were met from the supply previously stored; where such demands exceeded the stored supply the difference represents a shortage in the supply. In years of excess run-off the demand for storage is small and the reservoir can be carried forward partly filled. In dry years the supply for storage is less than the demand unless there has been sufficient storage carried forward from previous years. There will be fewer shortages with the larger reservoir capacities; their economy will depend on the frequency of the use of such larger capacities in relation to their costs.

**TABLE 24.**

**Summary of Estimated Use and Costs of Storage at Ward Reservoir Site on Kaweah River Supporting an Annual Irrigation Draft of 375,000 Acre-feet.**

| Constructed capacity | Estimated total cost | Average storage used annually acre-feet | Estimated average cost per acre-foot of constructed capacity | Estimated cost per acre-foot of storage used annually | Increase in storage used annually acre-feet | Increase in estimated cost | Estimated cost per acre-foot of increased in storage used annually |
|---|---|---|---|---|---|---|---|
| 50,000 acre-feet | $3,600,000 | 48,000 | $72 | $75 | | | |
| 100,000 acre-feet | 5,700,000 | 79,000 | 57 | 72 | 31,000 | $2,100,000 | $68 |
| 150,000 acre-feet | 7,500,000 | 97,000 | 50 | 77 | 18,000 | 1,800,000 | 100 |
| 200,000 acre-feet | 9,500,000 | 109,000 | 48 | 87 | 12,000 | 2,000,000 | 167 |
| 250,000 acre-feet | 11,100,000 | 115,000 | 44 | 96 | 6,000 | 1,600,000 | 267 |
| 300,000 acre-feet | 12,700,000 | 120,000 | 40 | 106 | 5,000 | 1,600,000 | 320 |

The results of such computations for different storage capacities are shown in Table 24 and Fig. 12. For capacities up to 50,000 acre-feet per year practically full use can be secured. For larger capacities the average use is relatively less; with 300,000 acre-feet capacity an average use of only 120,000 acre-feet per year would be secured.

While the average cost per acre-foot of constructed capacity decreases with the larger sizes of reservoirs, the less frequent use of the upper portions of such larger capacities results in an increased cost per acre-foot of capacity actually used. The increase in capacity from 50,000 to 100,000 acre-feet would result in an increased average annual use of 31,000 acre-feet of storage; the same amount of increase from 250,000 to 300,000 acre-feet of capacity would make available an increase in average annual use of only 5000 acre-feet.

The cost which it may be feasible to expend for useful storage varies with the crop on which the storage is to be used and no rigid limit can be set. It is considered that storage costing in excess of $150 per acre-foot of average annual use is above any limit now feasible or which will be feasible for as far into the future as it is possible to plan at the present time. It is not thought that sufficient use can be secured

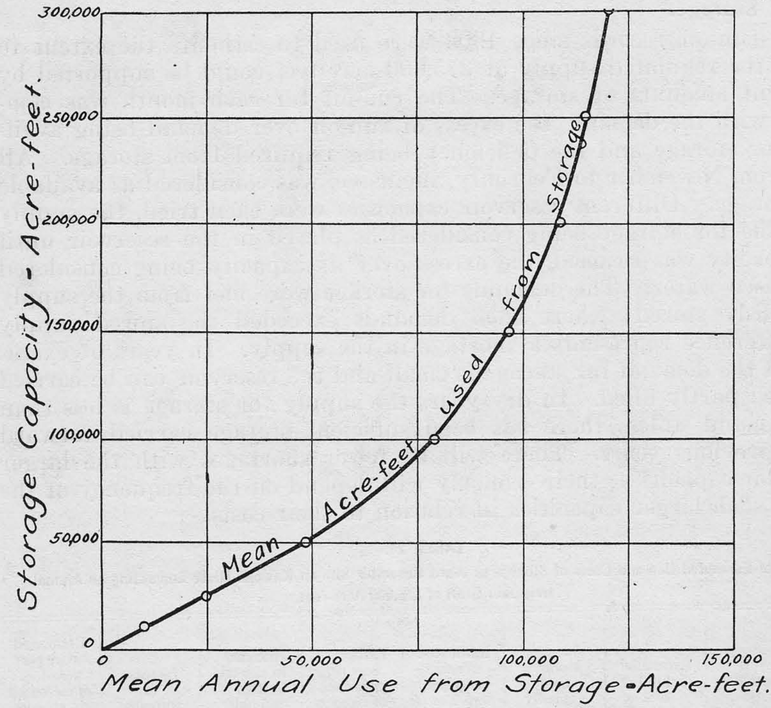


Fig. 12. Relation of Storage Used to Constructed Capacity from Reservoirs on Kaweah River Supporting an Annual Irrigation Draft of 375,000 Acre-feet.

from a reservoir in excess of 150,000 acre-feet capacity to warrant its construction.

Some shortages in supply would result even with 300,000 acre-feet of storage capacity. The extent of shortages that would have occurred from 1903 to date are shown in Table 25.

Table 25 indicates that with only 100,000 acre-feet of storage capacity there would be shortages in supply in thirteen years of the eighteen years on record and that the regulated supply which could be maintained with this storage should be less than the 375,000 acre-feet per year on which Table 25 is based.

With 150,000 acre-feet of storage, shortages are eliminated or reduced in nine years of the thirteen giving shortages with 100,000 acre-feet of storage. The increase of 50,000 acre-feet of storage capacity results in an increased average use of storage of 18,000 acre-feet per year or 36 per cent of the increased storage capacity. As this increased capacity would be used in whole or in part in one-half of the years of record, its construction is considered desirable even at the relatively high costs per acre-foot of storage used as previously given.

TABLE 25.

**Shortage in Regulated Irrigation Supply of 375,000 Acre-feet with Storage of Different Capacities on Kaweah River.**

Shortages in acre-feet.

| Season | Storage capacity of | | | |
|---|---|---|---|---|
| | 100,000 acre-feet | 150,000 acre-feet | 200,000 acre-feet | 300,000 acre-feet |
| 1903-04 | 35,000 | | | |
| 1904-05 | 44,700 | 30,600 | | |
| 1905-06 | | | | |
| 1906-07 | | | | |
| 1907-08 | 97,300 | 47,300 | | |
| 1908-09 | | | | |
| 1909-10 | 82,100 | 32,100 | | |
| 1910-11 | | | | |
| 1911-12 | 162,100 | 112,100 | 62,100 | |
| 1912-13 | 153,500 | 153,500 | 153,500 | 115,600 |
| 1913-14 | 10,300 | | | |
| 1914-15 | 21,000 | | | |
| 1915-16 | | | | |
| 1916-17 | 20 100 | | | |
| 1917-18 | 135,400 | 105,500 | 55,500 | |
| 1918-19 | 101 800 | 101,800 | 101,800 | 57,300 |
| 1919-20 | 31,500 | 7,600 | 7,600 | 7,600 |
| 1920-21 | 31,500 | 20,100 | 20,100 | 20,100 |
| Mean | 52,000 | 34,000 | 22,000 | 11,000 |

With 200,000 acre-feet of storage capacity shortages occurring in three years with 150,000 acre-feet of storage capacity are removed and those in two additional years reduced. The average use of the increase in capacity is 24 per cent. With a reservoir of low cost per acre-foot of capacity construction to 200,000 acre-feet would be desirable for this extent of usefulness. For the estimated costs previously given the cost of the use secured from this increased capacity is considered higher than its present value and a capacity above 150,000 acre-feet is not recommended.

With 300,000 acre-feet of storage capacity the increase over 200,000 acre-feet would have been used only twice in eighteen years. To entirely eliminate shortages would require a storage capacity of 415,000 acre-feet. With storage capacities above 150,000 acre-feet it would be preferable to undertake to obtain a somewhat larger regulated supply even with the resulting shortages in order to have a larger use over which to distribute the increased storage costs.

The table showing shortages in the regulated supply since 1903 brings out the conditions on the Kaweah River which make unusually expensive the regulation of the supply so as to entirely prevent shortages. With 150,000 acre-feet of storage the only shortages which exceed 15 per cent of the season's supply occur where there are at least two dry years in succession. To meet such conditions stored water would have to be carried forward from previous years. The shortage in 1913 would have to be met with storage carried forward from 1909, that in 1919 from water stored in 1916. To reduce the regulated supply so that no shortages would occur in such series of dry years would result in a large increase in the unused water in other years.

The records of run-off in Table 1 show the past four years to have been the longest period of record between years of more than average run-off. The river discharge has been below normal since 1917. There have been no previous periods since 1903 when more than two dry years have occurred between years of more than normal run-off.

The storage studies discussed have been based on the records of run-off since 1903. In the discussion of water supply it has been shown that the precipitation during this period has exceeded the average since 1890. The precipitation records do not furnish a basis from which the monthly run-off and the performance with storage can be estimated for the period 1890 to 1903, they do, however, indicate an average run-off from 1890 to 1903 of about 10 per cent less than that from 1903 to date. There appears to have been a series of dry years in succession from 1898 to 1900 with fully as low a run-off as the period 1918 to 1920. It is probable that the shortages in the supply as regulated by storage from 1890 to 1903 would have averaged somewhat greater than those since 1903.

### Evaporation Losses.

The above computations and discussion have been based on the flow at the reservoir site without making any allowances for evaporation losses. Computations were made for the storage obtained with 200,000 acre-feet of storage capacity for the evaporation which would have occurred during the eighteen years period of record. The estimated rate of evaporation is shown in Table 26.

**TABLE 26.**

**Estimated Evaporation from Reservoir at Ward Site on Kaweah River.**

| Month | Estimated gross depth of evaporation in feet | Estimated mean depth of rainfall in feet | Estimated net depth of evaporation in feet |
|---|---|---|---|
| October | 0.30 | 0.07 | 0.23 |
| November | 0.16 | 0.16 | 0 |
| December | 0.10 | 0.17 | —0.07 |
| January | 0.10 | 0.31 | —0.21 |
| February | 0.12 | 0.29 | —0.17 |
| March | 0.20 | 0.34 | —0.14 |
| April | 0.30 | 0.16 | 0.14 |
| May | 0.50 | 0.12 | 0.38 |
| June | 0.60 | 0.01 | 0.59 |
| July | 0.65 | 0 | 0.65 |
| August | 0.55 | 0 | 0.55 |
| September | 0.55 | 0.05 | 0.50 |
| Totals | 4.13 | 1.68 | 2.45 |

The estimate of gross depth of evaporation is based on data collected for and discussed in the Kern County Investigations, Bulletin 9, of this Department, the most directly applicable data being that from Tulare Lake. The estimated rainfall is that of Lemon Cove, increased by 20 per cent due to the increase in elevation at the reservoir. The estimate indicates an actual gain by rainfall during the winter months.

For the estimated stage of the reservoir in each month the corresponding area of water surface was used to give the total evaporation. The monthly losses were summed for the years. For the 200,000 acre-foot capacity the average total annual evaporation loss for the eighteen years of record was 3000 acre-feet, the maximum being 5400 acre-feet in 1906 when the reservoir was full nearly the whole season and the minimum zero in 1913 when there was practically no flow available for storage. Much of the loss as figured could be replaced from excess or unused water in years when such excess flow occurred so that the actual net loss to the regulated supply was an average of only 700 acre-feet per year. As this item was very small in proportion to the total supply it has been neglected and evaporation has not been considered for the other storage capacities studied.

### Summary of Use Obtainable from Storage.

A summary of the run-off and use for each year since 1903 that could have been secured from the Kaweah River for an irrigation use of 375,000 acre-feet, supported by 150,000 acre-feet of storage capacity, is shown in Table 27. This extent of use and storage capacity are considered to be the most economical for regulation of the run-off of the Kaweah River by storage if present conditions of use should be changed to those of a regulated supply.

TABLE 27.

Summary of Water Supply Available from Kaweah River With a Demand of 375,000 Acre-feet Supported by 150,000 Acre-feet of Storage Capacity.

| Year | Thousand of acre-feet. Year from Nov. 1 to Oct. 31. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Unregulated run-off | Runoff used directly without storage | Runoff available for storage | Supply required from storage | Storage in reservoir at end of season | Shortage in irrigation supply | Water used from storage | Runoff in excess of irrigation demand |
| 1902-03 | | | | | 35 | | | |
| 1903-04 | 402 | 239 | 163 | 136 | 35 | | 136 | 26 |
| 1904-05 | 309 | 239 | 70 | 136 | 0 | 31 | 106 | |
| 1905-06 | 1,093 | 343 | 750 | 32 | 118 | | 32 | 600 |
| 1906-07 | 593 | 301 | 292 | 74 | 76 | | 74 | 260 |
| 1907-08 | 252 | 178 | 74 | 197 | 0 | 47 | 150 | |
| 1908-09 | 800 | 308 | 492 | 67 | 83 | | 67 | 342 |
| 1909-10 | 408 | 193 | 216 | 182 | 0 | 32 | 150 | 149 |
| 1910-11 | 546 | 283 | 264 | 92 | 58 | | 92 | 114 |
| 1911-12 | 205 | 182 | 23 | 193 | 0 | 112 | 80 | |
| 1912-13 | 222 | 203 | 19 | 172 | 0 | 154 | 19 | |
| 1913-14 | 487 | 265 | 222 | 110 | 40 | | 110 | 72 |
| 1914-15 | 368 | 253 | 115 | 122 | 28 | | 122 | 4 |
| 1915-16 | 779 | 302 | 477 | 73 | 86 | | 73 | 346 |
| 1916-17 | 455 | 255 | 200 | 120 | 30 | | 120 | 135 |
| 1917-18 | 236 | 198 | 38 | 177 | 0 | 109 | 68 | |
| 1918-19 | 282 | 184 | 98 | 191 | 0 | 93 | 98 | |
| 1919-20 | 378 | 248 | 130 | 127 | 3 | | 127 | |
| 1920-21 | 368 | 241 | 127 | 134 | 0 | 5 | 129 | |
| Mean | 453 | 245 | 208 | 139 | 30 | 34 | 96 | 114 |

Table 27 shows the run-off in excess of the capacity of the reservoir and the needs of the regulated supply for direct use. Such excess supply would have occurred in ten years of the eighteen years of record, varying from 4000 to 600,000 acre-feet in different years with an average of 114,000 acre-feet. Much of excess water could be used to replenish the ground water. This could be accomplished near the stream channel. Some flood water canal construction for the conveyance of such waters to areas not adjacent to stream channels would be warranted. For years of very excessive flow it will not be feasible to retain all of the run-off within the Kaweah Delta. In only four years out of eighteen does the excess flow exceed 135,000 acre-feet and it should be feasible to retain such excess below this figure or an average supply of 55,000 acre-feet per year. This with the average of 245,000 acre-feet used by direct diversion and the 96,000 acre-feet drawn from storage, would give a total mean annual supply available for use from the Kaweah River for the period since 1903 of 396,000 acre-feet.

It has previously been shown that the probable mean annual discharge over a long period of years of the Kaweah River is 451,000 acre-feet of which probably an average of 55,000 would not be retained under existing conditions of use or that the mean annual supply now used would be 396,000 acre-feet. For the period 1903 to 1921 the similar estimate of the net available supply was 383,000 acre-feet.

The above comparisons indicate that storage for the full regulation of the flow of Kaweah River will not make available any materially larger quantities of water than are now retained on the delta under existing conditions. Such storage would represent a change in the character of use from the present practice of diverting the run-off when it occurs and supplementing the canal supply by pumping to a practice of regulation of the run-off by storage and release for direct use. The changes that would result from the construction of such storage are ones of cost rather than of total water supply. By storage, together with the use of improved canal systems and methods of irrigation which would reduce percolation losses to a minimum, much of the present cost of pumping would be avoided. The estimated cost would be $7,500,000 for the storage alone. It would not permit the irrigation of more area than is now served except as such changes in methods would result in the net consumption of less water by present areas. In view of the relatively high costs of storage at the only sites available on Kaweah River, together with the costs of the necessary changes in methods of diversion and use involved, the substitution of a regulated river supply with storage for the present methods is not recommended. The benefits that might be secured from such a change in practice would not be sufficient in proportion to the costs and the legal complications involved to warrant undertaking to make the change.

**Power Development at Dam.**

The construction of storage at the Ward site would make available some hydroelectric power using the discharge from the reservoir and the depth of storage at different periods. Any returns that might be obtainable from the sale of much power in excess of the direct costs chargeable to power would be available to reduce the costs of storage chargeable to irrigation. The regulation proposed would not give any discharge from the reservoir during the nonirrigating months of November to February except when the reservoir was filled and overflowing. During the remaining months the discharge would vary with the irrigation demand as shown previously in Table 23.

The river bed at the Ward dam site has an elevation of 620 feet. The crest of the dam for 150,000 acre-feet capacity would have an elevation of 855 feet giving a maximum head on the power plant of 235 feet. The maximum rate of use for irrigation with the regulated supply would be 1250 second-feet. The regulated supply would exceed 1000 second-feet from May to July. The computations for storage by months were used to give the depth of water in the reservoir in each month, this head with the discharge giving the power obtainable from the power plant. An average overall efficiency of 70 per cent based on the water and head available was used.

**TABLE 28.**

**Summary of Estimated Power Output Obtainable with Plant at Dam of Reservoir Site on Kaweah River, Plant Capacity 1000 Second-feet; Storage Capacity 150,000 acre-feet; Regulated Annual Supply for Irrigation 375,000 Acre-feet.**

| Year | Power outputs in million kilowatt hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nov. to Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Season | Remark |
| 1903-04 | Full flow held in storage. | 2.9 | 6.2 | 10.4 | 10.0 | 19.1 | 5.8 | 3.0 | 0.9 | 48.1 | |
| 1904-05 | | 2.7 | 5.5 | 8.8 | 8.6 | 8.2 | 4.3 | 0.4 | 0.0 | 38.5 | |
| 1905-06 | | 9.3 | 10.0 | 10.4 | 10.0 | 10.4 | 8.3 | 5.6 | 1.6 | 65.6 | Wet |
| 1906-07 | | 10.4 | 10.0 | 10.4 | 10.0 | 10.4 | 7.9 | 5.2 | 1.3 | 65.6 | Wet |
| 1907-08 | | 3.2 | 6.6 | 10.2 | 8.8 | 7.1 | 2.1 | 0.1 | 0.1 | 38.2 | |
| 1908-09 | | 8.9 | 10.0 | 10.4 | 10.0 | 10.4 | 8.1 | 5.1 | 1.4 | 64.3 | Wet |
| 1909-10 | | 8.3 | 6.8 | 10.1 | 9.3 | 7.9 | 3.0 | 0.0 | 0.0 | 45.4 | |
| 1910-11 | | 3.2 | 10.0 | 10.4 | 10.0 | 10.2 | 7.5 | 4.5 | 1.2 | 57.0 | |
| 1911-12 | | 2.6 | 5.0 | 8.6 | 7.9 | 2.7 | 0.0 | 0.0 | 0.0 | 26.8 | Dry |
| 1912-13 | | 1.4 | 2.7 | 3.2 | 1.0 | 0.3 | 0.2 | 0.2 | 0.0 | 9.0 | Dry |
| 1913-14 | | 3.4 | 10.0 | 10.4 | 10.0 | 10.4 | 7.2 | 4.2 | 1.1 | 56.7 | |
| 1914-15 | | 2.7 | 5.6 | 9.3 | 9.7 | 9.8 | 6.9 | 4.0 | 0.9 | 48.9 | |
| 1915-16 | | 10.4 | 10.0 | 10.4 | 10.0 | 10.4 | 7.8 | 4.9 | 1.4 | 65.3 | Wet |
| 1916-17 | | 6.1 | 10.0 | 10.4 | 10.0 | 10.0 | 6.9 | 4.0 | 1.0 | 58.4 | |
| 1917-18 | | 2.3 | 5.0 | 9.1 | 8.1 | 2.5 | 0.0 | 0.1 | 0.2 | 27.3 | Dry |
| 1918-19 | | 2.3 | 4.9 | 10.2 | 9.7 | 4.3 | 0.0 | 0.0 | 0.0 | 31.3 | Dry |
| 1919-20 | | 1.9 | 4.6 | 8.5 | 9.2 | 8.9 | 5.6 | 1.8 | 0.0 | 40.5 | |
| 1920-21 | | 2.5 | 5.4 | 8.8 | 9.0 | 9.6 | 5.1 | 1.2 | 0.0 | 41.6 | |
| All years mean | 0 | 4.7 | 7.1 | 9.4 | 9.0 | 7.9 | 4.8 | 2.5 | 0.6 | 46.0 | |
| Mean four wet years | | 9.8 | 10.0 | 10.4 | 10.0 | 10.4 | 8.0 | 5.2 | 1.4 | 65.2 | |
| Mean four dry years | | 2.2 | 4.4 | 7.8 | 6.4 | 2.4 | 0.0 | 0.0 | 0.0 | 23.4 | |

The outputs of power obtainable for 1000 second-feet capacity during the operating months are shown in Table 28. A plant of 1250 second-feet capacity would have an average output of 51.6 million kilowatt hours per year but would not have any larger output in dry years than the smaller plant.

The cost of the power plants, exclusive of any portion of the cost of the dam, has been estimated at $600,000 for the 1000 second-foot capacity. The plant for full load and maximum head would have a capacity of 14,000 kilowatts. The estimated cost of installation per million kilowatt hours of mean annual output is $13,500 for the 1000 second-foot plant and $15,000 for the 12,500 second-foot plant. The smaller plant would have as large an output as the larger plant in dry years such as would be expected to occur one year in four. The smaller plant is considered preferable.

A somewhat detailed discussion of the price for which power to be produced on Kern River in connection with storage might be sold has been given in Bulletin 9 of this department. The conclusion was there reached that power of average availability in proportion to the seasonal demand and of average dependability might be sold for as much as 0.5 cents per kilowatt hour of total output. The Railroad Commission has approved a price of 0.45 cents for power in connection with storage proposed by the Merced Irrigation District. The power that would be produced at the Kaweah River dam with a plant of 1000 second-feet capacity would have an output in the dry years such as can be expected to occur in one year in four of only 50 per cent of the mean. The lack of winter output would prevent its use except in connection with systems having other sources for carrying the load in such months. As the maximum demand for power in these areas occurs in the summer, the output of this plant would be useful for service at such times. It is doubtful if the total output of such a plant could be sold at a price equal to 0.45 cents per kilowatt hour.

With a mean return of 0.45 cents per kilowatt hour the total earning with a mean output of 46 million kilowatt hours per year would be $207,000. Allowing $22,000 per year for operating costs would give $185,000 to meet fixed charges. Interest and depreciation at 10 per cent on the estimated cost of $600,000 for the power plant would leave $125,000 per year applicable for carrying a part of the cost of the dam. If the interest on funds for the construction of the dam is taken as 6 per cent and 1 per cent allowed for depreciation, the estimated net earning would meet the charges on $1,800,000 of the cost of the dam.

The above assumptions are considered to be more favorable to the returns obtainable from power than it will be feasible to actually obtain. The larger output would occur in years when the water supply for other plants is also ample and would be deficient in those seasons when the shortage in stream flow would make the demand for power for pumping most difficult to meet. It is not thought that the development of power can be expected to carry more than $1,000,000 of the cost of construction of the dam. This is about 13 per cent of the total estimated cost. The reduction in the estimated costs of this storage for irrigation alone, as previously given, due to the earnings possibly obtainable from power will not be sufficient to affect the conclusions reached as to the feasibility of such storage.

## STORAGE OF SURPLUS WATERS.

There is another basis on which storage on the Kaweah River can be considered. There are now certain portions of the discharge which are not retained for use on the Kaweah Delta and some water now retained during the winter months which may not be directly required. The storage of such portions of the run-off, particularly as to winter flow, would probably require adjustment with existing uses but might be feasible if the costs of storage were sufficiently low in proportion to the benefits derived.

The water supply developed by any such storage should preferably be used to supplement present pumping supplies on areas already developed rather than in undertaking to supply new lands. The costs per unit quantity of water supply which developed lands now finding their pumping supply inadequate can afford to pay will be greater than that feasible for undeveloped lands seeking a full supply.

An attempt has been made to estimate the extent of the water supply that might be made available by storage and use of surplus water. Such a study obviously requires a definition of what are surplus waters. Until there has been a more definite judicial determination of the existing rights on the Kaweah River it is not possible to define the surplus waters in terms of such rights.

For the purposes of this investigation surplus waters have been considered to be the entire flow in the months of November to February and such run-off in the remaining months as it has been estimated would leave the Kaweah Delta as outflow. This is equivalent to assuming that winter irrigation is not essential and that winter run-off could be stored without injury to existing rights. It is recognized that winter use is now practised and may be of benefit; the extent of such benefit, however, is considered materially less than for summer use and the storage of run-off during these winter months is not considered to be a material injury to existing diversion rights. Present use of winter run-off is of benefit to the maintenance of ground water but the areas directly benefited are in general those which receive adequate summer water supplies.

It is considered that the existing canal rights will be fully served if they receive the total discharge in the river which past records indicate they now retain. As previously discussed, the records indicate that all run-off in excess of about 1800 to 2000 second-feet will cross the Kaweah Delta without diversion or absorption. The storage of any run-off in excess of such present retention on the delta should not work any injury to present uses. The present conditions of use under some of the diversions may be in excess of the amount for which beneficial use could be shown under a reasonably strict standard of practice so that storage of the stream flow in excess of somewhat smaller rates of discharge than 1800 second-feet might not result in actual injury to present diversions. However, storage of any water now used on the Kaweah Delta would represent a change in character of use rather than the making available of water not now used as in the case of water not now retained on the delta.

Using the estimates of the outflow from the Kaweah Delta as given in Table 10 and the record at Three Rivers for the run-off of November to February, inclusive, the water supply available for each year of record since 1903 was computed. The amounts so available varied from 18,000 to 616,000 acre-feet in different years with an average of 133,000 acre-feet per year.

A portion of the excess run-off in the summer months could be used directly without storage. The winter flow would have to be held in storage for later use in irrigation. The estimated excess run-off was studied to determine the extent of storage which would be required to provide different amounts of irrigation supply. The results are summarized in Table 29.

TABLE 29.

**Summary of Regulated Water Supply Obtainable by Storage of Run-off from November to February and of Excess Summer Flow Estimated to Leave the Kaweah Delta under Existing Conditions in Thousands of Acre-feet.**

| Year | Total run-off Nov. to Feb. | Total excess flow | 50,000 acre-feet regulated supply 50,000 acre-feet of storage capacity | | | | | 20,000 acre-feet regulated supply 15,000 acre-feet of storage capacity | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Direct use | Storage in reservoir end of season | Shortage in supply | Storage used | Unused supply | Storage in reservoir end of season | Shortage in supply | Direct use | Storage used | Unused supply |
| 1903-04 | 53 | 81 | 9 | 18 | ------- | 41 | 13 | 3 | 0 | 4 | 16 | 58 |
| 1904-05 | 34 | 36 | 2 | 0 | ------- | 50 | 2 | 0 | 3 | 2 | 15 | 22 |
| 1905-06 | 80 | 616 | 33 | 33 | ------- | 17 | 533 | 8 | 0 | 13 | 7 | 588 |
| 1906-07 | 81 | 161 | 33 | 33 | ------- | 17 | 111 | 8 | 0 | 13 | 7 | 133 |
| 1907-08 | 50 | 50 | 0 | 0 | ------- | 50 | 33 | 0 | 5 | 0 | 15 | 43 |
| 1908-09 | 180 | 357 | 28 | 33 | ------- | 22 | 274 | 8 | 0 | 11 | 9 | 329 |
| 1909-10 | 136 | 136 | 0 | 0 | ------- | 50 | 119 | 0 | 5 | 0 | 15 | 129 |
| 1910-11 | 100 | 138 | 18 | 25 | ------- | 32 | 63 | 5 | 0 | 8 | 12 | 113 |
| 1911-12 | 23 | 27 | 4 | 2 | ------- | 46 | 0 | 0 | 1 | 4 | 15 | 13 |
| 1912-13 | 19 | 19 | 0 | 0 | 30 | 20 | 0 | 0 | 5 | 0 | 15 | 4 |
| 1913-14 | 120 | 128 | 9 | 9 | ------- | 41 | 70 | 3 | 0 | 4 | 16 | 106 |
| 1914-15 | 36 | 62 | 24 | 21 | ------- | 26 | 0 | 8 | 0 | 9 | 11 | 37 |
| 1915-16 | 167 | 318 | 33 | 33 | ------- | 17 | 256 | 8 | 0 | 13 | 7 | 298 |
| 1916-17 | 82 | 108 | 13 | 25 | ------- | 40 | 66 | 5 | 0 | 6 | 14 | 92 |
| 1917-18 | 18 | 18 | 0 | 0 | 7 | 43 | 0 | 0 | 5 | 0 | 15 | 8 |
| 1918-19 | 45 | 47 | 0 | 0 | 3 | 45 | 0 | 0 | 3 | 2 | 15 | 30 |
| 1919-20 | 44 | 32 | 9 | 0 | 18 | 23 | 0 | 4 | 0 | 6 | 14 | 8 |
| 1920-21 | 53 | 57 | 4 | 4 | ------- | 46 | 3 | 0 | 1 | 4 | 15 | 42 |
| Mean | 73 | 133 | 12 | 13 | 3 | 35 | 86 | 3 | 1 | 6 | 13 | 114 |

On the basis used in the estimate a water supply of 50,000 acre-feet per year could be made available with 50,000 acre-feet of storage capacity which would have resulted in material shortages in only two years of the eighteen years of record. The cost of such storage capacity at the Ward site has been estimated as $3,500,000 or an average cost of $70 per acre-foot of capacity.

The utilization of any such supply would require the construction of canal systems. The cost of such canals would be relatively high as the cost of storage would necessitate its diversion in canals of minimum seepage loss. The cost per acre to any lands receiving such a supply would be the cost of its proportional part of the storage plus the proportional part of the cost of its local canal system. The use of such supply would not need to be confined to any one area. A group of areas might combine in the construction of the storage and each provide its own canal system independently. The costs of any such supply would be in excess of $100 per acre for both storage and canals if one acre-foot of storage per acre was provided. For the land now developed by pumping on which the draft exceeds the supply so that ground water lowering is continuous an average supplemental canal supply of one acre foot per acre, plus what may be permanently obtainable from the ground water, may be adequate. It is considered to the interest both of the individuals now having such developed lands and of the public in securing the most effective use of its water resources that the use of any additional water supplies that it may be possible to make available should be limited to lands on which the cost of development has already been incurred before any additional development of new lands is undertaken. Any such storage development of winter and flood water is only considered feasible if at all for those lands nearer the upper portion of the Kaweah Delta or adjacent areas for use on crops of large return such as orchards or vines.

Similar studies of an attempted use of excess waters with 30,000 acre-feet of storage capacity to maintain a supply of 50,000 acre-feet per year were also made. The reduction in storage capacities results in increased shortages; in one-half of the years there would be shortages of one-third or more in the supply. The estimated cost for the storage is $2,400,000. For the service secured from such storage, this development is considered less desirable than the previous estimate using 50,000 acre-feet of storage capacity.

A smaller supply, such as 20,000 acre-feet per year with 15,000 acre-feet of storage capacity, could be secured with few shortages. The summary for such a supply is also given in Table 29. In four years out of the eighteen years of record there would have been shortages in the supply of 25 per cent. The estimated cost of 15,000 acre-feet of storage at the Ward site is $1,400,000 or over $90 per acre-foot. The cost of storage plus the costs of canals would make the cost of securing such a water supply higher than present standards would ordinarily justify.

The present development of the Lindsay-Strathmore Irrigation District utilizes storage in a ground water basin along the river channel. The water considered available for storage from the winter and flood flow, as given in Table 29, should be reduced by the amounts of such flow that may be used to replace the water pumped by the district from the basin now used.

**Storage of Winter Flow Only.**

The amounts of discharge of the Kaweah River for November to February, inclusive, are shown in Table 29. If rights to the storage of this flow could be secured a minimum of 18,000 acre-feet per year would be available with 18,000 acre-feet of storage capacity. With 35,000 acre-feet of storage capacity a supply of 35,000 acre-feet could be made available in fifteen years out of the eighteen years of record. With 45,000 acre-feet of storage capacity a supply of 45,000 acre-feet could be secured in thirteen years out of eighteen, the shortage in the five years averaging about 40 per cent of the supply. This storage would be equally useful whether obtained at the Ward site or in ground water basins, the differences being matters of cost. A reservoir used for the storage of winter flow would be partly emptied by the time of the main stream flow in May and June and in many years additional use could be secured both by direct diversion and by refilling of storage from such excess flow. A total storage capacity of 50,000 acre-feet for storage under such conditions would appear warranted. If all of such storage should be obtained at the Ward site the estimated cost would be $3,600,000.

**Storage of Flood Flow Only.**

The use of a part of the water now passing across the Kaweah Delta by its retention in storage might be feasible without the additional storage of winter flow if it should be found that the existing uses of such winter flow presented legal difficulties not readily adjusted. The water supply available for such storage in each year has been taken as the outflow as given in Table 10. The use that might be obtained from such outflow is shown in Table 30.

TABLE 30.

**Regulated Irrigation Supplies Obtainable on Kaweah River from Storage of Water Not Now Retained on Kaweah Delta.**

| Year | Estimated outflow from Kaweah River, acre-feet | Supply of 20,000 acre-feet supported by 30,000 acre-feet of storage capacity | | | | Supply of 30,000 acre-feet supported by 50,000 acre-feet of storage capacity | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Used directly, acre-feet | Secured from storage, acre-feet | Shortage in supply, acre-feet | Unused flow, acre-feet | Used directly, acre-feet | Secured from storage, acre-feet | Shortage in supply, acre-feet | Unused flow |
| 1903-04 | 28,000 | 4,000 | 16,000 | 0 | 0 | 6,000 | 22,000 | 2,000 | 0 |
| 1904-05 | 2,000 | 2,000 | 8,000 | 10,000 | 0 | 2,000 | 0 | 28,000 | 0 |
| 1905-06 | 550,000 | 13,000 | 7,000 | 0 | 507,000 | 20,000 | 10,000 | 0 | 480,000 |
| 1906-07 | 80,000 | 13,000 | 7,000 | 0 | 60,000 | 20,000 | 10,000 | 0 | 50,000 |
| 1907-08 | 0 | 0 | 20,000 | 0 | 0 | 0 | 30,000 | 0 | 0 |
| 1908-09 | 255,000 | 11,000 | 9,000 | 0 | 217,000 | 16,000 | 14,000 | 0 | 199,000 |
| 1909-10 | 0 | 0 | 20,000 | 0 | 0 | 0 | 30,000 | 0 | 0 |
| 1910-11 | 56,000 | 8,000 | 12,000 | 0 | 19.000 | 12,000 | 18,000 | 0 | 0 |
| 1911-12 | 4,000 | 4,000 | 16,000 | 0 | 0 | 4,000 | 26,000 | 0 | 0 |
| 1912-13 | 0 | 0 | 6,000 | 14,000 | 0 | 0 | 6,000 | 24,000 | 0 |
| 1913-14 | 33,000 | 4,000 | 16,000 | 0 | 0 | 6,000 | 24,000 | 0 | 0 |
| 1914-15 | 14,000 | 9,000 | 11.000 | 0 | 0 | 12.000 | 5,000 | 13,000 | 0 |
| 1915-16 | 234,000 | 13,000 | 7,000 | 0 | 198,000 | 20,000 | 10,000 | 0 | 164,000 |
| 1916-17 | 27.000 | 6,000 | 14,000 | 0 | 14,000 | 9,000 | 21,000 | 0 | 8,000 |
| 1917-18 | 0 | 0 | 16,000 | 4,000 | 0 | 0 | 29,000 | 1,000 | 0 |
| 1918-19 | 0 | 0 | 0 | 20,000 | 0 | 0 | 0 | 30,000 | 0 |
| 1919-20 | 9,000 | 6,000 | 3,000 | 11,000 | 0 | 9,000 | 0 | 21,000 | 0 |
| 1920-21 | 5,000 | 4,000 | 1,000 | 15,000 | 0 | 5,000 | 0 | 25,000 | 0 |
| Mean | 72,000 | 5,500 | 10,500 | 4,000 | 56,000 | 8,000 | 14,000 | 9,000 | 50,000 |

Table 30 indicates that with 30,000 acre-feet of storage capacity a regulated supply of 20,000 acre-feet per year might be obtained with an average shortage of 20 per cent; the shortages occurring in six years out of the eighteen years of record. Four of the years giving shortages are the years 1918 to 1921; in 1919 there would have been no water obtainable. Additional storage capacity would have been used only three times in the eighteen years. The estimated cost of storage would have been $2,500,000 or $125 per acre-foot of the supply it was attempted to maintain. Table 30 also gives the use that could have been secured from 50,000 acre-feet of storage capacity used to support a regulated draft of 30,000 acre-feet. The average shortage would have been 25 per cent. Shortages exceeding 40 per cent of the supply would have occurred in six years out of eighteen; of these six years three are consecutive from 1919 to 1921. The estimated cost of the 50,000 acre-feet of storage capacity is $3,600,000 or $120 per acre-foot of supply it is attempted to maintain. Additional storage would have been useful only three times during the eighteen years of record. The construction of 30,000 acre-feet additional storage capacity at an estimated increase in cost of $1,200,000 would have given an average use of 5000 acre-feet per year at an estimated construction cost of $240 per acre-foot of mean annual use for such increased capacity.

# CHAPTER VI.

# POSSIBLE CHANGES IN USE OF RUN-OFF OF KAWEAH RIVER.

In the preceding chapters the extent of the Kaweah River water supply, the extent and effect of present use and the results to be anticipated in the different portions of the area dependent on Kaweah River have been discussed. The conclusion is expressed that the present net use of water for the whole area closely equals the net available supply but that under existing conditions the available supply is not distributed to the different parts of the area in proportion to the present rates of use with the result that shortages in supply now exist in some areas. In the present chapter possible methods of changing the use of the available water supply so as to give a more efficient use are considered.

TABLE 31.

**Summary of Present Irrigation and its Effect on the Ground Water in the Kaweah Delta in 1921.**

| Area | Gross area, acres | Area irrigated, acres | Average lowering of ground water, feet | Draft in acre-feet per acre of gross area |
|---|---|---|---|---|
| Portion of main area receiving canal service in which ground water held its elevation in 1921 | 135,000 | 73,000 | 0 | 0.3 |
| Remainder of delta area covered by canals | 55,000 | 30,300 | 2.6 | 1.3 |
| Area covered by canals diverting for lands mainly above Venice Hills | 60,000 | 19,300 | .8 | 0.45 |
| Area of lower Kaweah Delta outside of areas covered by canals | 95,000 | 15,900 | 1.8 | 0.3 |
| Area west of Lindsay-Strathmore Irrigation District toward which ground water slopes from the Kaweah Delta | 20,000 | 7,300 | 1.3 | 0.85 |
| Total areas | 365,000 | 145,800 | 1.0 | 0.45 |

Table 31 shows the results of conditions of use on the Kaweah Delta in 1921. The water supply for 1921 was 93 per cent of the mean net annual available supply under existing conditions. The larger part of the run-off was received within a gross area of 135,000 acres either by canal diversion or by stream channel percolation. This area contained about one-half of the land irrigated and held its ground water elevation for the year. The other areas containing the remaining one-half of the irrigation on the delta all show a lowering of the ground water in proportion to their use or distance from direct sources of ground water supply. The results presented should be convincing that some modification of present conditions of use must occur if a continual lowering of the ground water over many parts of the Kaweah Delta is to be avoided. Should such lowering continue it must eventually result in an increase in the pumping cost to a point where pumping will no longer be profitable. The time before such a condition may be reached will depend on the rate of lowering and the increase in lift which present returns can meet. In some areas of relatively slow rate of lowering such conditions may not be reached for a considerable number of years; in other areas of relatively rapid rate of lowering critical conditions if present ground water conditions continue, will be reached in a relatively short period. Further additions to the area irrigated by pumps in those areas now showing a lowering of the ground water can only serve to shorten the period until such critical conditions may be reached.

There are two general conditions under which additional supply may be secured for those areas now having an overdraft on their ground water supply. One of these would consist in such modifications as might be made in present conditions without materially disturbing the present character of practice, the other would be changes that would require the substitution of new practices materially affecting at least a part of the present methods.

Among the changes which would not require material modifications in the present general methods of diversion from the stream would be the improvement by lining or otherwise of canals now diverting from the Kaweah River so as to reduce seepage losses in the areas adjacent to the stream and already containing an excess of ground water. Such changes would be mainly of direct benefit to the canals serving areas further from the stream, such as the Tulare Irrigation District, and the Packwood Ditch. The reduction in seepage on such systems would increase the supply which could be delivered to the outer canal areas with benefit both from the additional irrigation secured and from the replenishment of the ground water. An improvement in delivery to the advantage of those using water from canals would result from a more definite scheduling of diversion with rotation between the smaller ditches. This would reduce seepage losses in canals and channels and supply larger deliveries for more effective use in irrigation.

In connection with any improvements for canals now serving areas where the ground water is lowering some increase in existing canal capacities would also be desirable. The existing canals have been developed to utilize unregulated stream flow and presumably have been extended to a total capacity which on the basis of the values at the time of construction was economically profitable. Any increase in diversion capacities could divert water for only limited periods during normal years and for very short periods in years of less than normal run-off. With the present values in these areas some additional diversion capacity over that of the original construction should be feasible. The benefits of such increased diversion capacity would apply mainly to canals on the lower portion of the delta where the soil conditions are such that direct replenishment of the ground water will occur from such increased canal use. In the higher areas of close textured soil, short periods of canal use while of benefit by reducing the pumping draft during such periods would not result in material additions to the ground water by percolation.

The present development has been found to be equal to one acre irrigated for each 2.2 acre-feet of mean annual net available supply. This represents a relatively high rate of development. While some reduction in use might be secured by reduction in the area of crops of larger water use such as alfalfa and a substitution of such crops as orchards, a change which has been in progress in recent years, the total decrease in water consumption to be expected by this method is not large. Alfalfa and wild pasture represent less than one-half of the area now irrigated on the Kaweah Delta.

The areas not producing crops on which there may be loss by evaporation due to high ground water represent about 5 per cent of the cropped area. Changes in the distribution of canal diversion and local pumping which would reduce such losses are desirable. It will not be feasible to reduce losses from this source entirely; there will necessarily be some areas of high ground water adjacent to the stream channels.

The increase in the net available supply by the construction of storage to retain excess flood flows only has been discussed. The costs of storage for such flood water only were shown to be relatively high. Such shortage would not result in injury or interferenc with existing rights as only the run-off in excess of existing rights would be stored. It would, however, require a determination of the extent of existing rights. Due to the high costs involved, other methods of utilizing portions of the excess flow now occurring by increased canal capacity and by lowering of ground water adjacent to the channels so as to increase absorption of flood flow are thought to be more practical. Storage of flood flows might be the only means by which excess water could be made available for the upper lands.

No changes in existing conditions on the Kaweah River are feasible or advisable which would result in material injury to present rights. It is considered reasonable, however, that present diversions should be determined on a standard of beneficial use which, while supplying an adequate amount of water for essential crop needs, will enforce a standard of practice consistent with public interest under present conditions and standards of values. Such a standard of use may be found to result in somewhat less diversion by some of those ditches having older priorities of right than may have been the practice in the past with a resulting increase in water supply available for diversion by those ditches of later priority which have been limited to shorter seasons of diversion. This would be of benefit mainly to the outer and lower portions of the delta as the area served by the ditches of later priority are generally those further from the stream channels.

The methods of increasing the use of Kaweah River which involve changes in the present conditions of use, both legally and physically, would include transfers of existing canal rights to other areas, storage of winter flow and of excess summer flow and substitution of pumping in areas near the river channels for present canal use.

It is possible to increase the production secured by the use of Kaweah River by changes in the character and location of use of parts of the present development. A transfer of all or part of the water now diverted by the Lakeside Ditch into areas not on the Kaweah Delta to areas where greater production per unit of water supply could be obtained would increase the total benefit derived from the available water supply. The substitution in the main canal area of high ground water elevation of pumped water for the present canal service with a transfer of the present canal diversions to areas of deficient canal or ground water supply would reduce the average lift of pumping, cause a draft on the ground water near the stream where replenishment takes place most readily with a corresponding lessening of the draft on those areas of least rapid recharge. A determination in definite terms of the extent of the diversion rights of existing canals both as to amount and as to the season at which diversion could be made, would enable other means of use for such portions of the discharge of Kaweah River as are not needed to supply existing rights to be undertaken. Except for the portions of the discharge now leaving the delta as outflow, such additional developments would be of the nature of changes in present conditions of use rather than the making available of new sources of supply.

There is little present loss from the Kaweah Delta of the run-off during the winter months. The flow at such periods is absorbed or diverted mainly for areas adjacent to the stream channel for which there is adequate replenishment available from the discharge during the main season. Storage of the winter flow would result in a lowering of the ground water near the stream channels by the general movement outward of the ground water during the winter months. This would result in having a larger capacity available for absorption of the summer flow.

The present use of winter flow is of some benefit to those canals which now divert during such periods. The extent of the benefit, however, is considered to be less than that from use at other periods and it is not considered that any material actual injury will result to those lands near the stream channels by storage of such winter flow.

Storage of winter flow might be accomplished either in surface reservoirs such as that at the Ward site or by ground water storage in such basins as that now used by the Lindsay-Strathmore Irrigation District. The use of ground water storage basins along the stream channel would require means of preventing the accumulation of storage from the portions of the flow to which prior rights are entitled. Means of preventing such refilling of ground water basin storage from water required for other rights are available. There are many surface reservoirs on streams where the portion of the use to which no storage rights attach is permitted to flow through or over the reservoir without depletion in amount. The differences physically between the use of surface reservoirs and ground water basins are ones of availability and cost rather than of the results secured. The extent to which storage of winter flow might be available if rights to its use could be secured have already been discussed.

The following program represents the conclusions based on these investigations of the most feasible means of protecting the water supply of the areas now developed with the minimum interference with existing conditions:

1. Complete a determination of existing rights on a basis which protects existing diversions in their essential needs but in which the standards of practice required are commensurate with present economic conditions of value of land and water. Such a determination should include a definition of the rates of diversion to which each right is entitled and a limitation of the season in which such rights may be exercised. It may be secured through existing legal means or probably much more quickly and effectively by voluntary adjustment among the parties concerned if agreement by such methods can be reached.

2. Improve existing canals so as to reduce seepage losses in areas near the stream so as to deliver a larger part of the diversion to areas away from the stream in which ground water is now lowering. Increase canal capacities for those systems serving such outer areas.

3. Increase pumping in areas near the river channels using pumped water as a substitute for present canal use in these areas so that the present canal use can be transferred to areas of deficient ground water supply. This will also increase ground water storage capacity for absorption of flood flow from the river channels.

4. Permit use of winter flow by storage for upper lands either in surface or ground water basins or a combination of both as may prove to be most economical.

5. Make direct transfers of present canal use from areas of less production per unit of water supply to those of a higher type of use where such transfers can be arranged.

The benefits that would result from carrying out the program suggested would be the securing of sufficient additional water in the upper and outer areas to enable present development to be maintained without causing injuries to present use which could not be subject to compensation. The changes in present use in the main canal areas which would be required are matters of method of securing water rather than of amount and no material injury should result. The continuance without change of present conditions of diversion and pumping must eventually result in the reduction of the area now irrigated on some parts of the Kaweah Delta. The changes suggested would permit of the irrigation of such additional areas as could be supplied from any reduction of present use or losses such as the decrease in the amounts of water now leaving the area or the more efficient use of water now retained. For the interests of the area as a whole the maintenance of existing development is regarded as of more relative importance than the irrigation of such new areas as could be supplied by the program outlined.

It is considered that it is to the interest both of the individuals concerned and of the community as a whole that land on which the cost of development has already been incurred should have its water supply protected before additional lands are brought under irrigation. Such developed lands can offer security for higher costs in securing the water needed to supplement their existing supply than lands not developed and requiring a complete water supply.

Under existing conditions all landowners have an equal right to draw upon the ground water underlying their lands for a reasonable use of such ground water. It has been shown that in several parts of the area the present ground water draft with only part of the area developed is in excess of the ground water supply. Additional pumping plants installed in such areas can only hasten the time when the ground water will be lowered to a point where pumping may not be profitable. The irrigation of additional land in the areas of present high ground water will intercept water now moving toward the outer areas with a resulting reduction in the supply reaching the outer areas.

The changes suggested in the present conditions of use on the Kaweah Delta are all ones which require adjustment with present rights to such use. Such changes in present use are largely ones which can not be forced upon the owners of the rights to such use. There are not means of compelling an area now receiving canal service to substitute pumping in order that the canal service may be carried to other areas of deficient ground water. Storage of winter flow will to some extent affect present conditions of replenishment. The determination of what flood flow may be available for storage requires a definition of existing rights. That such adjustments can not be brought about without much delay, bitterness and cost unless approached in a spirit of fairness and community interest as a whole is indicated by the litigation which has been in progress over the pumping of the Lindsay-Strathmore Irrigation District for the past five years with no tangible results as yet except large costs and much ill feeling among the parties concerned.

If the questions of the maintenance of the present irrigation development on the Kaweah Delta are approached with a realization of the injury that will result to the entire area from any permanent injury to any part it is thought that at least a part of the suggested changes can in time be brought about. The problems involved, however, are more largely human than technical and their solution can only be reached by a thorough realization among those directly concerned of their interest in the accomplishment of such adjustments with the minimum of injury to those affected by the changes and a maximum benefit at minimum cost to those receiving the more direct benefits.

PART III.

# UTILIZATION OF WATER SUPPLY OF SOUTHERN PART OF TULARE COUNTY.

deficient ground water. Storage of winter flow will to some extent affect present conditions of replenishment. The determination of what flood flow may be available for storage requires a definition of existing rights. That such adjustments can not be brought about without much delay, bitterness and cost unless approached in a spirit of fairness and community interest as a whole is indicated by the litigation which has been in progress over the pumping of the Lindsay-Strathmore Irrigation District for the past five years with no tangible results as yet except large costs and much ill feeling among the parties concerned.

If the questions of the maintenance of the present irrigation development on the Kaweah Delta are approached with a realization of the injury that will result to the entire area from any permanent injury to any part it is thought that at least a part of the suggested changes can in time be brought about. The problems involved, however, are more largely human than technical and their solution can only be reached by a thorough realization among those directly concerned of their interest in the accomplishment of such adjustments with the minimum of injury to those affected by the changes and a maximum benefit at minimum cost to those receiving the more direct benefits.

water may exist in granitic formations, its amount and movement are small except along lines of fracture or faulting. It would be contrary to experience in other areas to expect any material amount of such movement here. The greatest losses would naturally by expected to occur along present stream channels. Measurements given later show that there is no appreciable loss from the Kaweah River channel above McKay Point. Pumping near Lindsay lowered the water level to a considerable depth, general ground water movement from the upper areas, if it existed in this area, should have served to maintain the pumping supply adjacent to the hills.

Except for the two marginal areas first mentioned all of the water supply for the areas in Tulare County can be considered as entering the area as surface run-off in the definite stream channels. The extent of such run-off measures the extent of the water supply tributary to the area and available for irrigation. The available records are mainly those obtained by the Water Resources Branch of the U. S. Geological Survey since 1901 with some additional records secured by local interests. Estimates of the run-off from 1878 to 1884 have been published based on the data obtained during this period by the State Engineer. As such records are based on less detail of observation than those more recently obtained and as the results are in many cases inconsistent with the more complete recent records no use has been made of the earlier estimates.

In these investigations no study has been given to the feasibility of bringing into this area water supplies not naturally tributary thereto. Such studies are outside the scope and purpose of this work. There can be no question, however, that full utilization of local sources of water supply should take precedence over any plans for securing distant sources of supply.

## KAWEAH RIVER.

Kaweah River is the largest stream in Tulare County and supplies about two-thirds of the area irrigated. The run-off of the main stream has been measured by the U. S. Geological Survey below Three Rivers since 1903. Records are also available for the North and South Forks since 1911. Records at McKay Point have been kept since October, 1916, by Mr. H. H. Holley for parties interested in the diversions from the river. The power companies which have plants on the Middle Fork have kept records on East and Marble Forks as well as Middle Fork. All of these records have been made available for the purposes of this report.

The run-off of the separate branches of Kaweah River is not of direct interest in the study of the utilization of this stream for irrigation as no reservoir sites of sufficient size to be important were found on these branches. The only site offering possibilities of full regulation of the stream is below the junction of the three forks at Three Rivers. The run-off of the main stream at Three Rivers gives the total supply available for irrigation.

The record of the U. S. Geological Survey station at Three Rivers during 1918 to 1920 is open to some question due to uncertainty as to the accuracy of the reported gage heights on which it is based. A somewhat detailed analysis of these records for this period has been made and a substitute record of discharge used. The method of deriving this substitute record is explained in detail later.

For the period 1903 to date the run-off of the Kaweah River at Three Rivers is shown in Table 1. The records, except for 1919 and 1920 are those of the U. S. Geological Survey. The annual mean for the 18-year period is 455,000 acre-feet. Rainfall records for this vicinity are available since 1890. A study of these indicates that the precipitation for the period 1890 to 1903 was only 93 per cent of that for the period 1903 to 1921 and that the recorded run-off for the latter period would exceed the mean for the longer period 1890 to date. A comparison by years indicated an average annual run-off of 416,000 acre-feet for the period 1890 to 1903 which combined with the recorded run-off since 1903 gives a mean annual discharge for the period 1890 to date at Three Rivers of 438,000 acre-feet. The estimated run-off of the small streams entering below Three Rivers, as given later, is 13,000 acre-feet per year, giving a total mean annual run-off of the Kaweah drainage area of 451,000 acre-feet.

TABLE 1.

**Discharge of Kaweah River at Three Rivers. Record of U. S. Geological Survey, Except for 1919 and 1920, for Which Discharge is Computed from McKay Point.**

| Month | Discharge in total acre-feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1903 | 1903-04 | 1904-05 | 1905-06 | 1906-07 | 1907-08 | 1908-09 | 1909-10 | 1910-11 | 1911-12 |
| October | -------- | 2,644 | 31,420 | 2,669 | 7,380 | 6,890 | 6,060 | 5,670 | 4,430 | 4,800 |
| November | -------- | 3,332 | 6.962 | 3,368 | 7,080 | 6,250 | 4,260 | 13,000 | 4,240 | 4,960 |
| December | -------- | 2,951 | 5,841 | 5,103 | 15,100 | 12,100 | 5,240 | 46,600 | 6,580 | 5,570 |
| January | -------- | 4,796 | 7,133 | 48,200 | 25,300 | 12,700 | 92,200 | 50,600 | 53,400 | 6,270 |
| February | -------- | 41,933 | 14,330 | 23,200 | 33,300 | 18,800 | 77,200 | 25,900 | 35,800 | 6.040 |
| March | -------- | 39,352 | 34,000 | 150,000 | 63,300 | 36,800 | 53,400 | 48,700 | 70,100 | 12,200 |
| April | -------- | 57,600 | 46,590 | 114,000 | 117,000 | 47,200 | 89,800 | 79,100 | 75,600 | 22,500 |
| May | 123,406 | 126,296 | 85,220 | 197,000 | 120,000 | 54,500 | 162,000 | 86,700 | 106,000 | 67,600 |
| June | 104,073 | 62,598 | 80,210 | 278,000 | 121,000 | 35,900 | 217,000 | 34,900 | 122,000 | 61,300 |
| July | 28,407 | 13,527 | 18,620 | 211,000 | 62,700 | 11,400 | 70,100 | 12,000 | 51,800 | 10,600 |
| August | 3,074 | 6,641 | 4,710 | 42,500 | 16,000 | 5,250 | 16,000 | 3,680 | 11,400 | 3,360 |
| September | 2,559 | 11,306 | 2,690 | 13,400 | 5.380 | 4,850 | 6,600 | 2,880 | 4,680 | 2,210 |
| Total for season | -------- | 373,000 | 338,000 | 1,090,000 | 594,000 | 253,000 | 800,000 | 410,000 | 546,000 | 207,000 |

| Month | Discharge in total acre-feet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1912-13 | 1913-14 | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 |
| October | 2.340 | 3,070 | 4,300 | 2,640 | 19,600 | 3,040 | 9,900 | 2,400 | 7,810 |
| November | 3,040 | 6,550 | 3,460 | 3,370 | 8,630 | 3,300 | 8,510 | 2,740 | 8,750 |
| December | 2,900 | 7,380 | 4,950 | 7,620 | 17,400 | 3,370 | 8,790 | 9,100 | 9,590 |
| January | 5,020 | 71,900 | 8,300 | 94,100 | 17,200 | 3,460 | 6,500 | 6,030 | 16,500 |
| February | 7,610 | 33,700 | 19,200 | 61,600 | 38,300 | 7,890 | 22,100 | 8,400 | 23,700 |
| March | 15,400 | 51,500 | 27,000 | 108,000 | 35,700 | 33,500 | 29,300 | 37,900 | 54,700 |
| April | 37,800 | 67,200 | 52,800 | 127,000 | 70,800 | 46,900 | 58 800 | 72,900 | 49,300 |
| May | 68,200 | 108,000 | 104,000 | 145,000 | 102,000 | 65,200 | 99,000 | 116,500 | 89,200 |
| June | 43,100 | 86,300 | 105,000 | 131,000 | 120,000 | 46,200 | 32,900 | 86,100 | 85,100 |
| July | 15,600 | 38,700 | 30,700 | 59,000 | 30,600 | 9,720 | 9,250 | 22,500 | 20,000 |
| August | 10,700 | 7,500 | 6,400 | 16,700 | 7,870 | 3,200 | 2,650 | 4,900 | 4,060 |
| September | 8,990 | 4,240 | 3,400 | 6,130 | 3,370 | 3,920 | 1,490 | 2,650 | 2,610 |
| Total for season | 221,000 | 486,000 | 370,000 | 762,000 | 471,000 | 230,000 | 289,190 | 372,120 | 371 310 |

The run-off of Kaweah River is subject to relatively wide variations in different years as shown in Table 1. The maximum measured annual run-off at Three Rivers since 1903 is 1,090,000 acre-feet, the minimum is 207,000 acre-feet. Two consecutive years, 1912 and 1913, have had a mean discharge of 214,000 acre-feet or less than one-half the normal. Of recent years, 1916 was a year of excessive run-off; 1917 was about normal; and the last four years have varied from 53 to 89 per cent of normal. The four years 1918 to 1921 are the longest period of record in which no year had a run-off equal to or greater than normal.

### Accuracy of Kaweah River Records.

The records of run-off of the Kaweah River at Three Rivers as obtained by the U. S. Geological Survey have been based on gage height readings taken usually twice per day. During the summer of 1921 an automatic register was also installed by Mr. H. H. Holley. During 1921 the gage height readings have been taken at 7 a.m. and 7 p.m. The resulting discharges as obtained by the recording gages and the two gage height readings are shown in the following table. The same rating table was used for both computations so that the differences in discharge are due to variations of the mean of two gage readings per day from the actual mean.

| Month | Mean discharge, recording gage, second-feet | Mean discharge, 2 gage height readings, second-feet | Difference, second-feet | Difference, per cent |
|---|---|---|---|---|
| April | 826 | 780 | 46 | 5.6 |
| May | 1,440 | 1,360 | 80 | 5.6 |
| June | 1,430 | 1,320 | 110 | 7.6 |

These records indicate that two readings per day at the hours used give a smaller discharge than the actual at this station during the months of snow water flow. This difference is due to the fluctuation of the discharge during the day caused by the variations in the hourly rate of snow melting. As the three tributaries of the Kaweah have an approximately equal length of channel to the portions of their drainage areas contributing the larger portion of the run-off the daily peak of each branch coincides in time at the Three Rivers station. This results in a greater range of daily discharge than would be expected on most of such streams. These daily variations are limited to the months of melted snow flow. Discharge, during the rainy season, does not show similar variations. Typical records are shown in Fig. I.

The comparisons made in 1921 might be used as a basis for a conclusion that the discharge at Three Rivers as published is less than the actual discharge and that some increase in such records would be warranted. Any such corrections would apply only in the summer months and the amount of the correction would depend on the actual time of reading of the gage. The actual time of reading of the gage in the past is not definitely known although it was probably in the early morning and toward evening. The uncertainties as to the time of reading make the application of a correction inadvisable. The conclusion appears warranted, however, that the actual discharge at Three Rivers is probably slightly more rather than less than the amount shown by the record.

**Kaweah River Records 1919 and 1920.**

Since 1916 a record of the discharge of Kaweah River at McKay Point has been kept by the canals interested in the division of flow at that point, the actual record being secured under the supervision of Mr. H. H. Holley, engineer for the canal association. A comparison of the record at McKay Point with that at Three Rivers indicated differences not explainable by intermediate diversions. These differences began to occur late in 1918. In order to secure a check on the Three Rivers record an automatic register was installed at Three Rivers in 1921 by Mr. Holley. A change was also made in the Geological Survey observer. The records during 1921 (Table 2) indicated a close agreement of the discharge at Three Rivers and at McKay Point when allowances for intermediate diversions are made. As the Three Rivers record for 1919 and 1920 appears to be based on inaccurate gage height records a substitute record has been prepared based on the McKay Point record plus the intermediate diversions.

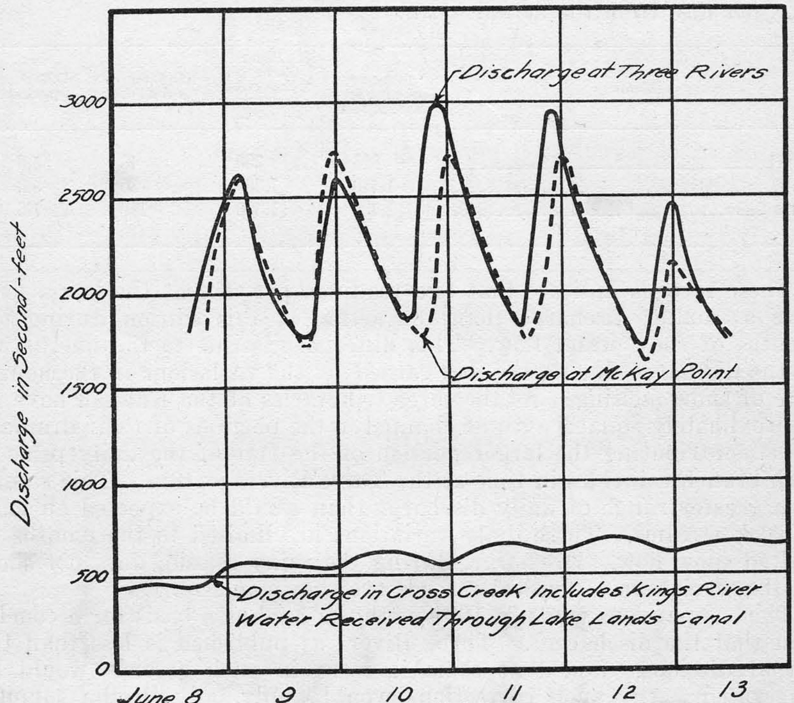


Fig. 1. Comparison of Discharge of Kaweah River at Three Rivers and at McKay Point Based on Automatic Registers

**TABLE 2.**

**Comparison of U. S. Geological Survey Record of Discharge of Kaweah River at Three Rivers for 1918-1921 with Record Computed by Adding Intermediate Diversions to Discharge of Kaweah River at McKay Point.**

| Month | Total acre-feet, 1918-19 | | | Total acre-feet, 1919-20 | | | Total acre-feet, 1920-21 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Computed | U.S.G.S. | Difference U.S.G.S. minus computed | Computed | U.S.G.S. | Difference U.S.G.S. minus computed | Computed | U.S.G.S. | Difference U.S.G.S. minus computed |
| October | *9,900 | 9,900 | ---------- | 2,400 | 3,880 | +1,480 | 6,350 | 7,810 | +1,460 |
| November | *8,510 | 8,510 | ---------- | 2,740 | 3,620 | +880 | 7,910 | 8,750 | +840 |
| December | *8,790 | 8,790 | ---------- | 9,100 | 29,100 | +20,000 | 9,470 | 9,590 | +120 |
| January | 6,500 | 6,640 | +140 | 6,030 | 7,190 | +1,160 | 15,700 | 16,500 | +800 |
| February | 22,100 | 18,900 | —3,200 | 8,400 | 9,610 | +1,210 | 22,700 | 23,700 | +1,000 |
| March | 29,300 | 26,300 | —3,000 | 37,900 | 60,100 | +22,200 | 45,500 | 54,700 | +9,200 |
| April | 58,800 | 66,000 | +7,200 | 72,900 | 69,600 | —3,300 | 51,000 | 49,300 | —1,700 |
| May | 99,000 | 99,000 | ---------- | 116,500 | 108,000 | —8,500 | 89,500 | 89,200 | —300 |
| June | 32,900 | 29,400 | —3,500 | 86,100 | 97,000 | +10,900 | 84,400 | 85,100 | +700 |
| July | 9,250 | 7,130 | —2,120 | 22,500 | 22,800 | +300 | 21,270 | 20,000 | —1,270 |
| August | 2,650 | 2,410 | —240 | 4,900 | 5,830 | +930 | 4,140 | 4,060 | —80 |
| September | 1,490 | 2,340 | +850 | 2,650 | 3,660 | +1,010 | 2,850 | 2,610 | —240 |
| Totals | 289,190 | 285,320 | —3,870 | 372,120 | 420,390 | +48,270 | 360,790 | 371,310 | +10,530 |

*U. S. Geological Survey record used.

The McKay Point record since 1917 has been secured by means of an automatic register. The rating is controlled by the weir used to divide the flow between the Kaweah and St. Johns channels. The records of diversion (secured by Mr. Holley) of the canals diverting between Three Rivers and McKay Point are not complete and estimates have been used for portions of the record. The estimates are considered to be fairly accurate as the diversions are relatively uniform and the amounts estimated are a small part of the computed totals. The intermediate run-off between Three Rivers and McKay Point was relatively small in all of the years used in these comparisons.

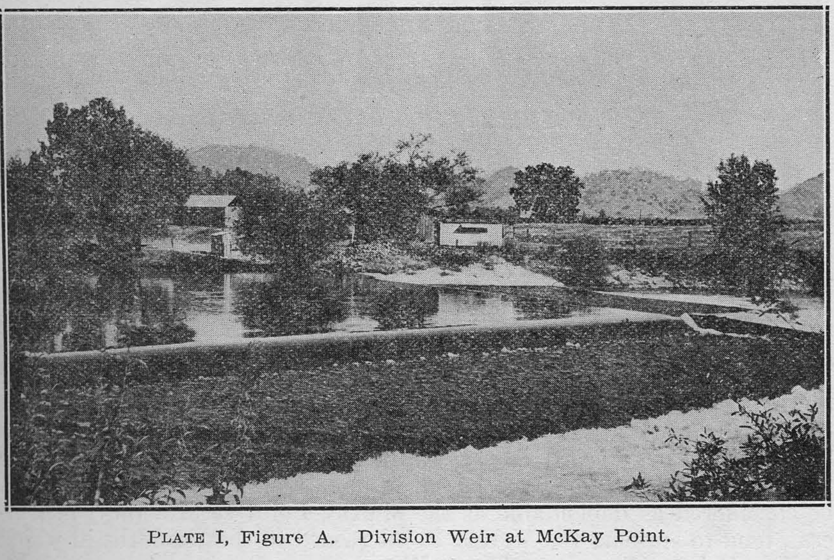

PLATE I, Figure A. Division Weir at McKay Point.

The agreement of the Three Rivers and McKay Point records for a typical period in 1921 as well as the extent of daily fluctuation are shown in Fig. 1. The difference in discharge is due to intermediate diversions. At the dates where the river is rising the time difference between Three Rivers and McKay Point, a distance of 9 miles is only one to two hours; on other dates when the river is falling the difference in time is about seven hours. The extent of the daily fluctuations indicates the probability of error where records are based on single gage readings. The river rises for about six hours during the day and recedes during the other eighteen hours. These period correspond with the time of melting at the higher altitudes. The percentage fluctuations at McKay Point are larger than at Three Rivers indicating that there is no spreading out of the maximums or minimums in the stream channel between these two points.

Other comparisons were tried in order to check the Three Rivers records. The total annual discharge of the Kaweah River was compared with that of the Kings and Tule rivers. The variations in the ratio of run-off in different years are greater than the variations in the

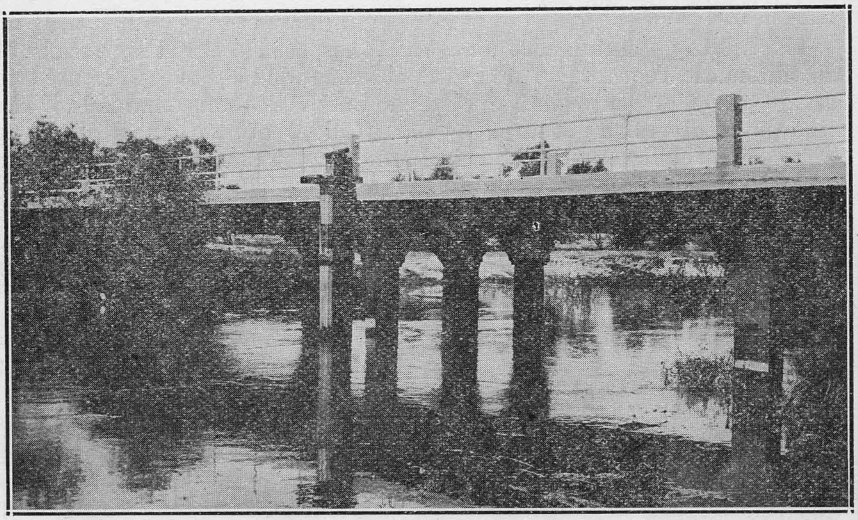

PLATE I, Figure B. Gaging Station on Cross Creek at Hanford Road Bridge.

years in question on the Kaweah River. Apparently the storms producing the larger portions of the precipitation vary in their distribution over these adjacent drainage areas in different years so that the relationship of the resulting run-off is not consistent.

A comparison of the sum of the records on the North, Middle and South forks with that at Three Rivers was also made. The records on the Middle Fork are kept by the power companies at their diversions. The South Fork record is not complete in recent years. While the records of these stations are based on gage readings only and can not be considered as dependable as the McKay Point record, they, in general, tend to support the McKay Point record in those months in which McKay Point differs from Three Rivers.

As these comparisons indicated that the record computed for the discharge at Three Rivers was more consistent than the Three Rivers record, the computed results have been used for the years 1918–19 and 1919–20. For 1920–21 the Three Rivers record was used as it agrees quite consistently with that computed from McKay Point except during March.

**Channel Losses in Kaweah River.**

In order to determine whether there is any channel seepage either above or below Three Rivers a series of measurements were made during the low water period in August and September, 1921. Measurements were made of each of the three forks and of the diversions and the records at Three Rivers and McKay Point for the same dates secured. The results are shown in the following table:

| | Upper measurement, second-feet | Lower measurement, second-feet | Diversions, second-feet | Losses or gain, second-feet |
|---|---|---|---|---|
| North Fork | 2.84 | 1.79 | 3.02 | +1.97 |
| South Fork | 4.82 | 1.0 | 2.92 | —0.90 |
| Middle Fork | ---------- | 43.30 | ---------- | ---------- |
| Total | ---------- | 46.20 | ---------- | ---------- |
| Kaweah River at Three Rivers Sta. | ---------- | 51.00 | ---------- | +4.80 |

The gain on North Fork is considered to be due to return flow from irrigation diversions. The loss on South Fork occurs in the coarse material in the lower portion of its length. Measurements up the Middle Fork were not made due to conditions of diversion for power. There is probably little, if any, loss except by seepage from the power flumes which may be lost before reaching the river.

From the junction of North and Middle Forks there appears to have been a gain of nearly five second-feet to the gaging station below Three Rivers, a distance of about four miles. In the nine miles between Three Rivers and McKay Point there was an indicated gain of seven second-feet. The extent to which these gains may continue throughout the year is not known. It is probable that they represent mainly ground seepage to the river channel from early season flood flow or diversion for irrigation rather than a continuous ground water movement. The conclusion appears warranted that there is at least no channel loss above McKay Point and that the flow at Three Rivers is the total run-off of the upper drainage area. The wells above McKay Point have in general given small yields, a further indication of lack of seepage.

## TULE RIVER.

There are two points of measurement whose records give the principal part of the run-off of the Tule River drainage area. These are the stations (1) on the main river above the mouth of the South Fork and (2) on the South Fork. The run-off of the small area below these stations is discussed with the other minor drainage areas.

**Main Tule River.**

The record of the main stream gives the run-off from 266 square miles of drainage area including the Middle and North Forks and their tributaries. The drainage area extends back to the divide of the Kern River drainage at elevations of over 9000 feet along most of the crest. The North Fork of Middle Fork extends northward to the east of North Fork and receives the drainage of much of this higher area. The mean annual run-off of the North Fork of the Middle Fork appears to be about 900 acre-feet per square mile, of the South Fork of the Middle Fork about 600 acre-feet per square mile and for the remainder including the North Fork about 275 acre-feet per square mile.

The record on the main stream is continuous since 1901. There are a few small diversions above the station but the record gives the water available for use below. Its accuracy is considered satisfactory. The records are based on daily gage heights. There are no continuous gage records available. The daily fluctuations due to snow melting are probably less on this stream than on the Kaweah. The annual discharges are given in Table 3.

TABLE 3.

**Runoff of Tule River Near Porterville, Above Mouth of South Fork. Drainage Area, 266 Square Miles. Record of U. S. Geological Survey.**

| Month | Discharge in total acre-feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1901 | 1901-02 | 1902-03 | 1903-04 | 1904-05 | 1905-06 | 1906-07 | 1907-08 | 1908-09 | 1909-10 |
| October | -------- | 1,783 | 1,476 | 1,045 | 3,382 | 775 | 2,370 | 2,830 | 1,920 | 2,740 |
| November | -------- | 2,559 | 2,975 | 1,428 | 1,785 | 2,523 | 2,900 | 3,150 | 2,030 | 5,270 |
| December | -------- | 3,074 | 3,812 | 1,722 | 2,275 | 5,792 | 5,970 | 6,520 | 2,720 | 36,600 |
| January | -------- | 2,767 | 15,618 | 1,845 | 2,914 | 30,700 | 14,300 | 7,130 | 55,000 | 21,100 |
| February | -------- | 8,830 | 9,608 | 6,960 | 4,215 | 11,100 | 15,800 | 15,200 | 49,800 | 10,000 |
| March | -------- | 22,259 | 15,864 | 17,401 | 14,140 | 84,200 | 21,800 | 18,200 | 32,600 | 13,300 |
| April | -------- | 33,977 | 26,598 | 16,602 | 12,200 | 45,900 | 45,500 | 10,600 | 45,200 | 13,600 |
| May | 25,702 | 21,090 | 22,013 | 16,110 | 19,250 | 66,400 | 20,800 | 10,100 | 45,000 | 9,470 |
| June | 14,281 | 11,306 | 9,402 | 4,403 | 8,688 | 57,800 | 15,600 | 4,750 | 34,300 | 3,180 |
| July | 3,751 | 2,644 | 2.337 | 1,045 | 2,023 | 22,300 | 5,060 | 1,230 | 10,100 | 1,110 |
| August | 1,168 | 1,291 | 1,045 | 553 | 603 | 5,180 | 2,260 | 633 | 3,300 | 406 |
| September | 1,012 | 893 | 833 | 1,190 | 488 | 2,820 | 1,780 | 1,100 | 2,300 | 631 |
| Totals | *45,900 | 112,000 | 112,000 | 70,300 | 71,000 | 335,000 | 154,000 | 81,400 | 285,000 | 117,000 |

| Month | Discharge in total acre-feet | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1910-11 | 1911-12 | 1912-13 | 1913-14 | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 |
| October | 1,360 | 1,520 | 429 | 212 | 928 | 581 | 5,840 | 928 | 490 | 529 | 879 |
| November | 1,900 | 2,550 | 904 | 2,230 | 1,210 | 1,750 | 3,800 | 1,680 | 1,430 | 976 | 1,690 |
| December | 2,980 | 2,930 | 1,390 | 4,180 | 2,560 | 3,790 | 12,600 | 2,180 | 2,790 | 3,230 | 3,070 |
| January | 17,800 | 4,000 | 1,740 | 44,400 | 4,500 | 58,200 | 9,410 | 2,370 | 2,490 | 1,920 | 4,960 |
| February | 15,100 | 3,370 | 1,640 | 14,300 | 9,720 | 33,200 | 19,300 | 2,870 | 6,500 | 2,160 | 8,500 |
| March | 26,900 | 5,450 | 5,130 | 14,300 | 10,600 | 51,800 | 16,100 | 12,800 | 13,500 | 18,100 | 14,400 |
| April | 21,000 | 9,700 | 7,970 | 15,900 | 14,900 | 38,700 | 23,000 | 8,930 | 15,600 | 25,600 | 9,640 |
| May | 17,400 | 12,200 | 6,210 | 16,500 | 37,400 | 33,200 | 24,800 | 5,810 | 12,100 | 20,700 | 15,300 |
| June | 10,800 | 6,720 | 2,950 | 9,640 | 16,100 | 18,500 | 17,500 | 1,960 | 2,700 | 9,340 | 8,930 |
| July | 3,380 | 842 | 445 | 2,480 | 3,510 | 6,200 | 3,640 | 167 | 259 | 1,510 | 1,090 |
| August | 1,330 | 175 | 142 | 627 | 744 | 2,240 | 1,150 | 56 | 34 | 194 | 98 |
| September | 988 | 314 | 278 | 397 | 625 | 1,200 | 547 | 159 | 18 | 209 | 57 |
| Totals | 121,000 | 49,800 | 29,200 | 125,000 | 103,000 | 249,000 | 138,000 | 39,900 | 57,911 | 84,468 | 68,614 |

The mean annual discharge of the main river station since 1901 has been 120,000 acre-feet. This record does not cover the dry period between 1890 and 1900. As the rainfall records begin in 1889, the measured run-off since 1901 was plotted against the rainfall for each year and the indicated relationship used to estimate the probable run-off for 1889 to 1900. The rainfall for these earlier years averaged 88 per cent of the long time mean. The resulting estimates of run-off averaged 88,000 acre-feet per year for this earlier period.

For the full period, 1889 to 1921, the estimated and measured run-off indicates a mean annual discharge of 106,000 acre-feet per year for the area above the present gaging station on the main Tule River.

For the period of actual record the years of smallest discharge were 1912 and 1913 with a total of 50,000 and 29,000 acre-feet respectively or 47 and 27 per cent of the probable long time mean. In 1918 the discharge was 38 per cent of the long time mean. The largest measured discharge was in 1906 with 335,000 acre-feet or three times the long time mean. Two other years, 1909 and 1916, were 2½ and 2¼ times the mean. For the years 1889 to 1901 the estimates indicate a minimum discharge of 28,000 acre-feet in 1898 with no years exceeding 1.5 times the probable long time mean.

For the long time period the discharge at the gaging station on the main Tule River appears to be derived about as follows:

| Drainage area | Mean annual run-off, acre-feet | Per cent of total |
|---|---|---|
| South Fork of Middle Fork | 25,000 | 23 |
| North Fork of Middle Fork | 30,000 | 27 |
| Bear Creek | 5,000 | 5 |
| Remainder of drainage area | 46,000 | 45 |
| Totals | 106,000 | 100 |

**South Fork of the Tule River.**

The records on the South Fork of Tule River began in 1910. The record is not complete for all parts of the period since 1910. The discharges are given in Table 4 in which the missing records which have been supplied by estimates based on comparison with the record of the main Tule River are indicated.

For the eleven years of record the mean annual discharge has been 28,750 acre-feet. The maximum measured run-off has been 87,000 acre-feet in 1916 and the minimum 9040 acre-feet in 1913.

In order to estimate the run-off on the South Fork over a longer period than that covered by the record, the recorded discharges on the South Fork were plotted against the discharge of the main Tule River. From the relationship indicated the discharges for previous years were estimated by comparison with the measured or estimated discharges on the main Tule River.

For the period 1890 to 1921, the mean annual discharge of the South Fork of Tule River, as estimated on the above basis, appears to have been 29,000 acre-feet with variations from 8000 to 95,000 acre-feet in different years.

The gaging station on the South Fork is several miles above its entrance into the main stream. The gaging station on the main stream is also above the base of the hills. While the portion of the drainage area from which the run-off is not measured furnishes a relatively small part of the total discharge it has been estimated for purposes of completeness. The results are shown with those for all areas in Table 6. In minimum years the discharge is negligible; in wet years it is estimated that as much as 9000 acre-feet of run-off may occur with an average of about 2000 acre-feet per year. The estimate for this lower area was based on the same methods that were used for other small unmeasured areas as explained later.

TABLE 4.

**Runoff of South Fork of Tule River Near Porterville. Drainage Area, 76 Square Miles. Record of U. S. Geological Survey Except as Noted.**

| Month | Discharge in total acre-feet | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1910-11 | 1911-12 | 1912-13 | 1913-14 | 1914-15 | 1915-16 | 1916-17 | 1917-18 | 1918-19 | 1919-20 | 1920-21 |
| October | 302 | 440 | 285 | 132 | 326 | 264 | 1,680 | 330 | 470 | 311 | 430 |
| November | 780 | 509 | 546 | 584 | 405 | 738 | *750 | 550 | 750 | 370 | 893 |
| December | 916 | 719 | 555 | 1,760 | 818 | 2,340 | *1,000 | 607 | 1,030 | 2,210 | 1,540 |
| January | 3,210 | 615 | 941 | 15,300 | 1,440 | 21,600 | 2,800 | 715 | 756 | 568 | 1,840 |
| February | 2,850 | 555 | 944 | 4,670 | 2,850 | 12,500 | *4,000 | 1,524 | 1,790 | 863 | 2,780 |
| March | 6,760 | 1,640 | 1,650 | 4,090 | 3,190 | 18,800 | 5,200 | 3,204 | 4,480 | 6,390 | 4,610 |
| April | 4,560 | 4,150 | 1,830 | 5,360 | 4,320 | 13,000 | *5,000 | 2,012 | 4,590 | 9,340 | 3,270 |
| May | 2,860 | 3,740 | 1,040 | 4,110 | 14,300 | 9,900 | *3,500 | *1,200 | 3,140 | 3,830 | 3,330 |
| June | 1,480 | 1,830 | 684 | 1,570 | 4,250 | 4,630 | 3,720 | *500 | 940 | 1,970 | 2,150 |
| July | 481 | 595 | 303 | 658 | 1,380 | 1,920 | 1,340 | 114 | 233 | 726 | 615 |
| August | 196 | 210 | 112 | 151 | 435 | 849 | 586 | 46 | 133 | 322 | 242 |
| September | 162 | 158 | 152 | 165 | 256 | 496 | 270 | 209 | 135 | 417 | 210 |
| Totals | 24,600 | 15,200 | 9,040 | 38,000 | 34,000 | 87,000 | 29,846 | 11,011 | 18,447 | 27,317 | 21,910 |

*Records incomplete; discharge estimated by comparison with Main Tule River in connection with these investigations.

### Summary for Entire Tule River Drainage Area.

A summary of the run-off for the different parts of the Tule River drainage area gives a total estimated long time mean annual run-off of 137,000 acre-feet with a minimum of 36,000 acre-feet and a miximum of 439,000 acre-feet. For the thirty-two years covered by the records and estimates, there are three years in which the run-off exceeds twice the mean. The run-off in each of the last four years has been less than normal, the average for the four years being 59 per cent of normal. This is the longest period during the thirty-two years in which no year had a run-off at least equal to the mean.

### Run-off of Smaller Drainage Areas in Tulare County.

In addition to Kaweah and Tule rivers there are Deer and White creeks and various other small drainage areas which discharge their run-off into the valley portion of Tulare County. Except for Deer and White creeks the discharge of these streams has not been measured. In order to make an estimate of the total water supply of the area some basis of estimating the discharge of such drainage areas is required.

The method used has consisted of an estimate of the precipitation at different elevations on each drainage area with an estimate of the run-off resulting from such precipitation. The details of the method are discussed in Bulletin 9 of this office entitled "Water Resources of Kern River and Adjacent Streams and Their Utilization." The curves used for Tulare County are as shown in Figs. 2 and 3.

Most of the precipitation records available are for relative low elevations. Precipitation increases with elevation; the rate at which such increase occurs appears to be as indicated in Fig. 2, based on such records as are available.

The relationship of rainfall and run-off as shown in Fig. 3 is also based on such records as are available. The curves for drainage areas for which the discharge has been measured were developed by trial. The curves for unmeasured areas were then estimated by comparison of the character of the drainage areas.

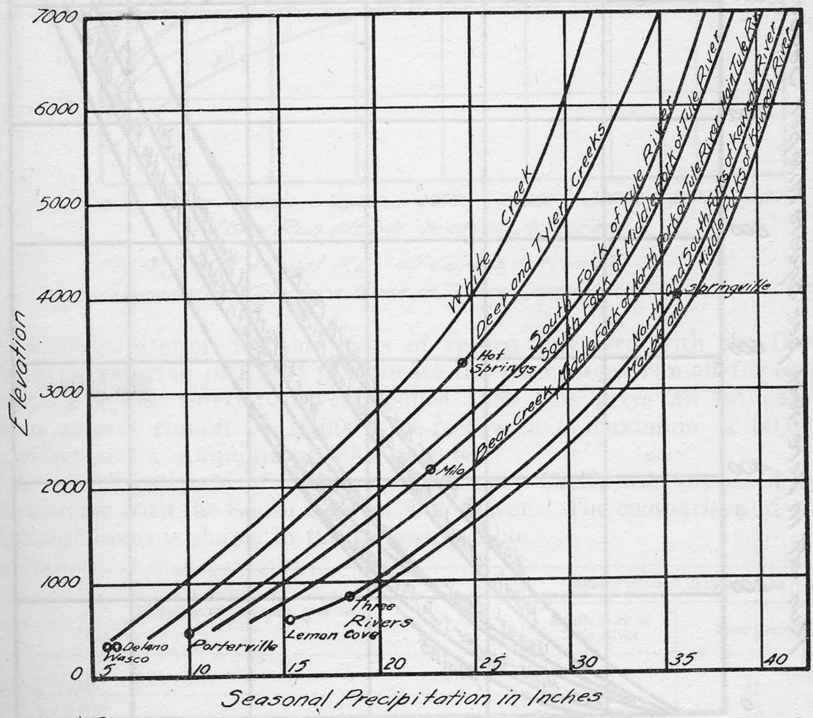


Fig. 2. Relation of Precipitation and Elevation for Tulare County Streams

While such a method of estimation can not be exact it is thought to represent the probable run-off within reasonable limits. The figures given are thought to be fully as large as the actual run-off.

**Deer Creek.**

There is a record for the upper 17 miles of drainage area at Hot Springs from 1911 to date, one for 15 square miles on Tyler Creek for 1911-13 and one for 1919 to date for 76 square miles of drainage as secured by Mr. Irving Althouse, engineer for the Terra Bella Irrigation District.

The Tyler Creek records are classed as poor by the U. S. Geological Survey. The Hot Springs record on Deer Creek is generally fairly consistent; the 1920-21 record, however, appears excessive in comparison with other adjacent streams. The elevation, rainfall, and run-off relationships were developed for Deer Creek above Hot Springs as shown in Figs. 2 and 3. These agree fairly well with the records. These curves were used for estimating the long time run-off of the remaining upper drainage area on Tyler Creek. For the drainage

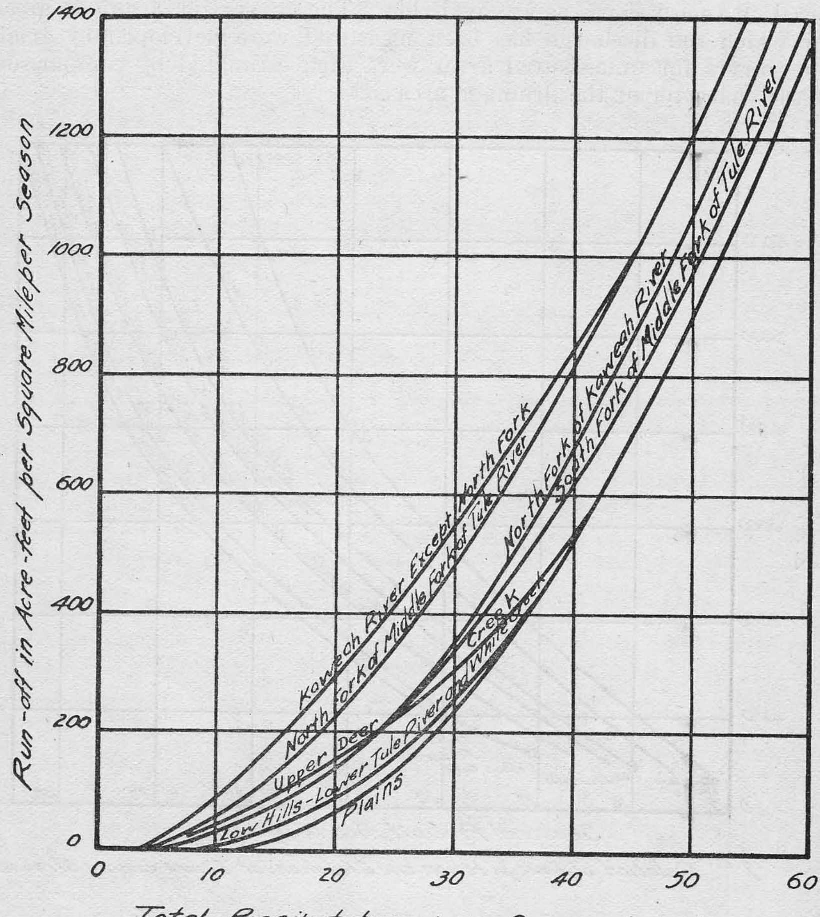


Fig. 3. Relation of Precipitation and Run-off for Tulare County Drainage Areas

area below Hot Springs the rainfall run-off records for 'plains' conditions was used. From the parts, the run-off of the total drainage area was computed giving the curve shown in Fig. 4.

The run-off curve for the entire Deer Creek drainage area given in Fig. 4 gives results averaging about 18 per cent greater for 1920 and

1921 than the measurements made by the Terra Bella Irrigation District. The conditions in both of these years were such as to produce probably less than the average run-off from the precipitation. The run-off curve used appears, however, to give results as great, if not somewhat greater, than would probably be shown by a long direct record of run-off.

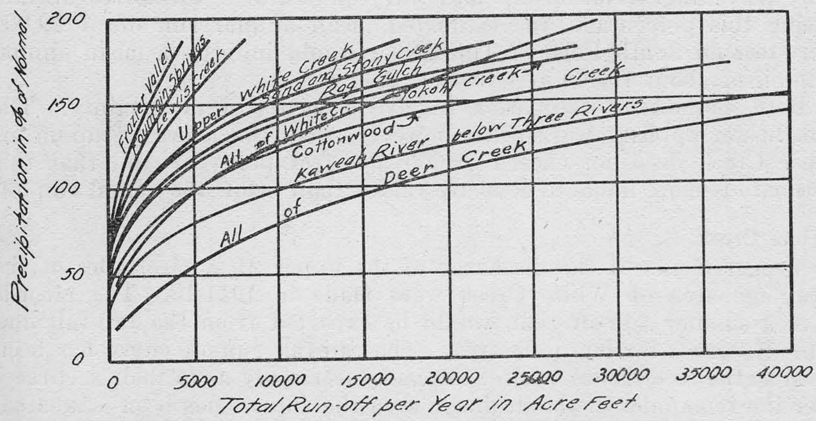


Fig. 4. Total Annual Run-off Curves for Small Unmeasured Drainage Areas in Tulare County

The precipitation for the years of record was used with the Deer Creek curve given in Fig. 4 to estimate the Deer Creek run-off for each year. For the thirty-two years since 1890 this gives an estimated mean annual run-off of 19,000 acre-feet with a maximum of 50,000 acre-feet and a minimum of 5000 acre-feet.

A second estimate of the run-off of Deer Creek was prepared by comparison with the South Fork of Tule River. The comparison of the drainage areas is shown in the following table.

| Elevation of drainage, acre-feet | Square miles of drainage area | |
|---|---|---|
| | South Fork of Tule River | Deer Creek |
| Below 2,000 | 4 | 41 |
| 2,000 to 3,000 | 8 | 15 |
| 3,000 to 4,000 | 20 | 21 |
| 4,000 to 5,000 | 15 | 12 |
| 5,000 to 6,000 | 12 | 10 |
| Over 6,000 | 17 | 11 |
| Totals | 76 | 110 |
| Total above 2,000 | 72 | 69 |

Some of the South Fork drainage area exceeds 8000 feet in altitude. While the total areas above 2000 feet elevation are closely similar, the South Fork has 44 square miles over 4000 feet elevation as compared with 33 square miles for Deer Creek. The rainfall curves, Fig. 2, indicate that the South Fork will receive about one-eighth more precipitation than Deer Creek due to its location farther north.

The recorded run-off of South Fork of Tule River for 1920 and 1921 is 27,300 and 21,900 acre-feet. The measured run-off of Deer Creek was 14,100 and 11,400 acre-feet for these years. This equals 52 per cent of the estimated run-off of South Fork in each of the two years. The percentage relationship may vary in years of excessive rainfall. Using this percentage, the estimated mean annual run-off of 29,000 acre-feet on South Fork of Tule River would indicate a mean annual run-off of about 15,000 acre-feet on Deer Creek.

Both methods of estimation involve elements of uncertainty. The conclusion appears warranted, however, that the average run-off of Deer Creek does not exceed 19,000 acre-feet per year and that this estimate is more liable to be above rather than below the actual run-off.

**White Creek.**

Measurements of the discharge of the upper 21 square miles of the drainage area of White Creek were made in 1911-13. The records give a smaller run-off than would be expected from the rainfall and run-off curves for low hills area. The rainfall run-off curve has been used as the records are subject to some uncertainty as to their accuracy. For the remainder of the drainage area the run-off has been estimated, using the rainfall run-off curve for the plains area. The resulting curves are shown in Figs. 2, 3 and 4.

The estimated mean annual run-off for the 77 square miles below the gaging station is 2500 acre-feet and that for the area above the gaging station is 3800 acre-feet, a total for the whole stream of 6300 acre-feet. All of this run-off can be considered as reaching the ground water as the flow is absorbed from the creek channel, the distance to which the flow reaches varying with the run-off in different years. The estimated total run-off varies from 1500 to 26,000 acre-feet in different years. The estimated average run-off for the five years 1917 to 1921 is 4000 acre-feet.

White Creek drains a narrow strip of area extending directly back to the divide of the Kern River drainage area. It does not extend along this divide to the same extent as Deer Creek and consequently has a smaller drainage area at the higher elevations. The run-off of White Creek appears to be less, relatively, than that of Deer Creek.

In 1921, the rains in May resulted in flow as far as the Southern Pacific Railroad south of Ducor, a discharge of 12 second-feet being used in irrigating grain at that point on May 23. The flow rapidly decreased and receded up the creek channel within a few days. The flow at the east line of township 27 east began early in May and continued at a general average of about four second-feet until the middle of June. About two miles further upstream the flow began early in April and continued to the end of June. In 1909 it is stated that water reached the east line of township 24 east. In 1919, the water is reported to have reached Sec. 7, T. 24 S., R. 26 E., and in 1920, Sec. 11, T. 24 S., R. 26 E. The channel in this portion of its length has been eroded into the older sediments and has not built a more recent delta until the areas further west are reached.

## RUN-OFF OF MINOR DRAINAGE AREAS IN TULARE COUNTY.

In this discussion are included the small streams and the portions of the main streams below the gaging stations. While small in amount and uncertain in occurrence some attempt to estimate quantitatively the run-off of these drainage areas appears to be desirable. Such an estimate is difficult to make due to the absence of direct records. The estimates given are those for the total quantity of water which would be expected to be discharged from each area. In some cases locations

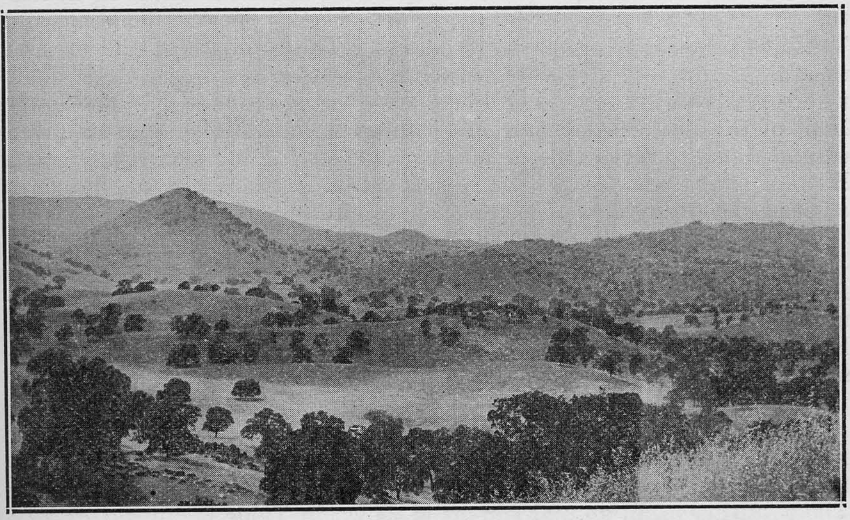

PLATE II, Figure A. General View of Drainage Area of Yokohl Creek.

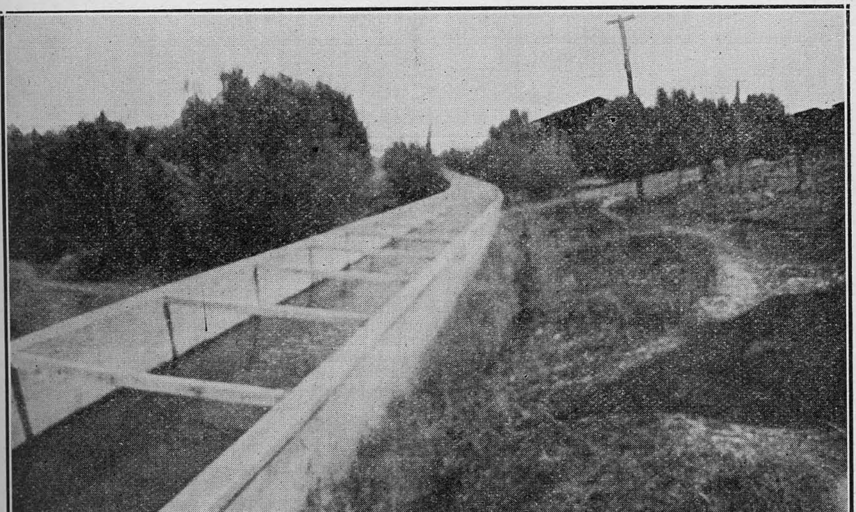

PLATE II, Figure B. Concrete Flume of Lindsay-Strathmore Irrigation District.

for measuring the quantities given probably would be difficult to find as the channels probably lose water within the drainage areas. The figures given are the total amount of water which it is estimated the drainage areas contribute to the ground water or to direct diversion. While there is no basis for testing the accuracy of the estimates it is thought that they are greater rather than less than the actual run-off.

The smaller drainage areas were taken from the 1919 Forest Service map of the Sequoia National Forest, having a scale of one-fourth inch to the mile. This map shows streams but not elevations. As far as the area covered permitted these were checked by the Kaweah and Tehipite U. S. G. S. quadrangle sheets. The estimate of the area in each thousand feet of elevation was made from the U. S. G. S. sheet where available and by general estimate for the remainder. The lower limit of the area contributing any run-off is indefinite, the areas given extend down to elevations of 500 to 600 feet for most of the streams. Run-off from areas below 2000 feet elevation is practically negligible in amount except in years of excessive precipitation.

The drainage areas are given in Table 5.

The estimated precipitation was taken for the different elevations from the precipitation and elevation curves shown in Fig. 2. The estimated run-off was taken from the rainfall run-off curves shown in Fig. 3. The 'plains' curve was used for the lower drainage areas modified somewhat to take into account local factors in the probable variation of rainfall with elevation. The curves showing the resulting relation between the estimated run-off and the rainfall in per cent of normal are shown in Fig. 4. These curves are used with the precipitation for each year to give the estimated total run-off for that year. The resulting mean annual run-off is shown in Table 6.

TABLE 5.

Drainage Areas of Foot Hills Streams, Tulare County.

| Stream | Drainage area in square miles | Elevation of drainage area |
|---|---|---|
| Sand and Storey creeks east of Orosi | 50 | All estimated as less than 2000 feet elevation. No map available. |
| Cottonwood Creek above Woodlake | 87 | Estimated as 57 square miles 2000 to 3000 feet; 10 square miles 3000 to 4000 feet. |
| Limekiln Creek | 87 | Estimated as 40 square miles under 2000 feet; 25 square miles 2000 to 3000 feet; 15 square miles 3000 to 4000 feet; 5 square miles 4000 to 5000 feet; and 2 square miles over 5000 feet. |
| Greasy Creek and Kaweah River on north side below Three Rivers | 15 | 8 square miles over 2000 feet elevation—maximum, 3500 feet. |
| Kaweah River on south side below Three Rivers including Horse Creek | 37 | Varies from 600 to 3000 feet; 15 square miles over 2000 feet. |
| Yokohl Creek | 52 | 27 square miles under 2000 feet; 12 square miles 2000 to 3000 feet; 8 square miles 3000 to 4000 feet; 5 square miles 4000 to 5000 feet. |
| Lewis Creek | 32 | 5 square miles over 2000 feet; rest down to 700 feet. |
| Frazier Valley | 15 | All under 2000 feet. |
| Tule River below Success and South Fork below gaging station | 50 | 10 square miles over 2000 feet. |
| Deer Creek below Terra Bella Irrigation district station | 27 | All under 2000 feet. |
| Fountain Springs area | 36 | All under 2000 feet. |
| Rag Gulch | 130 | 72 square miles under 2000 feet; 50 square miles 2000 to 3000 feet; 5 square miles 3000 to 4000 feet; 3 square miles over 4000 feet. |
| White Creek below gaging station | 77 | 49 square miles under 2000 feet; 25 square miles 2000 to 3000 feet; 3 square miles 3000 to 4000 feet. |

For all drainage areas shown the estimated mean annual run-off is 39,000 acre-feet for the 700 square miles included. Of this about one-third is into Kaweah River below the Three Rivers gaging station, the largest part of this coming from Limekiln Creek which has some drainage area of 6000 feet elevation in Grouse Meadows. The upper portions of the drainage area of Limekiln Creek should have a rate of run-off similar to areas of equal elevation on the North Fork of the Kaweah. Cottonwood Creek has a drainage area similar in size to that of Limekiln Creek but of lower average elevation. The general topography is somewhat less rugged and a smaller rate of run-off is to be expected. This is indicated by conditions in 1920-21 when Limekiln Creek flowed during the winter and during the rain in May, 1921, while no surface flow reached the lower portions of Cottonwood Creek during this period.

The other lower tributaries of the Kaweah River are small and of limited discharge, flowing only after fairly heavy storms.

Yokohl Creek, while it may be considered as a tributary to Kaweah River, enters the valley lands before reaching the river and is practically a separate stream. The upper portion of the drainage area is fairly rugged with some bare granite, the lower hills are rounded and there are bottom areas along the creek in which the flow may be largely absorbed. In some portions willows and grass indicate some ground water supply. The upper one-half of the drainage area probably supplies over three-fourths of the run-off. The total run-off appears to reach the ground water along its course or in the adjacent areas in the valley.

TABLE 6.

Estimated Run-off of Minor Drainage Areas in Tulare County.

| Drainage area | Drainage area, square miles | Estimated mean annual runoff total, acre-feet | Estimated mean annual runoff, acre-feet per square mile |
|---|---|---|---|
| Sand and Storey creeks | 50 | 3,000 | 60 |
| Cottonwood Creek | 87 | 7,000 | 80 |
| Kaweah River below gaging station, including Limekiln Creek | 142 | 13,000 | 92 |
| Yokohl Creek | 55 | 4,000 | 73 |
| Lewis Creek | 22 | 1,500 | 68 |
| Frazier Valley | 22 | 500 | 23 |
| Tule River below gaging stations | 57 | 2,000 | 35 |
| Dear Creek below gaging station | 27 | 800 | 30 |
| Fountain Springs | 36 | 1,000 | 28 |
| White Creek below gaging station | 77 | 2,500 | 32 |
| Rag Gulch | 130 | 3,500 | 27 |
| Totals | 705 | 38,800 | 55 |

Lewis Creek has a small drainage area, all of which is less than 3000 feet in elevation. There is a dam with wells on this creek, the water being taken to lower lands. The lands served are now a part of the Lindsay-Strathmore Irrigation District. Lewis Creek is reported to flow only following relatively heavy rains such as storms giving a precipitation of two inches or over.

Frazier Valley and Fountain Springs areas are broad, flat land from which the surface run-off is negligible in amount but in which there may be minor absorption in the channels of local washes.

The lower Tule River areas are largely on the South Fork below the gaging station. The estimate used indicates that such run-off is less than 2 per cent of that measured at the gaging stations.

Deer Creek below the gaging station is a low area which probably contributes run-off only at times of excessive precipitation. The average amount may be as estimated.

White Creek below the gaging station is a rolling area two-thirds of which is below 2000 feet elevation. An erratic run-off of about the amount given is to be expected.

Rag Gulch has a rather extensive rolling drainage area of generally low elevation. In many years its run-off does not reach the valley as surface flow. This drainage is the only definite area tributary to the lands along the Tulare-Kern County line and its uncertain and limited discharge indicates the lack of direct sources of ground water replenishment in this area.

## TOTAL WATER SUPPLY FROM DRAINAGE AREAS DISCHARGING INTO TULARE COUNTY.

The preceeding discussions of the run-off of each drainage area may be summarized as follows:

**Total Mean Annual Run-off of Drainage Areas Discharging Into Tulare County.**

| Streams from North to South | Acre-feet |
|---|---|
| Sand and Storey Creeks | 3,000 |
| Cottonwood Creek | 7,000 |
| Kaweah River, entire drainage area | 451,000 |
| Yokohl Creek | 4,000 |
| Lewis Creek | 1,500 |
| Frazier Valley | 500 |
| Tule River, entire drainage area | 137,000 |
| Deer Creek | 18,900 |
| Fountain Springs | 1,000 |
| White Creek | 6,300 |
| Rag Gulch | 3,500 |
| Total | 633,700 |

The total given, 634,000 acre-feet, represents the total water supply which, from the data now available, appears to be the mean annual water supply from these areas. The records are considered adequate to furnish a basis for determining with practical accuracy the actual run-off. It is not probable that longer periods of measurement will show mean discharges materially different from the figure given. The total represents the water which is available for use in the portions of Tulare County dependent on this supply for their irrigation. Not all of this discharge is now used or can be used due to variations in its amount in different years. It is not evenly distributed over the areas requiring irrigation. Its utilization depends on the detailed conditions for storing in reservoirs, diversion by canals, or absorption as ground water all of which vary with different streams. The utilization of these water supplies is discussed separately for the areas dependent on the separate sources of supply.

As later discussed the average surface outflow of the Kaweah River is estimated to be 70,000 acre-feet per year and of the Tule River 17,000 acre-feet per year. Deducting these amounts from the total inflow of 634,000 acre-feet gives a mean annual water supply under present conditions of development for the lands dependent on these water supplies of 547,000 acre-feet.

## SURFACE OUTFLOW FROM VALLEY AREAS.

The preceding discussions have covered the water supply entering the irrigable areas covered by this report. Not all of such flow is retained within the area. At times of flood a part of the run-off passes across the valley areas and enters Tulare Lake. The following discussion relates to the surface flow which passes across the valley areas. Questions regarding the escape from these areas of ground water supplies are discussed later in Chapter IV.

Of the streams entering the valley lands in Tulare County only Kaweah and Tule rivers contribute any material flow to Tulare Lake. While no direct records for Deer and White creeks are available for flood years the indirect data does not indicate that any such excess run-off reaches Tulare Lake. The records available on Kaweah and Tule River cover the seasons of 1916, 1917, 1920 and 1921.

### Outflow from Kaweah Delta.

Excess run-off from Kaweah River may reach Tulare Lake through two groups of channels. The flow of the river is divided at McKay Point between the St. Johns and Kaweah rivers. Water flowing through St. Johns River without being diverted enters Cross Creek near Goshen and finally reaches Tulare Lake. Water not diverted from the Kaweah River channels may reach Tulare Lake by either entering Cross Creek or by mingling with Tule River water in Elk Bayou. Outflow from the delta occurs more generally through Cross Creek than through Elk Bayou. The latter flow is usually small in amount except in years of excessive run-off.

Water reaching Cross Creek may be used by diversion into lower canals before reaching Tulare Lake. Such diversions, however, are outside the area covered by these investigations, and do not affect what is regarded as the delta of Kaweah River.

Records of the outflow of Kaweah and Tule rivers were kept in 1916 by the State Department of Engineering. The Kaweah River records were secured near the entrance of Cross Creek into Tulare Lake and do not include diversions from Cross Creek. The conditions for measurement were somewhat unfavorable. The records for the winter flow are incomplete. The records for Tule River were secured at the railroad crossing near Turnbull and are probably reasonably accurate. The actual records with the estimated division of the Tule River records between the two sources of its supply are given in Table 7.

**TABLE 7.**

**Records of Outflow of Kaweah and Tule Rivers in 1916, with Estimated Division of Flow Between Kaweah and Tule Rivers.**

| Months in 1916 | Total discharge of Cross Creek, acre-feet | Discharge of Kaweah River at Three Rivers, acre-feet | Total discharge to Tulare Lake through Tule River, acre-feet | Discharge of Main and South Fork of Tule River, acre-feet | Part of Tule River to Tulare Lake, estimated to have come from Elk Bayou, acre-feet | Total estimated outflow of Kaweah River, acre-feet | Per cent of Kaweah discharge reaching outflow channels | Per cent of Tule discharge reaching outflow channels | Total estimated discharge retained on Kaweah delta, acre-feet | Total estimated discharge retained on Tule delta, acre-feet |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 45,800 | 94,100 | 38,300 | 79,800 | ---------- | 45,800 | 49 | 48 | 48,000 | 41,500 |
| February | 29,000 | 61,600 | 34,500 | 45,700 | 7,500 | 36,500 | 59 | 59 | 25,000 | 18,700 |
| March | 50,800 | 108,000 | 53,100 | 70,600 | 8,100 | 58,900 | 55 | 64 | 49,000 | 25,600 |
| April | 27,600 | 127,000 | 4,860 | 51,700 | 2,400 | 30,000 | 24 | 5 | 97,000 | 49,200 |
| May | 26,000 | 145,000 | 3,000 | 43,100 | 3,000 | 29,000 | 20 | -------- | 116,000 | 43,100 |
| June | 22,800 | 131,000 | 270 | 23,130 | 300 | 23,100 | 18 | -------- | 108,000 | 23,100 |
| July | 10,500 | 59,000 | -------- | 8,130 | ---------- | 10,500 | 17 | -------- | 49,000 | 8,100 |
| Totals | 212,500 | 725,700 | 134,030 | 322,160 | 21,300 | 233,800 | 32 | 35 | 492,000 | 209,300 |

A comparison of these records for outflow from the Kaweah Delta in January with the inflow at Three Rivers shows that the outflow equals the inflow in excess of 1200 second-feet; that is, the inflow over 1200 second-feet on 14 days of the month is equal to the volume of the outflow. This is equivalent to saying that inflow up to 1200 second-feet was retained in January and that any excess passed across the delta. A similar comparison for February indicated that all inflow in excess of 450 second-feet appeared as outflow. The smaller amount retained in February can be accounted for by the heavy precipitation and January use satisfying the water requirements so that smaller diversions were made. For March the similar figures indicated that the outflow equaled the inflow in excess of 800 second-feet; for April, 1600 second-feet; for May, 1900 second-feet; for June, 1800 second-feet; and for July, 900 second-feet. The actual outflow during July is thought to have been delayed flow from June rather than direct outflow of July run-off.

The flow in Cross Creek at the bridge on the main Hanford road was measured by Mr. H. H. Holley during 1917. The record has been made available for use in this report. The measurements give directly the actual outflow from the Kaweah Delta below the Lakeside Canal. The records cover May and June. In May the discharge was 5000 acre-feet and in June 21,930 acre-feet. The outflow in May equalled the flow at Three Rivers in excess of 1800 second-feet, in June, in excess of 1750 second-feet. In 1917, the run-off was equal to about the average for the Kaweah River.

No direct records are available for 1918 and 1919. Indirect data indicates that there was little if any outflow in those years. The inflow was less than normal.

In 1920 water from Kings River was diverted into Cross Creek through the Lake Lands canal. A record of the diversions of the Corcoran District was secured under the direction of Mr. Max Enderlein. The difference between the Kings River diversion of the Lake Lands canal and of the diversions of the Corcoran District is considered to be Kaweah River water. On this basis in May the Kaweah River outflow would have been approximately equal to the flow at Three

## CHAPTER VIII.

# STORAGE SITES ON TULE RIVER.

Storage on the Tule River has not been as extensively investigated in the past as it has on the other adjacent rivers. In the report by Mr. A. E. Chandler in 1901 on Duty of Water in Tule River Basin, published as a part of Bulletin 119 of the Office of Experiment Stations of the United States Department of Agriculture comments on two proposed sites are given. These sites are at Pleasant Valley on the main stream and just below the Indian Reservation on the South Fork. The possibility of construction of the Pleasant Valley site has been under some general discussion at various times without any definite steps looking toward its development being taken. Plans for the use of the site on the South Fork have been made by the South Tule Independent Ditch Company for a capacity of about 500 acre-feet, construction being contemplated as soon as the financing of the work can be arranged.

The status of present water rights on Tule River, as previously discussed, indicates that there would be considerable difficulty in adjusting present diversions so as to enable any large portion of the run-off in normal years to be stored. It may well be that it would be to the advantage of at least some ditches to store a portion of the water they now receive in the earlier portion of the season for use in the late summer months but the extent of such storage is uncertain and the rearrangement of the present system of diversion of the river would be complicated. The discussion of the run-off in excess of present diversions shows such excess to occur in only occasional years. Its storage as a basis for a dependable annual supply would require a large capacity in proportion to the average annual use obtained from it and would only be economical in case storage sites having a very low cost per unit of capacity were available.

The desirability of extensive storage on Tule River involves considerations both of present use of the flow and of the availability of sites. The feasibility of storage can not be settled without fairly definite data on capacity and probable cost of available sites. For this reason it was considered advisable to make surveys and prepare cost estimates for the regulation of Tule River by storage although preliminary investigations indicated that the conclusions would be unfavorable.

Surveys were made of both the Pleasant Valley and the South Fork sites. On the South Fork the survey of the South Tule Independent Ditch was utilized and extended to cover a larger capacity. As the two sites are dependent on different sources of water supply they are most conveniently discussed separately. A general reconnaissance of the drainage areas of the tributaries of the main stream failed to reveal other desirable storage sites. The grades of the streams are generally steep without valley areas closed by narrow dam sites. On the Middle Fork there is a possible site below the mouth of Bear Creek; a preliminary estimate of cost and capacity indicated that the cost would be excessive and no surveys were made.

## PLEASANT VALLEY RESERVOIR SITE ON MAIN TULE RIVER.

Map 6 shows the topography of this site. The details of the dam sites are shown on Fig. 14. The survey was carried to elevation 800 giving a total capacity of about 80,000 acre-feet. The capacity and area curves are shown in Fig. 15.

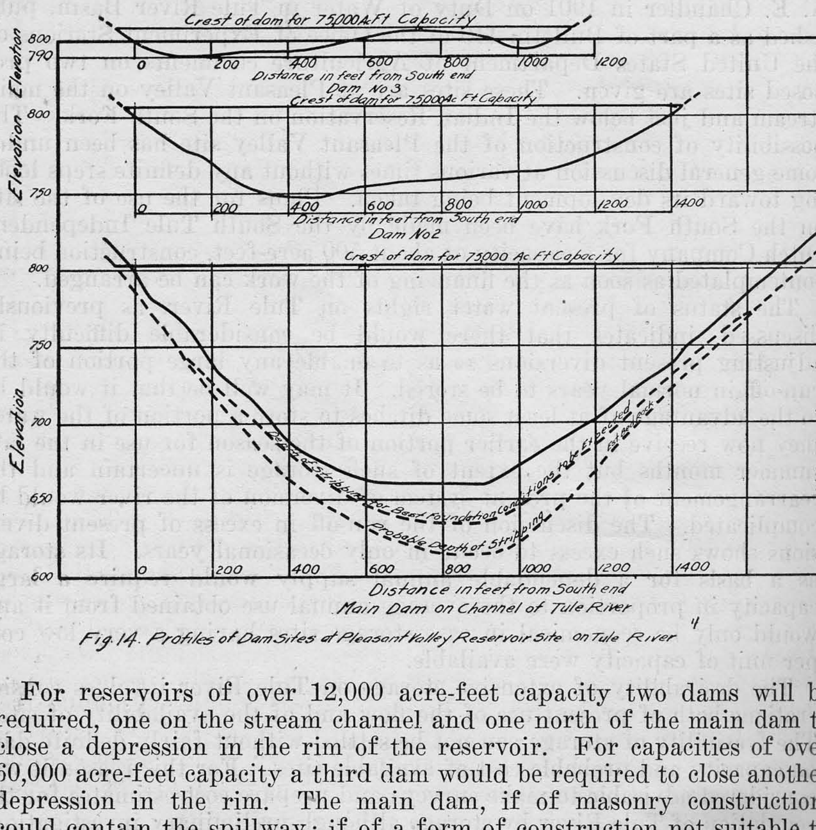


Fig. 14. Profiles of Dam Sites at Pleasant Valley Reservoir Site on Tule River

For reservoirs of over 12,000 acre-feet capacity two dams will be required, one on the stream channel and one north of the main dam to close a depression in the rim of the reservoir. For capacities of over 60,000 acre-feet capacity a third dam would be required to close another depression in the rim. The main dam, if of masonry construction, could contain the spillway; if of a form of construction not suitable to overpour, the spillway might be located at one of the depressions.

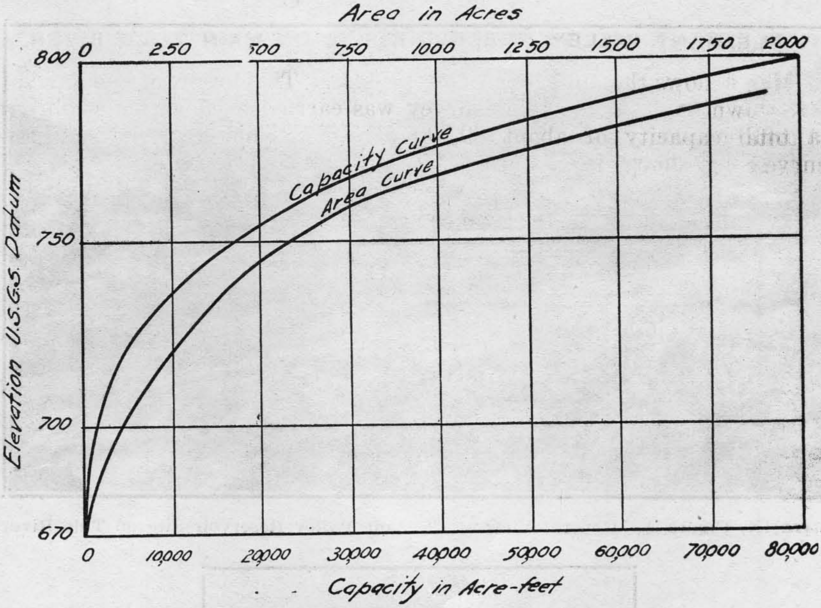


Fig. 15. Area and Capacity Curves for Pleasant Valley Reservoir Site on Main Tule River

At the main site (Plate IX, Fig. A) bed rock is not directly exposed. There are surface boulders of granitic rock both north and south of the river. Above the height of the dam on the slopes what appears to be bed rock is exposed. The depth of material over suitable bed rock on the slope is probably not excessive. There is little definite basis, however, for an estimate of the depth of bedrock at the present stream channel and across the bottom of the present low land adjoining the stream. As this low land has a width of about 400 feet the depth to bedrock in this portion of the dam would materially affect the cost of construction. The probability of recommending the use of this site was not sufficient to warrant the cost of borings at this time.

For a capacity of 80,000 acre-feet the length of crest of the main dam would be 1700 feet. For a capacity of 25,000 acre-feet it would be about 1400 feet. These lengths and the width of the valley bottom make some form of straight dam preferable to an arch type. Owing to the uncertainty as to depths of bedrock estimates of cost were prepared on three bases: (1) that no stripping would be required, (2) that stripping of the least amount considered probable would be required and (3) that stripping of an amount thought to be sufficient to cover any probable depth of bedrock would be required. The first assumption is obviously more favorable than can occur, the second is most favorable that can be expected and the third should include the least favorable conditions that would be expected. The depths of stripping given were based on examinations of surface conditions at the site and are shown in Fig. 14.

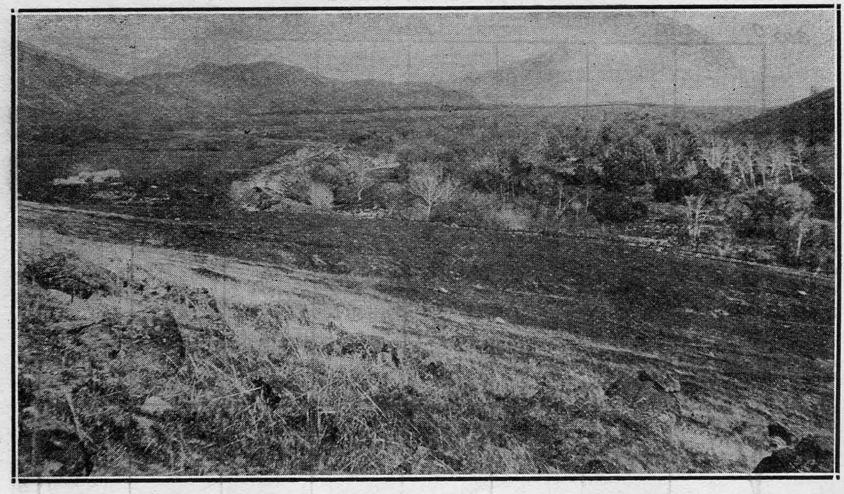

PLATE IX, Figure A. General View of Pleasant Valley Reservoir Site on Tule River.

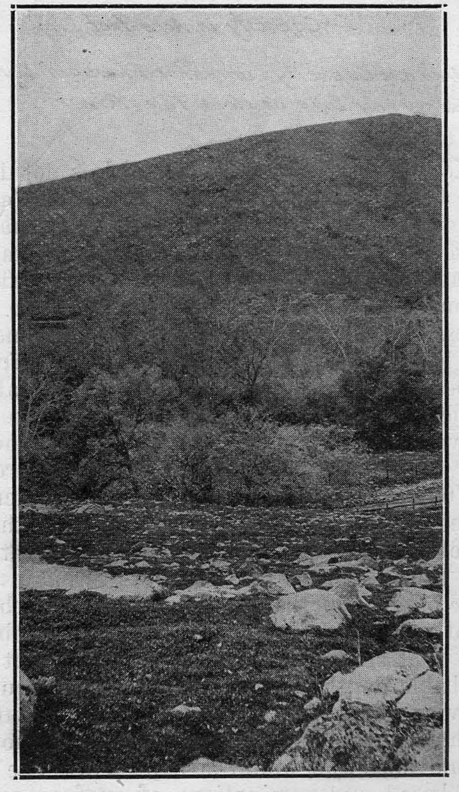

PLATE IX, Figure B. Looking Across Main Dam Site From South End at Pleasant Valley Reservoir Site on Tule River.

Cost estimates for the different assumptions regarding foundation conditions and for different capacities were made from which the curves shown in Fig. 16 have been plotted. The estimated costs were based on unit costs of $8 per cubic yard for masonry and $2 per cubic yard for stripping with items for paving, outlet gates, control of the river during construction, relocation of roads and railroad, and purchase of lands required. An addition of 15 per cent to the estimated cost of the above items was made to cover engineering and contingencies. The estimated cost of the masonry equals about 60 per cent of the estimated total cost.

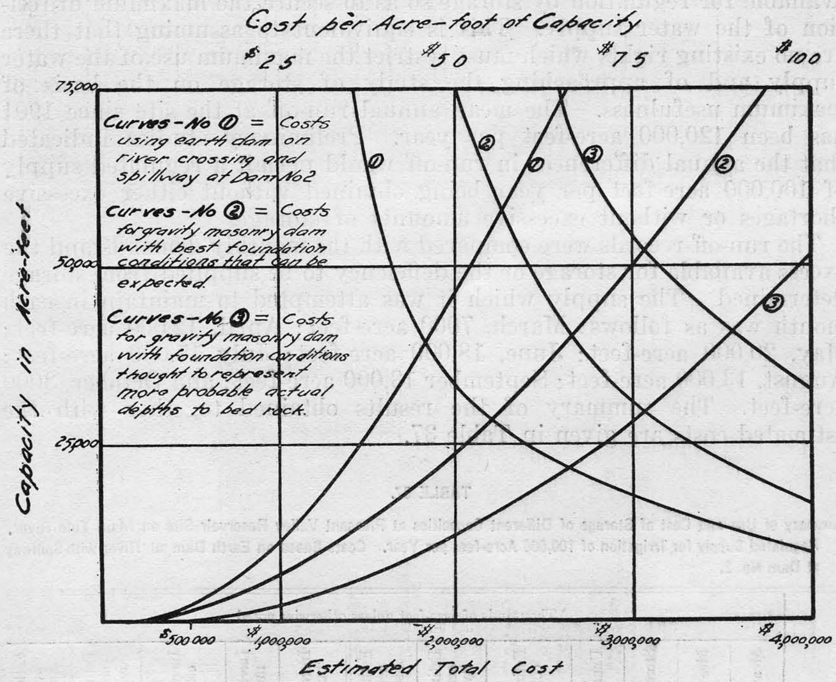


Fig. 16 Estimated Costs of Storage at Pleasant Valley Reservoir Site on Tule River.

The estimates as plotted in Fig. 16 show the cost of a masonry dam at this site to be relatively high per unit of capacity. Under the best foundation conditions to be expected the cost for the masonry dam at the largest capacity would $50 per acre-foot and might be $65 per acre-foot with foundation conditions which might be found to exist. For smaller capacities the unit costs are correspondingly greater.

Estimates were also made for an earth dam across the present stream channel with spillway at one of the other two dams depending on the height of the dam. Provision for puddled cut-off trenches and for the grouting in the foundation of the main dam were made. The spillway would require concrete construction to prevent cutting back and would be more expensive and less desirable than an overpour at the main dam.

An estimated cost of the earthwork of $0.60 per cubic yard was used. The material required in part at least would have to be brought from areas within the reservoir site. The estimated costs are also plotted in Fig. 16. These costs are lower than those of any masonry dam that could probably be built at this site although generally the type of construction would be less desirable than a masonry dam. In the following discussion of the possible use of this reservoir site the estimated cost for the earth dam has been used.

In order to determine the use which might be secured from such a reservoir it was assumed that the full flow of the Tule River was available for regulation by storage so as to secure the maximum utilization of the water supply. This is equivalent to assuming that there are no existing rights which must restrict the maximum use of the water supply and of approaching the study of storage on the basis of maximum usefulness. The mean annual run-off at the site since 1901 has been 120,000 acre-feet per year. Preliminary studies indicated that the annual differences in run-off would permit a regulated supply of 100,000 acre-feet per year being obtained without either excessive shortages or without excessive amounts of storage.

The run-off records were compared with the monthly demands and the excess available for storage or the deficiency to be supplied from storage determined. The supply which it was attempted to maintain in each month was as follows: March, 7000 acre-feet; April, 12,000 acre-feet; May, 20,000 acre-feet; June, 18,000 acre-feet; July 17,000 acre-feet; August, 13,000 acre-feet; September 13,000 acre-feet; and October, 3000 acre-feet. The summary of the results obtained together with the estimated costs are given in Table 37.

**TABLE 37.**

**Summary of Use and Cost of Storage of Different Capacities at Pleasant Valley Reservoir Site on Main Tule River. Regulated Supply for Irrigation of 100,000 Acre-feet per Year. Costs Based on Earth Dam at River with Spillway at Dam No. 2.**

| Acre-feet storage capacity | Thousands of acre-feet unless otherwise noted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean carry over | Mean shortage | Storage used | Unused supply | Estimated cost of construction | Estimated cost per acre-foot of capacity | Estimated cost per acre-foot of mean use | Increase in capacity built, acre-feet | Increase in mean annual use | Increase in estimated cost | Estimated cost per acre-foot of increase in capacity | Estimated cost per acre-foot of mean annual use |
| 20,000 | 0 | 31 | 18 | 51 | $1,300,000 | $65 | $72 | | | | | |
| | | | | | | | | 20,000 | 11 | $500,000 | $25 | $45 |
| 40,000 | 3 | 20 | 29 | 40 | 1,800,000 | 45 | 62 | | | | | |
| | | | | | | | | 10,000 | 3 | 250,000 | 25 | 83 |
| 50,000 | 6 | 17 | 32 | 37 | 2,050,000 | 41 | 64 | | | | | |
| | | | | | | | | 10,000 | 3 | 250,000 | 25 | 83 |
| 60,000 | 11 | 14 | 35 | 34 | 2,300,000 | 38 | 66 | | | | | |
| | | | | | | | | 20,000 | 3 | 450,000 | 22 | 150 |
| 80,000 | 21 | 11 | 38 | 31 | 2,750,000 | 34 | 72 | | | | | |

A capacity of 20,000 acre-feet is not sufficient to prevent shortages in almost all years in the supply it is attempted to maintain. A capacity of 40,000 acre-feet reduces the average shortage to 20 per cent of the regulated supply. Such shortages would have exceeded 20 per cent of the supply in nine years of the 20 years of record. A capacity of 50,000 acre-feet would have given shortages in excess of 20 per cent of the regulated supply in seven years and a capacity of 60,000 acre-feet in six years out of 20 years. A capacity of 80,000 acre-feet would have reduced the shortages by the amount of the increased capacity in only two years in the 20 years of record. Large storage capacities will not prevent shortages in series of dry years except by holding water in storage over several seasons. Shortages in 1904 and 1905 would have had to be met by storage carried forward from before 1902. Excess run-off in 1909 would have had to be held to meet the shortage in 1913. To have met the shortages of the last four years, storage would have had to have been carried forward from 1916 with a total storage capacity of 175,000 acre-feet. With the wide fluctuations occurring in the run-off in different years it is obvious that it is not feasible to completely eliminate shortages within reasonable limits of cost. For the conditions existing on the Tule River at this site it is thought that a reservoir of 50,000 acre-feet capacity is as large as would be warranted.

## STORAGE ON SOUTH FORK OF TULE RIVER.

There is a reservoir site on the South Tule River just below the Indian Reservation whose development to a capacity of 500 acre-feet is planned by the South Tule Independent Ditch Company. Such development would permit this company to hold run-off in the earlier portions of the season for use in the later portions.

This site also appears to be the most favorable one on the South Fork for larger storage capacities. Within the Indian Reservation the grade of the stream becomes steeper. Below this site there are other locations at which storage might be constructed. Preliminary investigations indicated that such sites would have less favorable costs and no greater capacities than the site of the South Tule Independent Ditch Company and no actual surveys of other sites were made.

In order to determine the probable costs and capacities of the South Tule Independent Ditch Company site the survey made for the canal company by Mr. G. B. Sturgeon was extended to a capacity of 5000 acre-feet. The topography is shown on Map 7 and the capacity curve in Fig. 17. This capacity would require a dam of about 100 feet in height. At this elevation the dam site begins to lengthen so that the costs of larger capacities would be increased.

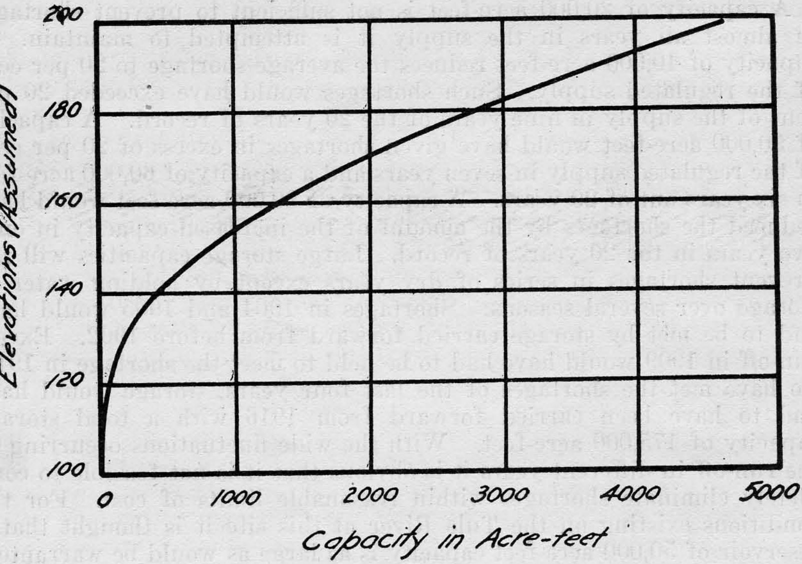


Fig. 17—Capacity Curve for Reservoir Site on South Fork of Tule River

The mean annual run-off of the South Fork of Tule River at this point has been estimated as 29,000 acre-feet. A storage capacity of 5000 acre-feet will not control this run-off and make it available for irrigation at the times needed. Such a reservoir, however, when operated in conjunction with one on the main Tule River at Pleasant Valley could be used to regulate both streams.

The dam site is located about one-half mile below the Indian Reservation boundary; for the capacities given some land within the reservation would be flooded. The exact location of the dam would be determined by its height; the formation is generally granitic with contact with schists of various textures. The depth to bedrock is probably small and the character of the rock satisfactory at all locations.

The cross sections at the various dam sites available are such that a single arch dam would give lower costs. For the 5000 acre-foot capacity a single arch dam with a radius of 500 feet, a crest length of 900 feet, a maximum height of 110 feet has been estimated to cost $535,000 or $107 per acre-foot of capacity. This is a relatively high unit cost. For smaller capacities the cost per acre-foot would be larger.

With a storage capacity of 5000 acre-feet, a regulated supply of 20,000 acre-feet per year could be secured with an average shortage of 4000 acre-feet, the shortages exceeding 30 per cent of the supply in one year in four.

## COMBINATION OF PLEASANT VALLEY AND SOUTH FORK STORAGE.

As the capacity of the reservoir site on the South Fork of Tule River is less relative to the run-off than the Pleasant Valley site on the main stream, a combination of the two sources of water supply might be used to advantage. Under such a combination the flow of the South Fork could be used for direct demand as far as it is available so as to enable a larger portion of the flow of the main Tule to be held in storage at the Pleasant Valley site.

Such a combination to furnish a total regulated supply of 120,000 acre-feet per year distributed through the season to meet the estimated crop needs with 5000 acre-feet storage capacity on the South Fork and 60,000 acre-feet storage capacity at Pleasant Valley was studied. The summary of the results is shown in Table 38. The monthly discharges for the South Fork prior to 1910 were estimated by comparison with the main Tule River.

**TABLE 38.**

**Summary of Use of Storage on Main Tule and on South Fork for Regulation of Whole Stream. Annual irrigation supply of 120,000 acre-feet with 5,000 acre-feet of storage on South Fork and 60,000 acre-feet of storage on Main Tule.**

Thousands of acre-feet

| Year | Natural flow Main Tule | Natural flow South Fork | Used directly | | Required from storage | Available for storage | | Storage in reservoir end of season | | Storage used | | Unused flow | | Shortage in supply |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | South Fork | Main Tule | | South Fork | Main Tule | South Fork | Main Tule | South Fork | Main Tule | South Fork | Main Tule | |
| 1901-02 | 112.2 | 30.0 | 24.7 | 44.6 | 50.7 | 5.3 | 67.6 | 0 | 14.3 | 5.0 | 45.7 | .3 | 7.6 | 0 |
| 1902-03 | 111.0 | 30.0 | 20.5 | 45.4 | 54.1 | 9.5 | 65.6 | 0 | 10.9 | 5.0 | 49.1 | 4.5 | 19.9 | 0 |
| 1903-04 | 72.6 | 19.0 | 15.0 | 39.5 | 65 6 | 4.0 | 33.1 | 0 | .9 | 4.0 | 43.1 | 0 | 0 | 18.5 |
| 1904-05 | 69.2 | 19.0 | 15.3 | 47.1 | 57.6 | 3.7 | 22.1 | 0 | 0 | 3.7 | 23.0 | 0 | 0 | 30.9 |
| 1905-06 | 337.1 | 95.0 | 70.0 | 33.4 | 16 6 | 25.0 | 303.7 | 0 | 48.4 | 5.0 | 11.6 | 20.0 | 243.7 | 0 |
| 1906-07 | 154.7 | 42.0 | 32.7 | 48.8 | 38.5 | 9.3 | 105.9 | 0 | 27.3 | 5.0 | 33.5 | 4.3 | 93.5 | 0 |
| 1907-08 | 80.5 | 21.0 | 13.5 | 33.3 | 73.2 | 7.5 | 47.2 | 0 | 0 | 5.0 | 60.0 | 2.5 | 14.5 | 8.2 |
| 1908-09 | 285.6 | 75.0 | 48.0 | 43.9 | 28.1 | 27.0 | 241.7 | 0 | 37.4 | 5.0 | 23.1 | 22.0 | 181.2 | 0 |
| 1909-10 | 116.1 | 30.8 | 11.4 | 32.3 | 76.3 | 19.4 | 83.8 | 0 | 0 | 5.0 | 60.0 | 14.4 | 61.2 | 11.3 |
| 1910-11 | 121.1 | 24.8 | 17.0 | 47.0 | 56 0 | 7.8 | 74.1 | 0 | 9.0 | 5.0 | 51.0 | 2.8 | 14.1 | 0 |
| 1911-12 | 48.6 | 15.1 | 12.7 | 35.8 | 71.5 | 2.4 | 12.8 | 0 | 0 | 2.4 | 21.8 | 0 | 0 | 47.3 |
| 1912-13 | 28.9 | 9.0 | 6.0 | 23.3 | 90.7 | 3.0 | 5.6 | 0 | 0 | 3.0 | 5.6 | 0 | 0 | 82.1 |
| 1913-14 | 125.8 | 38.1 | 16.4 | 44.0 | 59.6 | 21.7 | 81.8 | 0 | 5.4 | 5.0 | 54.6 | 16.7 | 21.8 | 0 |
| 1914-15 | 102.4 | 33.9 | 28.4 | 47.7 | 44.9 | 5.5 | 54.7 | 0 | 20.1 | 5.0 | 39.9 | .5 | .1 | 0 |
| 1915-16 | 254.5 | 87.0 | 39.0 | 45.8 | 36.2 | 48.0 | 208.7 | 0 | 31.9 | 5.0 | 31.2 | 43.0 | 165.7 | 0 |
| 1916-17 | 132.7 | 29.8 | 20.5 | 57.8 | 41.7 | 8.5 | 75.7 | 0 | 23.3 | 5.0 | 36.7 | 3.5 | 47.6 | 0 |
| 1917-18 | 39.6 | 11.0 | 7.5 | 22 5 | 90.0 | 3.5 | 17.1 | 0 | 0 | 3.5 | 40.4 | 0 | 0 | 46.1 |
| 1918-19 | 57.9 | 18.3 | 14.0 | 29.5 | 76.5 | 4.3 | 28.4 | 0 | 0 | 4.3 | 28.4 | 0 | 0 | 43.8 |
| 1919-20 | 84.7 | 22.0 | 18.5 | 43.5 | 57.0 | 3.5 | 41.2 | 0 | 0 | 3.5 | 41.2 | 0 | 0 | 12.3 |
| 1920-21 | 68.1 | 18.0 | 12.4 | 39.0 | 68.6 | 5.6 | 29.1 | 0 | 0 | 5.0 | 29.1 | .6 | 0 | 34.5 |
| Mean | 120 | 33 | 22 | 40 | 58 | 11 | 80 | 0 | 11 | 4 | 36 | 7 | 44 | 18 |

This study indicates that for the 20 years covered such a supply could be maintained with an average shortage of 7 per cent. Some shortages would have occurred in one-half of the years; shortages exceeding 25 per cent of the supply would have occurred in six years out of twenty. The supply is well maintained except where two or more dry years occur in succession, for such conditions the storage capacity provided is not sufficient to furnish adequate carry-over storage from previous years.

The mean annual storage used would be 40,000 acre-feet. The total cost of the two reservoirs is estimated as $2,750,000. This estimated cost is equivalent to an average of $42 per acre-foot of total capacity or $68 per acre-foot of mean annual use.

The additional storage capacity obtained from storage at Pleasant Valley between 50,000 and 60,000 acre-feet would have been useful only four times in twenty years and the smaller capacity would be fully as economical. Increasing the capacity at the Pleasant Valley site to 80,000 acre-feet would have reduced the shortages in five years of the twenty-year period of record.

The regulation of Tule River by the use of these two reservoir sites would not make available any materially larger amounts of water than are now retained on the Tule River Delta. The excess run-off now leaving Tule River is irregular in occurrence. Some parts of this would be made available for use by such storage but no extent of storage which is economically feasible will prevent the outflow of unused water in the occasional years of abnormal run-off. The estimates previously given indicate that excessive amounts of outflow have occurred on the Tule River in only three years in the last thirty-two years. The estimated average outflow of the remaining twenty-nine years has been only 4000 acre-feet per year. In view of the large estimated cost, the complications involved in the adjustments with existing rights which would be required and the small amounts of additional water supply which could be made available, it does not appear desirable to undertake to regulate the Tule River by storage at these two sites. Such storage as may be available, such as that proposed by the South Tule Independent Ditch Company where these unfavorable factors do not apply, is desirable.

Present conditions of development on the Tule River are utilizing nearly all of the runoff of this stream. As previously discussed, present ground water draft exceeds the replenishment. It is considered that the interest of the area dependent on Tule River will be better served by an understanding of the limitations of the available water supply and by efforts directed toward the use of more of the direct run-off as it occurs with greater care in the use of the water pumped from the underground supply.

# CHAPTER IX.

# OTHER AREAS IN SOUTHERN TULARE COUNTY.

## DEER CREEK AREA.

This area includes those lands which appear to be dependent on the run-off of Deer Creek for such surface and ground waters as may be available. It lies between the Tule River and White Creek areas and extends from the foothills to the general mingled ground water of the San Joaquin Valley. Like other areas its boundaries are not definite and some mingling of the ground water from adjacent sources may occur.

The estimated mean annual run-off of Deer Creek as previously given is 19,000 acre-feet. This with the run-off of such lower hill areas as are tributary to this area, which has been estimated as not over 1000 acre-feet, gives a mean annual water supply of 20,000 acre-feet. Some of the discharge of Deer Creek is diverted in the Deer Creek Ditch and used for irrigation but the much larger part of the run-off reaches the underground water.

The results of the canvass of the area irrigated in 1921 are given in Table 39. These are divided into four areas having different distances from the upper portions of Deer Creek. The areas irrigated by the Terra Bella Irrigation District are given separately; the water supply is secured from the upper of the other three areas. Orchards are the crop of largest acreage. These consist almost wholly of citrus types grown in the upper portions. There has been a large planting of vineyards within the past two or three years.

TABLE 39.

Lands Irrigated in 1921 in Deer Creek Area. Areas in Acres.

| Crop | In township 23 S., ranges 24 and 25 E. | In townships 22 and 23 S., range 26 E. | East of west line of range 27 E., excluding Terra Bella Irrigation District | By Terra Bella Irrigation District | Total |
|---|---|---|---|---|---|
| Alfalfa | 1,592 | 1,012 | 25 | | 2,629 |
| Orchard | 120 | 252 | 2,323 | 3,023 | 5,718 |
| Vines | 945 | 2,398 | | 726 | 4,069 |
| Corn | 861 | 199 | 12 | 18 | 1,090 |
| Miscellaneous | 1,582 | 253 | 32 | 74 | 1,941 |
| Totals | 5,100 | 4,114 | 2,392 | 3,841 | 15,447 |

The data on the amount of water pumped gave an average use of 3.6 acre-feet per acre for alfalfa. This is a relatively high rate of use and is the result of less careful methods of application in areas of less lift. There is a very marked difference in the amount of water used on orchards under individual pumping plants and that within the Terra Bella Irrigation District. Where individuals have their own pumping plants available for citrus orchards the average use was found to be 3.0 acre-feet per acre. In the Terra Bella district the average use was 1.7 acre-feet per acre for citrus and 1.0 acre-feet per acre for deciduous orchards. There is less young orchard relatively under the individual plants than within the district. The average use on vineyards was 1.9 acre-feet per acre within the district and 2.1 acre-feet per acre on those under small pumping plants, the larger part of the vines in both areas having been planted less than three years. The miscellaneous crops include grain, pasture, rice and cotton. The average use was 1.3 acre-feet per acre.

In Table 40 the total draft and its effect on ground water elevations are shown. The average fluctuations are for the gross areas included in each division. The pumping draft is generally concentrated within a portion of each area with a resulting variation of the fluctuation.

**TABLE 40.**

**Areas Irrigated and Draft on Ground Water in 1921 for Areas Dependent on Deer Creek for their Water Supply for Surface Irrigation and for Pumping.**

| Area | Gross area, acres | Area irrigated by pumping, acres | Total draft, acre-feet | Draft in acre-feet per acre irrigated | Draft in acre-feet per acre of gross area | Lowering of ground water for year ending Nov. 1, 1921, feet | Rise in ground water, Nov. 1, 1920, to Feb. 1, 1921, feet |
|---|---|---|---|---|---|---|---|
| In township 23 south, ranges 24 and 25 east | 38,400 | 5,100 | 12,384 | 2.4 | 0.32 | 1.9 | +0.10 |
| In townships 22 and 23 south, range 26 east | 27,500 | 4,114 | 9,501 | 2.3 | 0.35 | 2.7 | −0.10 |
| East of west line of range 27 east, excluding Terra Bella Irrigation District | 40,000 | 2,392 | 7,468 | 3.1 | [1]0.33 | 1.25 | +0.65 |
| Terra Bella Irrigation District | --------- | 3,841 | 5,815 | 1.5 | --------- | --------- | --------- |
| Totals | 105,900 | 15,447 | 35,168 | 2.3 | 0.33 | 1.9 | 0.25 |

[1]Includes pumping by Terra Bella Irrigation District.

The total draft for the whole area is 35,000 acre-feet. This was obtained by a canvass of each individual pumping plant in which data on its discharge and period of operation were obtained as definitely as the variable field conditions would permit. In some cases of excess use there may be some return to the ground water by seepage and percolation and the figures given probably exceed the net draft on the ground water. The figures for the Terra Bella district are based on carefully kept records of the district.

In 1921 the measured run-off of Deer Creek was 11,440 acre-feet at the gaging station of the Terra Bella district. Allowing for scattered run-off below the station, the total available water supply was about 15,000 acre-feet. The estimated draft in 1921 was over twice the run-off for that year and over 50 per cent in excess of the estimated mean annual run-off available for these areas. A maintenance of the present rate of draft can only be expected to result in a continued lowering of the ground water. The recovery of the ground water during the winter months is confined mainly to the upper portion of the area. The winter fluctuations were very limited in the outer portion, the ground water standing without material change during the months of minimum draft and lowering with the draft in the irrigation season. The rate of replenishment in these outer areas appears to be very slow and the lowering for the year appears to represent about the amount of water pumped. In the upper area the pumping of the Terra Bella district is included with that of the small plants. A similar rate of average draft resulted in less lowering than in the outer areas.

The Terra Bella Irrigation District was organized in 1917 and acquired about 70 per cent of the stock of the Deer Creek Ditch. This ditch was used for the irrigation of lands along Deer Creek at such times as flow occurred. Since 1918 the proportion of the flow obtained by the district has been used to recharge the areas from which ground water is pumped by the district or to some extent for direct diversion into the canal system. Since 1918 all of the flow of Deer Creek has been diverted, as there have been no large flows in these years.

The Terra Bella district has three methods of securing water besides direct diversion at the main pumping stations. What are known as the Valley Wells, located in sections 31 and 32 of T. 22 S., R. 27 E., are the main source of supply. These wells furnished 4429 acre-feet in 1921 or about three-fourths of the total secured. There is also a filtration gallery in the stream bed in section 20, T. 22 S., R. 28 E., from which 84.4 acre-feet were obtained in 1921.

The Upper Wells in section 22, T. 22 S., R. 28 E., pump from an area adjacent to Deer Creek above the edge of the valley. These were put into operation in 1921 and supplied 308 acre-feet. An additional 360 acre-feet were secured by direct diversion from Deer Creek.

On Map 3 the amount of lowering of the ground water in 1921 is shown. This was the greatest, about six feet, in the vicinity of the valley wells of the Terra Bella district. The lowering at these wells in 1918 was fifteen feet and in 1919 and 1920 five feet in each year. A lowering of four feet occurred near Pixley in an area of heavy pumping. There was no lowering at the western end of the Deer Creek area where the draft is relatively small. Within the Terra Bella district there was a rise in much of the area. There is very little pumping from wells within the boundaries of the district.

Since 1916, the records of six wells in townships 22 and 23 south, range 26 east, show an average drop of fourteen feet, the lowering being greatest nearest the valley wells of the Terra Bella district. Other records show a lowering of twenty to twenty-five feet in the past ten to fifteen years in the areas around Earlimart and Pixley.

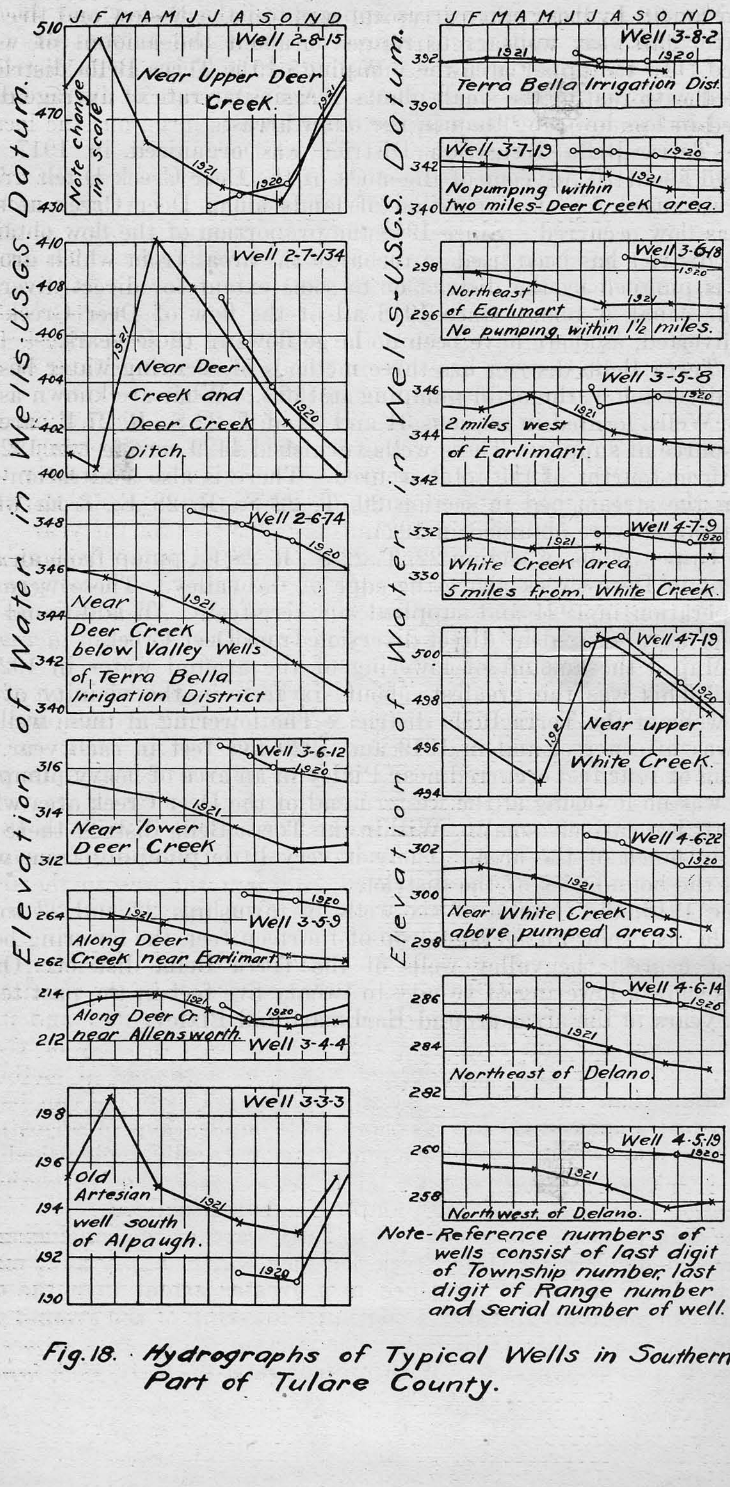


Fig. 18. Hydrographs of Typical Wells in Southern Part of Tulare County.

In Fig. 18 hydrographs of typical wells in the Deer Creek area are shown. These six wells are arranged in their order from the upper part of Deer Creek to the lower. Well 2-8-15 is adjacent to Deer Creek above the works of the Terra Bella Irrigation District in an area of heavy local pumping. The summer drawdown is large but the location results in a rapid recharge from the flow of Deer Creek.

Well 2-7-134 is adjacent to Deer Creek in the area where the ground water is affected by the water in Deer Creek Ditch. A large recharge followed by a heavy drawdown during the pumping season is shown. This well is a mile upstream from the valley wells of the Terra Bella district. The lowering from 1920 to 1921 was over one foot.

Well 2-6-74 is about 1½ miles downstream from the valley wells of the district. The water reaching the lower end of Deer Creek Ditch was not sufficient to cause any rise in this well; the conditions of draft resulted in a lowering of five feet from 1920 to 1921.

Well 3-6-12 is below all surface flow from Deer Creek in 1921 in an area of local pumping. There was a continual lowering with a total drop from 1920 to 1921 of four feet. Well 3-5-9 is near Deer Creek and between the areas of local pumping around Pixley and Earlimart. A continual lowering is shown amounting to 2.5 feet for the year. Well 3-4-4 is at the outer edge of the area considered to be dependent on Deer Creek sources for its water supply. There is less local pumping near this well and some winter recovery is shown. This is in an area of artesian pressure and the recovery is considered to be an increase of pressure rather than of volume.

Well 3-8-2 is within the Terra Bella Irrigation District in an area of limited irrigation by the district and without irrigation pumping from local wells. Very little fluctuation is shown. Well 3-7-19 is three miles west of the Terra Bella district and midway between Deer and White creeks. Although there is little local pumping in its vicinity there was a drop of over one foot from 1920 to 1921. Well 3-6-18 is in an area without local pumping. There was a continual drop amounting to nearly two feet for the year. Well 3-5-8 is to the west of the area of pumping around Earlimart and remote from any direct source of supply. A general drop is also shown.

No detailed study of storage sites on Deer Creek has been made, although there are available sites which might be used to regulate the stream flow. The data presented in regard to stream flow and its use indicates that the full run-off of this area is used directly or reaches the ground water and that storage would be a change in method of use rather than an increase in water supply. If storage can be constructed at a sufficiently low cost and the complications of adjustments with the rights of those using ground water naturally replenished from Deer Creek worked out, storage might be a less expensive method of utilization than that involving pumping as now practiced.

The data presented is considered to fully warrant the conclusion that the area dependent on Deer Creek for such water supply as it may be able to obtain has been developed to a greater extent than the water supply can maintain and that a continual lowering of the ground water in those areas further from the upper portion of the area adjacent to the creek is to be expected. With present rates of draft, such lowering will in time result in such an increase in the cost of pumping that irrigation will no longer be profitable. Every effort should be made to discourage further increase in the area irrigated in this area as any increase in the rate of draft can only result in increasing the rate of lowering and lessening the time until pumping in some parts of the area becomes unprofitable.

## WHITE CREEK AREA.

This area received the run-off of White Creek. It covers the area between the Deer Creek area and the south line of Tulare County. The western boundary has been taken at about the line of the Santa Fe Railroad. The area further west is considered to secure its ground water supply from sources to the south as well as from the east. The north and south boundaries are not definite. Those used represent the apparent general limits of the area over which recharge of ground water from White Creek may occur. It is not thought that the run-off of White Creek is sufficient to maintain the ground water over the area given.

The total mean annual run-off of White Creek has been previously estimated as 6300 acre-feet. This occurs irregularly and varies in different years from an almost negligible amount to several times the average. The larger part of the run-off appears to be absorbed in the channel which has been cut through the older sediments and may be one of the sources of the artesian supplies of the lower valley areas. The extent to which the surface run-off in recent years has reached in the stream channel has been discussed in Chapter II.

Table 41 gives the principal data secured on ground water fluctuations and use for this area. This data indicates that the present draft is resulting in a total use of the ground water about four times as large as the estimated average annual inflow, although only 11 per cent of the gross area is now using pumped water. The winter inflow into this area caused an average rise of 0.2 feet.

In the upper portion of this area, with less than three per cent of the gross area irrigated, there was an average lowering in 1921 of 0.8 feet. In the central area where recent developments have resulted in a large increase in the rate of use, the irrigation of about one-third of the gross area resulted in an average lowering in 1921 of over three feet and of over five feet in the area of heaviest use. In the lower portion the area irrigated was less than 10 per cent of the gross area and the average draft only 0.12 acre-feet per acre of gross area, yet an average lowering of 0.7 feet occurred.

The Allensworth Colony is located at the western edge of this area. The wells used flow during the winter months but with smaller rates of discharge than formerly. Two wells measured when flowing in February, 1921, gave discharges of 29 and 107 gallons per minute. The same wells when being pumped in April gave discharges of 375 gallons per minute.

TABLE 41.

**Summary of Areas Irrigated, Pumping Draft and Fluctuations of Ground Water in White Creek Area in 1921.**

| | Area east of center line of range 26 E. | West one-half of range 26 E. and east two-thirds of range 25 E. | Remainder of western White Creek area | Total | Average draft in acre-feet per acre for each crop |
|---|---|---|---|---|---|
| Crop-acres— | | | | | |
| Alfalfa | 3 | 1,103 | 242 | 1,348 | 3.7 |
| Orchard | 1,296 | 599 | ------------ | 1,895 | 2.1 |
| Vines | 201 | 4,010 | 13 | 4,224 | 2.5 |
| Corn | | 1,083 | 106 | 1,189 | 2.5 |
| Miscellaneous | 3 | 987 | 1,929 | 2,919 | 1.5 |
| Totals | 1,503 | 7,782 | 2,290 | 11,575 | 2.3 |
| Gross area, acres | 57,000 | 23,000 | 24,000 | 104,000 | |
| Total draft, acre-feet | 3,576 | 19,166 | 2,938 | 27,045 | |
| Draft in acre-feet per acre irrigated | 2.40 | 2.5 | 1.30 | 2.30 | |
| Draft in acre-feet per acre of gross area | 0.06 | 0.8 | 0.12 | 0.27 | |
| Lowering of ground water November 1, 1920, to November 1, 1921 | 0.80 | 3.2 | 0.70 | 1.30 | |
| Rise in ground water November 1, 1920, to Feb. February 1, 1921 | 0.15 | 0.5 | 0.08 | 0.20 | |

In Fig. 18 hydrographs of typical wells in the White Creek area are shown. Well 4-7-19 is near the upper portion of the creek and shows the rise due to flow in the creek following a heavy rain in May. There is no irrigation pumping near this well. Well 4-6-22 is near White Creek below any flow in the creek in 1921 and just above the pumping area extending from Delano to Earlimart. A continual lowering amounting to 2.5 feet for the year is shown. Well 4-6-14 is northeast of Delano in an area of much recent pumping development and distant from any large direct source of replenishment. A continual drop is shown amounting to 2.5 feet for the year. Well 4-5-19 is northwest of Delano at the western edge of present pumping development. A drop of two feet for the year, with a slight recovery in the fall of 1921, is shown.

Data on twelve wells in the area of pumping between Delano and Earlimart, for periods varying from six to fifteen years, gives an average lowering of sixteen feet. These records indicate that the lowering of the water table began before 1916. Further west the lowering has been less as the amount of pumping is less and the conditions of mingled sources of ground water are approached.

The conditions existing in this area should make it obvious that only limited pumping drafts can be made without serious lowering of the ground water. The distance from any dependable source of recharge and the sensitiveness of the ground water to draft as shown by the 1921 records, make it evident that pumping in this area is drawing mainly on reserve of ground water which has been accumulated over an indefinitely long period. When once depleted by pumping a similarly long period will be required for the refilling of the ground water storage. A continuation of the present rate of draft can only be expected to result in the lowering of the ground water to depths from which pumping will no longer be profitable. Every effort should be used to discourage additional development in this area as it can only lessen the period of time before this condition occurs.

## AREA IN SOUTHWESTERN TULARE COUNTY WHOSE GROUND WATER IS CONSIDERED TO COME FROM MINGLED SOURCES.

The field work of these investigations was extended to cover all of southwestern Tulare County. This includes some area which might receive ground water from Tule River and Deer and White creeks but which is also considered to be within the area which may receive ground water from the general valley sources. The change in the direction of the ground water contours on Map 2 indicates that the source of the ground water is from Kern County areas rather than from Tulare County sources for at least a part of this area.

The larger development in this area is that of the Alpaugh Irrigation District. The water supply is secured entirely from wells, part of which are located within the district and part are located in T. 25 S., R. 23 E., in Kern County. The area irrigated in 1921 included some irrigation of grain outside of the district boundaries. The quantity pumped from the wells within the district represented about one-third of the supply, the remaining portion being secured from the Kern County wells. The Kern County wells flow during the winter and are pumped during the irrigation season.

The data collected regarding the use of water in this area is summarized in Table 42. The area listed as miscellaneous consisted mainly of grain given one irrigation. The rate of draft both for the area irrigated and for the gross area was relatively small. For the year an average rise of 1.0 feet in the ground water occurred. Some rise occurred in all parts of the area except the southern part of T. 24 S., R. 24 E. There was also a relatively large recovery during the winter months. As this area is one of artesian pressure the ground water fluctuations represent changes of pressure rather than of volume of ground water.

TABLE 42.

**Summary of Use of Water and Ground Water Fluctuations in Area in Southwestern Portion of Tulare County in 1921**

| | Areas supplied by pumps exclusive of Alpaugh Irrigation District | Areas irrigated by Alpaugh Irrigation District | Total area |
|---|---|---|---|
| Alfalfa, acres | 478 | 1,806 | 2,284 |
| Corn, acres | 253 | 275 | 528 |
| Miscellaneous, acres | 4,646 | 3,352 | 7,998 |
| Total acres | 5,377 | 5,433 | 10,810 |
| Total acre-feet pumped | 5,870 | *3,600 | 9,470 |
| Gross area, acres | | | 64,500 |
| Total draft in acre-feet per acre of gross area | | | 0.15 |
| Average rise of ground water, November 1, 1920, to February 1, 1921 | | | 2.2 |
| Average rise of ground water, November 1, 1920, to November 1, 1921 | | | 1.0 |

*Estimated draft on wells within district only.

Well 3-3-3, in Fig. 18, represents the hydrograph of a well in the artesian area and shows the typical rise during the winter and lowering during the summer. A gain of two feet in 1921 over 1920 is shown. These fluctuations are considered to be mainly variations of pressure rather than of volume.

The sources of ground water for this area are too complex to enable the extent of the supply to be discussed definitely. The present conditions of draft did not result in a lowering of pressure during 1921. A reduction of flow of artesian wells has occurred in the past. The present rates of draft within the area would be expected to result in only limited reductions of pressure. It is, however, to be presumed that any continued overdraft by pumping in the areas in which the ground water supply of this area may originate will eventually result in a reduction of the supply reaching this area with a consequent reduction in the ground water levels.

## NORTHERN KERN COUNTY.

General ground water investigations in Kern County were made in 1920 and are discussed in Bulletin 9 of this Department. The areas in township 25 south, were only partially covered in these investigations. In order to connect the areas of the two investigations observations were extended into Kern County.

The only direct local source of water supply for the northern edge of Kern County is Rag Gulch. This has a very limited and variable run-off, which has been estimated as an average of 3500 acre-feet per year. In 1918 an unusually heavy storm on the South Fork of Rag Gulch is reported to have resulted in flow as far as the Southern Pacific tracks near Richgrove. During normal season the surface flow does not reach very far into the valley. The canvass of the area irrigated in the north half of T. 25 S., R. 25 and 26 E.., in 1920, gave a total draft of 9100 acre-feet. There has been a relatively large increase in the pumping draft in the vicinity of Delano in recent years. Well records show a lowering of the ground water of from two to five feet in 1921 in the vicinity of Jasmin and Delano and about one foot in the vicinity of Pond. As this area lies too far north to be affected by Poso Creek or by Kern River, its ground water supply is relatively limited in amount and a continuance of the present rate of development can only be expected to result in a permanent ground water lowering.

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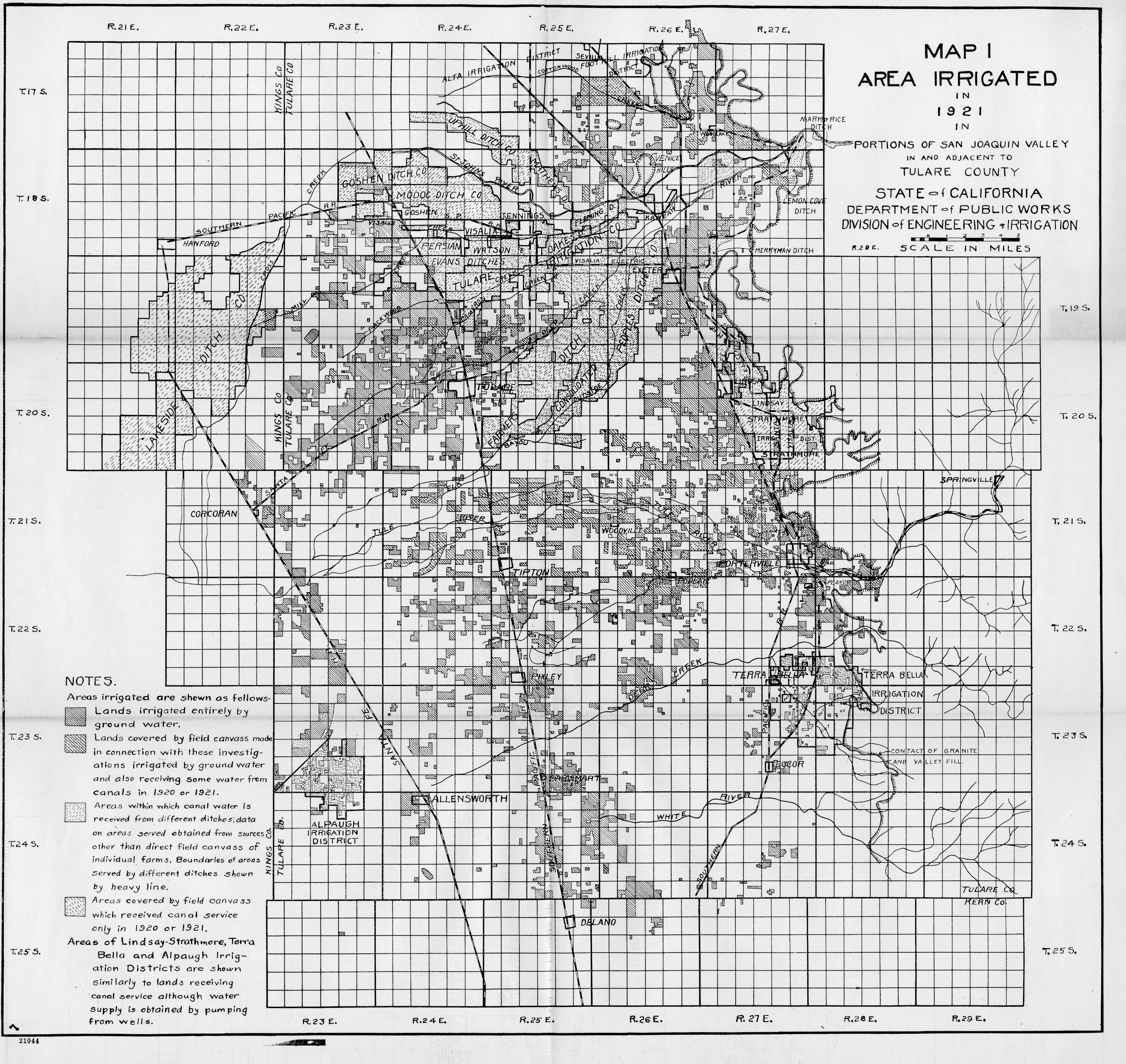
MAP I
AREA IRRIGATED
IN
1921
IN
PORTIONS OF SAN JOAQUIN VALLEY
IN AND ADJACENT TO
TULARE COUNTY
STATE of CALIFORNIA
DEPARTMENT of PUBLIC WORKS
DIVISION of ENGINEERING & IRRIGATION
SCALE IN MILES
NOTES.
Areas irrigated are shown as follows-
Lands irrigated entirely by ground water.
Lands covered by field canvass made in connection with these investigations irrigated by ground water and also receiving some water from canals in 1920 or 1921.
Areas within which canal water is received from different ditches; data on areas served obtained from sources other than direct field canvass of individual farms. Boundaries of areas served by different ditches shown by heavy line.
Areas covered by field canvass which received canal service only in 1920 or 1921.
Areas of Lindsay-Strathmore, Terra Bella and Alpaugh Irrigation Districts are shown similarly to lands receiving canal service although water supply is obtained by pumping from wells.
R.21 E.
R.22 E.
R.23 E.
R.24 E.
R.25 E.
R.26 E.
R.27 E.
R.28 E.
R.29 E.
T.17 S.
T.18 S.
T.19 S.
T.20 S.
T.21 S.
T.22 S.
T.23 S.
T.24 S.
T.25 S.
ALTA IRRIGATION DISTRICT
FOOTHILL IRRIGATION DISTRICT
COTTONWOOD CREEK
KINGS CO
TULARE CO
UPHILL DITCH CO
GOSHEN DITCH CO
MODOC DITCH CO
St JOHNS RIVER
KAWEAH RIVER
GOSHEN
VISALIA
JENNINGS
FLEMING D.
HANFORD
SOUTHERN PACIFIC R.R.
PERSIAN
WATSON
EVANS DITCHES
OAKES
TULARE IRRIGATION CO
VISALIA ELECTRIC
EXETER
LAKESIDE DITCH CO
PEOPLES DITCH CO
CONSOLIDATED
FARMERS
TULARE
LINDSAY
STRATHMORE
LINDSAY STRATHMORE IRRIG DIST
MARKS & RICE DITCH
LEMON COVE DITCH
MERRYMAN DITCH
VENICE HILLS
SPRINGVILLE
CORCORAN
SANTA FE
TULE RIVER
ELK BAYOU
WOODVILLE
TIPTON
PORTERVILLE
POPLAR
PIXLEY
DEER CREEK
TERRA BELLA
TERRA BELLA IRRIGATION DISTRICT
CONTACT OF GRANITE AND VALLEY FILL
DUCOR
EARLIMART
ALLENSWORTH
ALPAUGH IRRIGATION DISTRICT
WHITE RIVER
SOUTHERN PACIFIC
TULARE CO
KERN CO
DELANO

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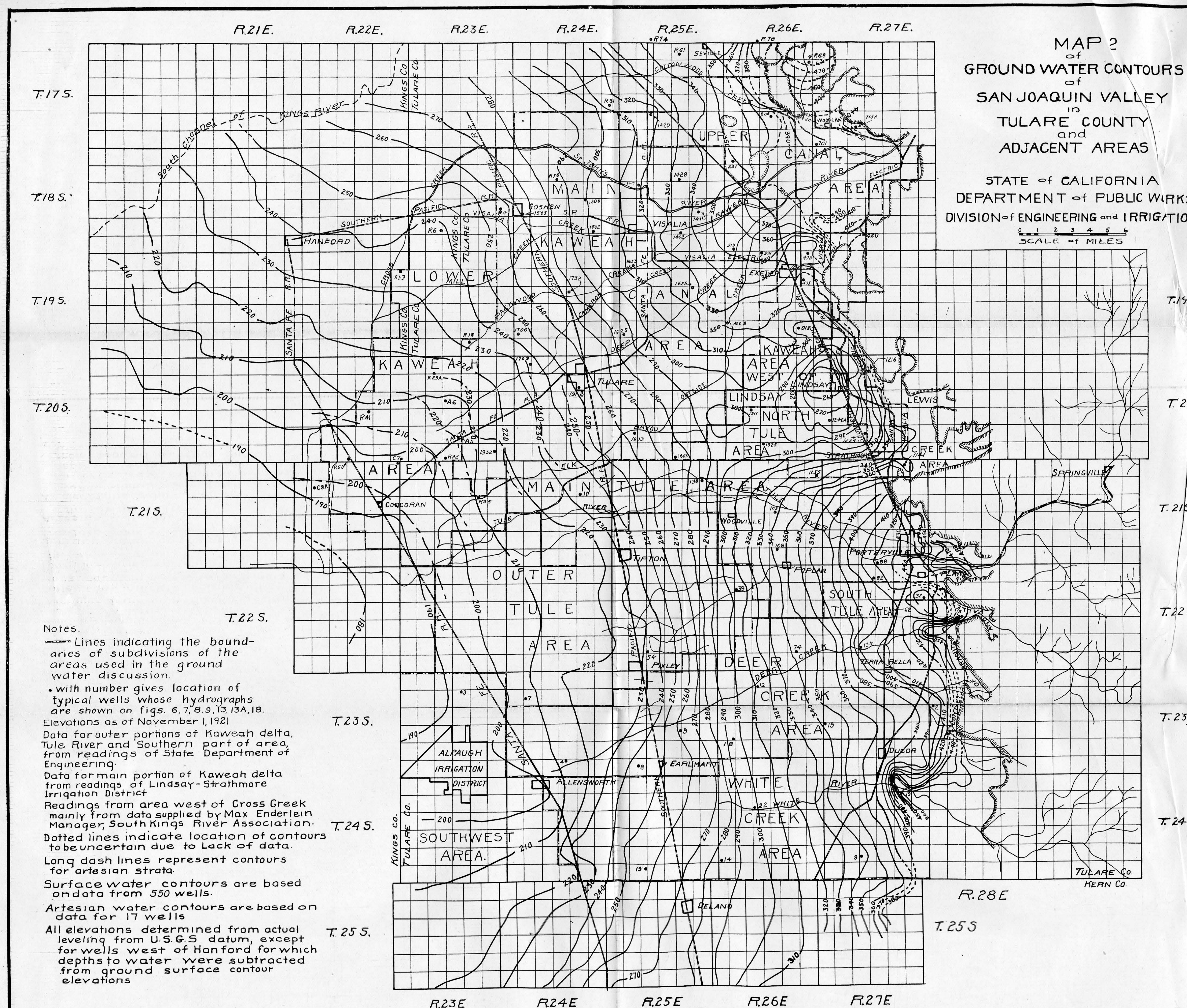
MAP 2
of
GROUND WATER CONTOURS
of
SAN JOAQUIN VALLEY
in
TULARE COUNTY
and
ADJACENT AREAS
STATE of CALIFORNIA
DEPARTMENT of PUBLIC WORKS
DIVISION of ENGINEERING and IRRIGATION
0 1 2 3 4 5 6
SCALE of MILES
Notes.
—— Lines indicating the boundaries of subdivisions of the areas used in the ground water discussion.
• with number gives location of typical wells whose hydrographs are shown on figs. 6, 7, 8, 9, 13, 13A, 18.
Elevations as of November 1, 1921
Data for outer portions of Kaweah delta, Tule River and Southern part of area, from readings of State Department of Engineering.
Data for main portion of Kaweah delta from readings of Lindsay-Strathmore Irrigation District
Readings from area west of Cross Greek mainly from data supplied by Max Enderlein Manager, South Kings River Association.
Dotted lines indicate location of contours to be uncertain due to lack of data.
Long dash lines represent contours for artesian strata.
Surface water contours are based on data from 550 wells.
Artesian water contours are based on data for 17 wells
All elevations determined from actual leveling from U.S.G.S datum, except for wells west of Hanford for which depths to water were subtracted from ground surface contour elevations
R.21E. R.22E. R.23E. R.24E. R.25E. R.26E. R.27E. R.28E
T.17S. T.18S. T.19S. T.20S. T.21S. T.22S. T.23S. T.24S. T.25S
UPPER CANAL AREA
MAIN KAWEAH CANAL AREA
LOWER KAWEAH AREA
KAWEAH AREA WEST OF LINDSAY
LINDSAY NORTH TULE AREA
MAIN TULE AREA
OUTER TULE AREA
SOUTH TULE AREA
DEER CREEK AREA
WHITE CREEK AREA
SOUTHWEST AREA.
ALPAUGH IRRIGATION DISTRICT
HANFORD
VISALIA
TULARE
LINDSAY
CORCORAN
TIPTON
PORTERVILLE
PIXLEY
EARLIMART
ALLENSWORTH
DUCOR
DELANO
SPRINGVILLE
TULARE Co.
KERN Co.

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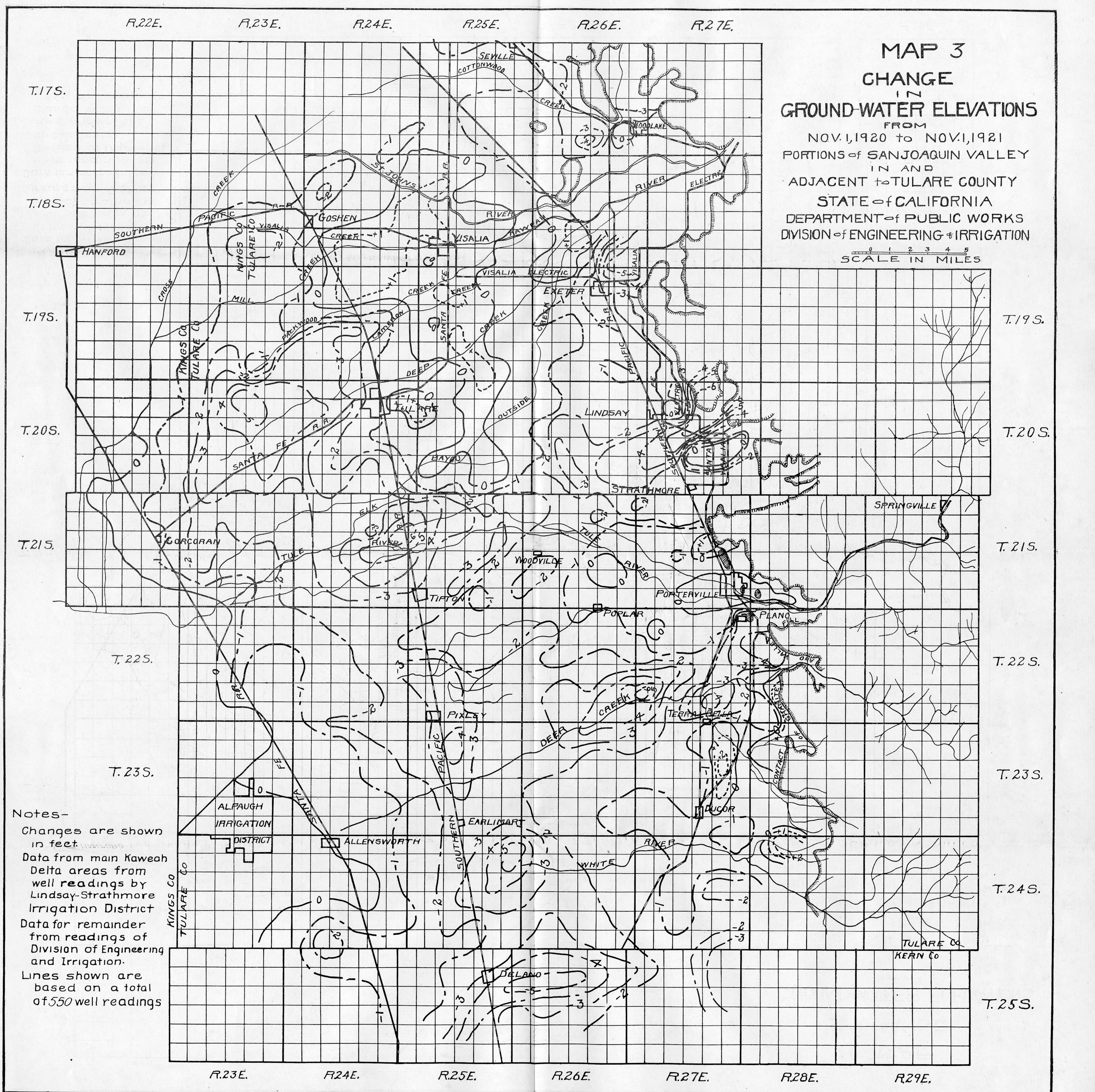
MAP 3
CHANGE
IN
GROUND-WATER ELEVATIONS
FROM
NOV. 1, 1920 to NOV. 1, 1921
PORTIONS of SAN JOAQUIN VALLEY
IN AND
ADJACENT to TULARE COUNTY
STATE of CALIFORNIA
DEPARTMENT of PUBLIC WORKS
DIVISION of ENGINEERING & IRRIGATION
0 1 2 3 4 5
SCALE IN MILES
Notes-
Changes are shown in feet
Data from main Kaweah Delta areas from well readings by Lindsay-Strathmore Irrigation District
Data for remainder from readings of Division of Engineering and Irrigation.
Lines shown are based on a total of 550 well readings
R.22E.
R.23E.
R.24E.
R.25E.
R.26E.
R.27E.
R.28E.
R.29E.
T.17S.
T.18S.
T.19S.
T.20S.
T.21S.
T.22S.
T.23S.
T.24S.
T.25S.
HANFORD
GOSHEN
VISALIA
WOODLAKE
EXETER
LINDSAY
TULARE
STRATHMORE
SPRINGVILLE
CORCORAN
WOODVILLE
TIPTON
PORTERVILLE
POPLAR
PLANO
PIXLEY
TERRA BELLA
DUCOR
EARLIMART
ALLENSWORTH
DELANO
ALPAUGH
IRRIGATION
DISTRICT
SEVILLE
COTTONWOOD
CREEK
St JOHNS
RIVER
KAWEAH
ELECTRIC
SOUTHERN
PACIFIC
R.R.
VISALIA ELECTRIC
CROSS
MILL
PACKWOOD
CAMERON
DEEP
SANTA FE
OUTSIDE
BAYOU
ELK
TULE
DEER
WHITE
CONTACT
KINGS Co
TULARE Co
KERN Co

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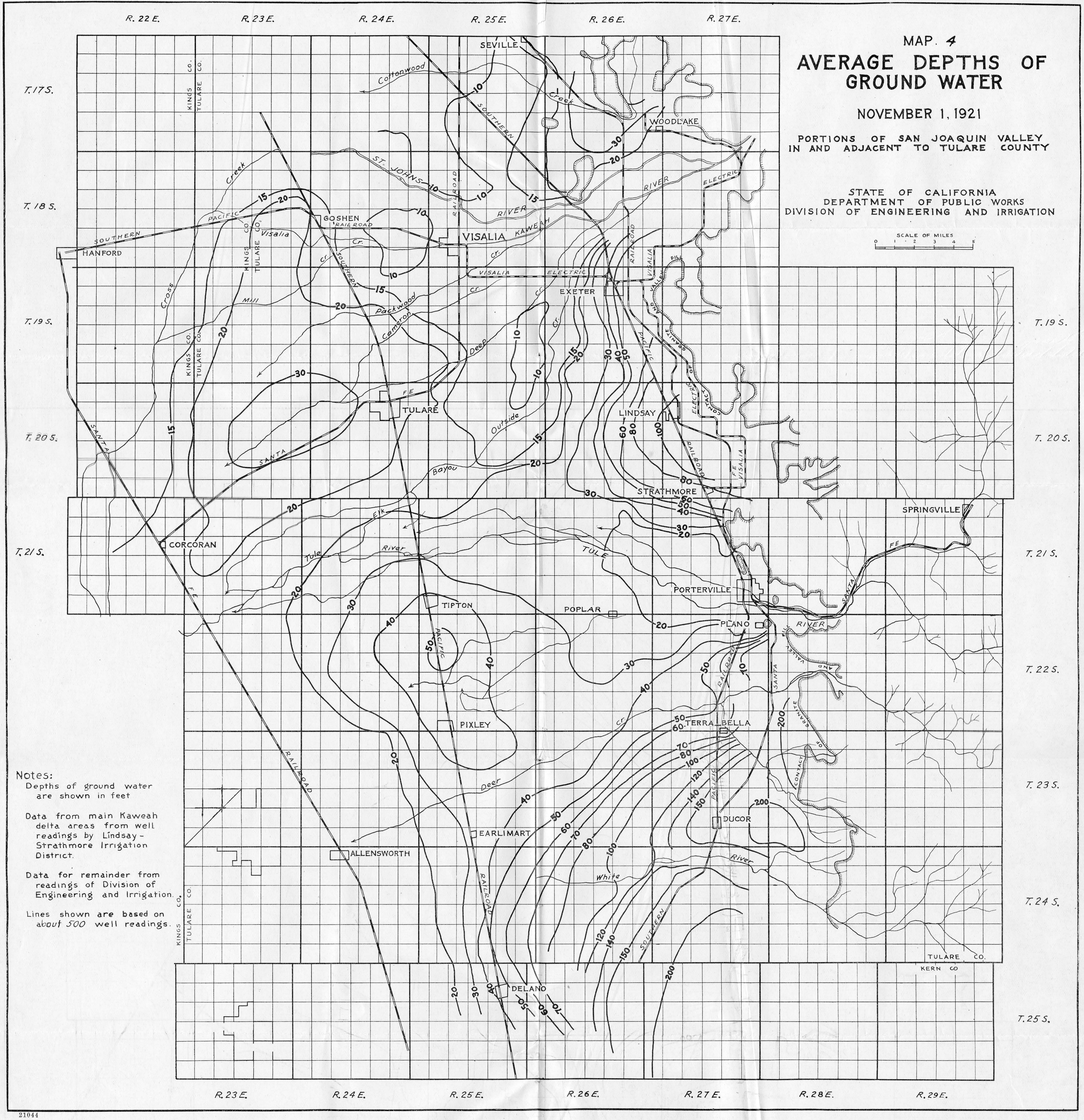

MAP. 4
AVERAGE DEPTHS OF GROUND WATER
NOVEMBER 1, 1921
PORTIONS OF SAN JOAQUIN VALLEY IN AND ADJACENT TO TULARE COUNTY
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
SCALE OF MILES
Notes:
Depths of ground water are shown in feet
Data from main Kaweah delta areas from well readings by Lindsay-Strathmore Irrigation District.
Data for remainder from readings of Division of Engineering and Irrigation.
Lines shown are based on about 500 well readings.
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
R. 28 E.
R. 29 E.
T. 17 S.
T. 18 S.
T. 19 S.
T. 20 S.
T. 21 S.
T. 22 S.
T. 23 S.
T. 24 S.
T. 25 S.
SEVILLE
WOODLAKE
GOSHEN
VISALIA
HANFORD
EXETER
TULARE
LINDSAY
STRATHMORE
CORCORAN
SPRINGVILLE
PORTERVILLE
TIPTON
POPLAR
PLANO
PIXLEY
TERRA BELLA
DUCOR
EARLIMART
ALLENSWORTH
DELANO
KINGS CO.
TULARE CO.
KERN CO.
Cottonwood Creek
St. Johns River
Kaweah River
Cross Creek
Mill Cr.
Packwood Cr.
Cameron Cr.
Deep Cr.
Outside Cr.
Elk Bayou
Tule River
Deer Cr.
White River
Southern Pacific Railroad
Santa Fe Railroad
Visalia Electric
Fe Visalia
Visalia and Valley Fill
Granite Contact

# MAP 5

## RESERVOIR SITE ON KAWEAH RIVER

BELOW

## THREE RIVERS

FROM SURVEY

OF

G. B. STURGEON CONSULTING ENGINEER

TO ACCOMPANY REPORT OF

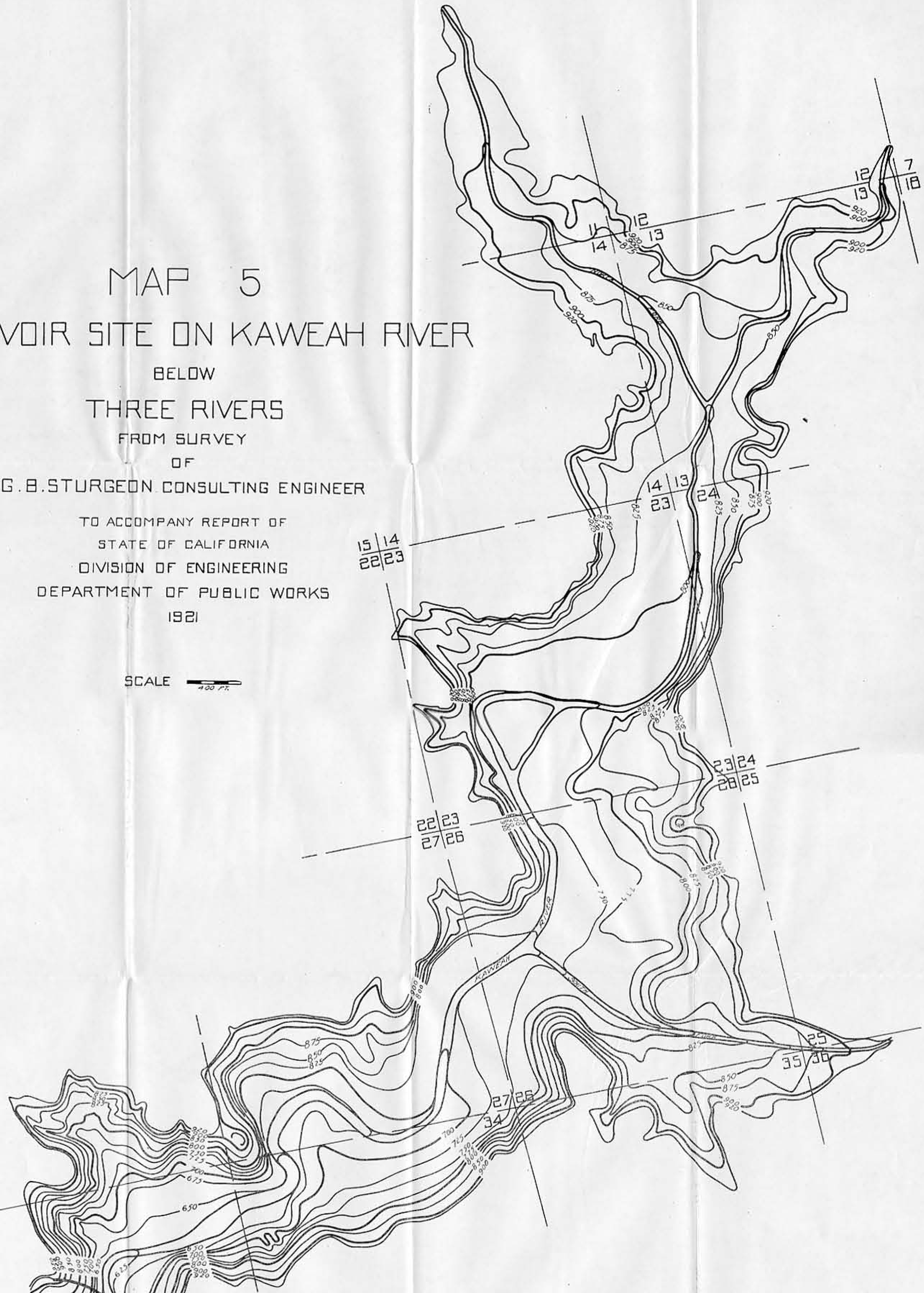
STATE OF CALIFORNIA

DIVISION OF ENGINEERING

DEPARTMENT OF PUBLIC WORKS

1921

SCALE 400 FT.

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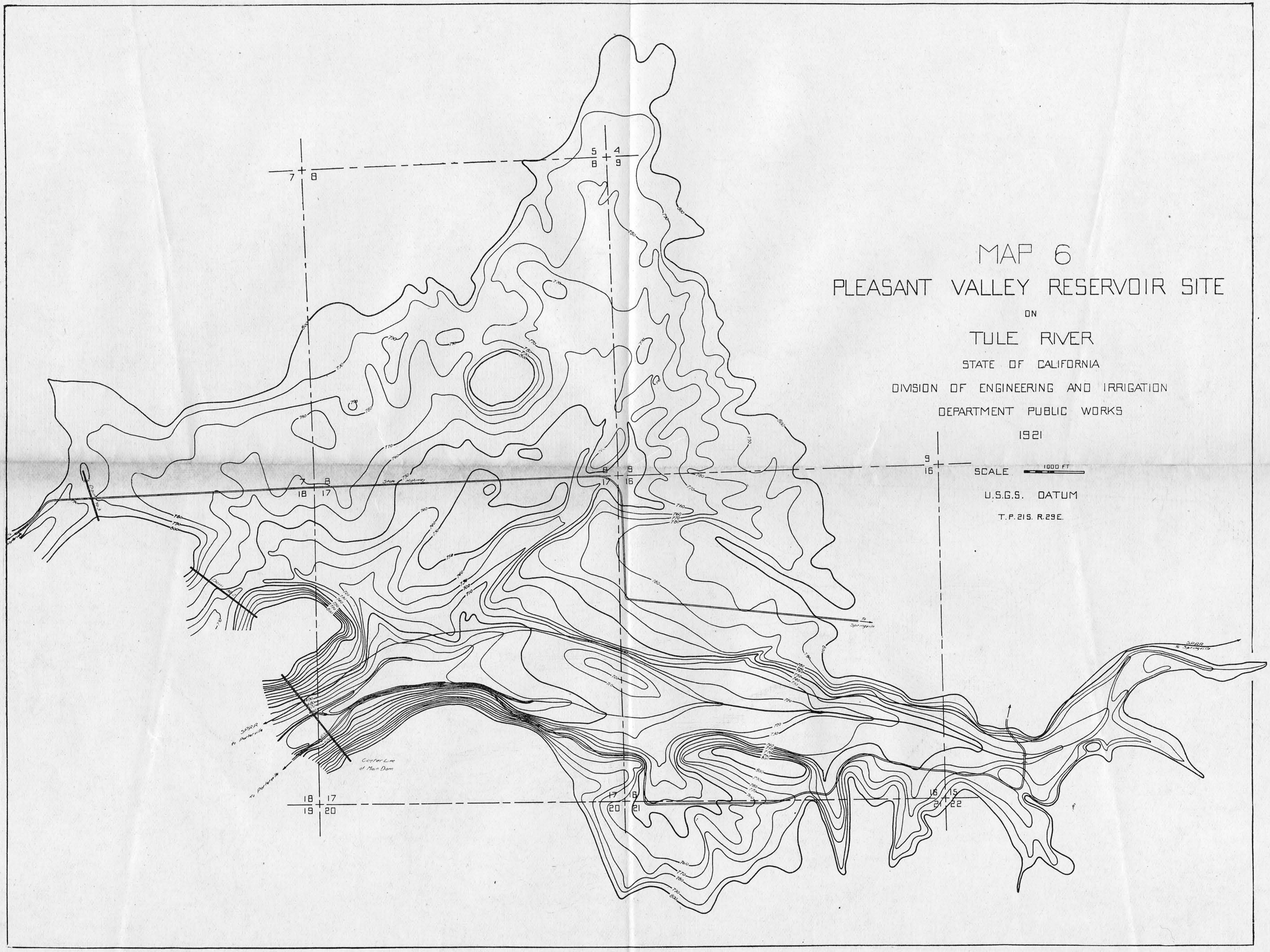
MAP 6
PLEASANT VALLEY RESERVOIR SITE
ON
TULE RIVER
STATE OF CALIFORNIA
DIVISION OF ENGINEERING AND IRRIGATION
DEPARTMENT PUBLIC WORKS
1921
SCALE
1000 FT
U.S.G.S. DATUM
T.P. 21S. R.29E.
Center Line of Main Dam
State Highway
SPRR to Porterville
to Porterville
SPRR to Springville
to Springville

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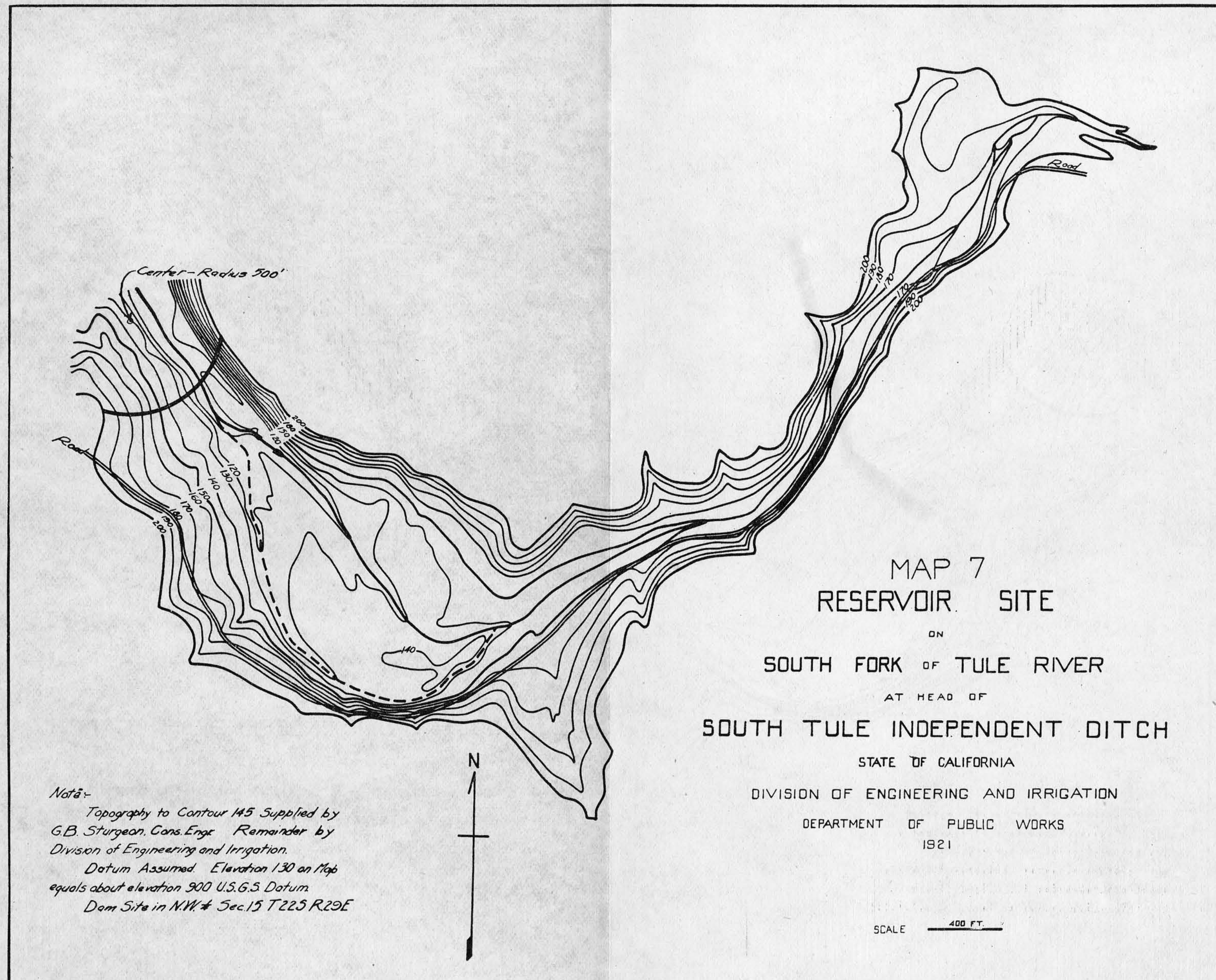


MAP 7

# RESERVOIR SITE

ON

## SOUTH FORK OF TULE RIVER

AT HEAD OF

## SOUTH TULE INDEPENDENT DITCH

STATE OF CALIFORNIA

DIVISION OF ENGINEERING AND IRRIGATION

DEPARTMENT OF PUBLIC WORKS

1921

21044