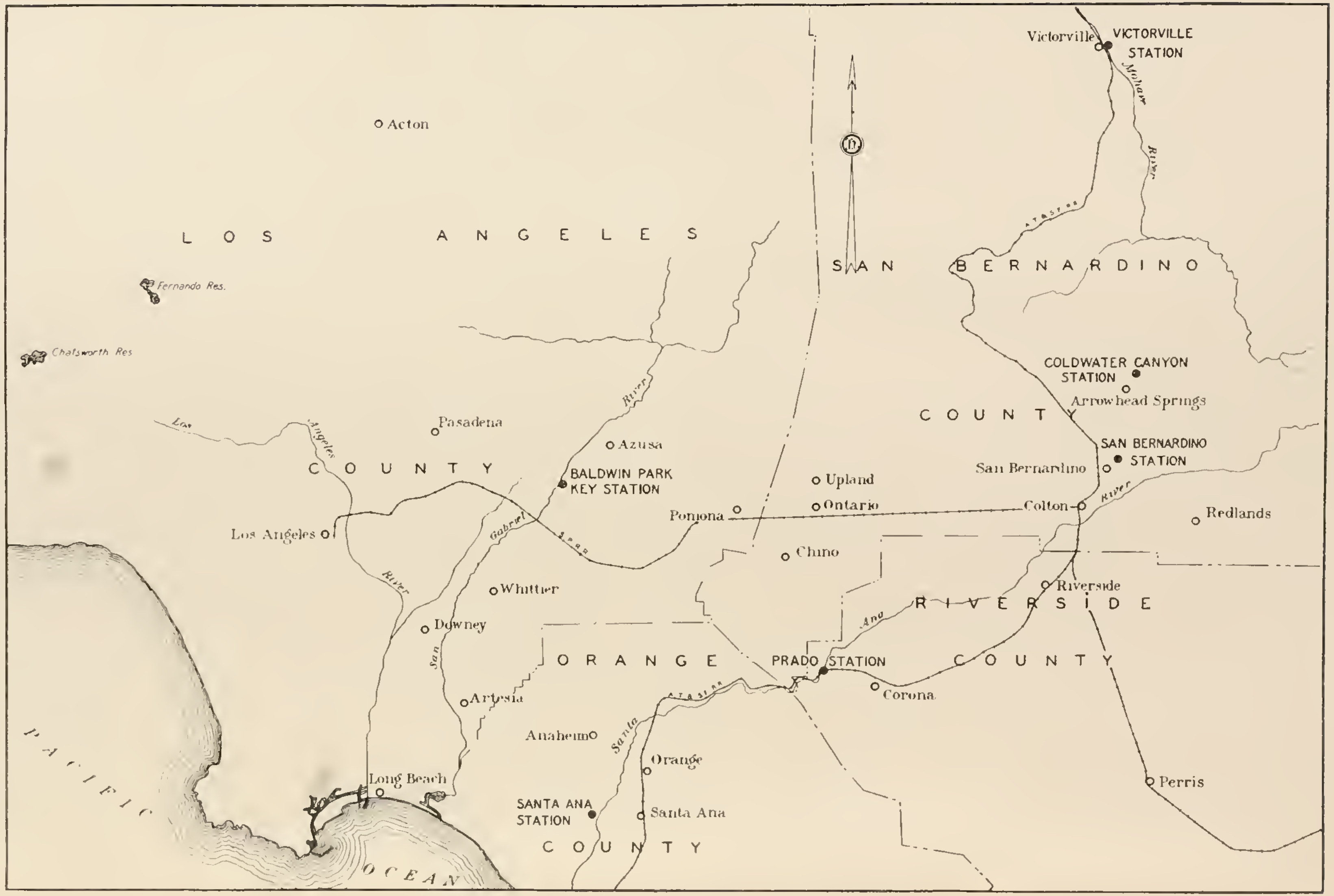

GEOGRAPHICAL LOCATIONS OF STATIONS.

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

PUBLICATIONS OF THE
DIVISION OF WATER RESOURCES
EDWARD HYATT, State Engineer

BULLETIN No. 44

SOUTH COASTAL BASIN INVESTIGATION

WATER LOSSES UNDER NATURAL CONDITIONS FROM WET AREAS IN SOUTHERN CALIFORNIA

PART I

Report of a Cooperative Investigation by the Division of Irrigation, Bureau of Agricultural Engineering, United States Department of Agriculture.

PART II

Report of a Cooperative Investigation by the Water Resources Branch Geological Survey, United States Department of the Interior.

1933

FOREWORD

The value of water that can be put to beneficial use in southern California is so great that it seems advisable to call attention to existing wastage along streams and in other wet-surfaced areas of that region. Studies that have been made recently lead to the conclusion that the possibility of utilizing such sources of supply to advantage is worthy of the most serious consideration. This bulletin gives basic data which may be applied in evaluating water now wasted that might be put to profitable uses.

The bulletin is in two parts: Part I, a report of investigations made by the Division of Irrigation, Bureau of Agricultural Engineering, U. S. Department of Agriculture, dealing with the disposal of water by evaporation and transpiration in various parts of southern California, and Part II, a report of investigations made by the Water Resources Branch, Geological Survey, U. S. Department of the Interior, dealing with loss of water from Santa Ana River in lower Santa Ana Canyon. Both reports were made cooperatively with the Division of Water Resources, Department of Public Works, State of California. It is believed that the publication of these two reports will throw needed light upon the little-understood subject of waste of water through natural causes.

PART I

CONSUMPTIVE USE OF WATER BY NATIVE PLANTS GROWING IN MOIST AREAS IN SOUTHERN CALIFORNIA

By Harry F. Blaney

(1) At stations in Santa Ana Valley and Coastal Plain near Santa Ana, Prado and San Bernardino,

(2) In the Mojave River Area near Victorville,

(3) In Coldwater Canyon near Arrowhead Springs, located in the San Bernardino Mountains, and

(4) At Baldwin Park and other evaporation stations in southern California.

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LETTER OF TRANSMITTAL

Mr. Edward Hyatt,
State Engineer,
Sacramento, California.

Dear Sir: I have the pleasure to transmit herewith for publication a report "Consumptive Use of Water by Native Plants Growing in Moist Areas in Southern California."

The report was prepared by Harry F. Blaney, assisted by Colin A. Taylor, A. A. Young and Harry G. Nickle, and is, I believe, one of the most comprehensive presentations of research data available dealing with the consumptive use of water by various noncrop plants native of southern California and the Southwest in general. It is of economic and practical importance in considering problems of water conservation and use.

As a final chapter there is brought together data on evaporation from a free-water surface, that will be of great value to engineers and others dealing with water utilization, especially its storage in open reservoirs.

The investigations on which the report is based were supported by and the report was prepared under cooperative agreement between the Division of Water Resources of the California State Department of Public Works and the Division of Irrigation of the Bureau of Agricultural Engineering, U. S. Department of Agriculture.

Respectfully submitted,

W. W. McLaughlin

Chief, Division of Irrigation,
Bureau of Agricultural Engineering,
U. S. Department of Agriculture.

Berkeley, California,
June 3, 1933.

ACKNOWLEDGMENT

The authors acknowledge the assistance rendered by members of the Division of Irrigation of the Bureau of Agricultural Engineering, United States Department of Agriculture, especially Dean W. Bloodgood, Associate Irrigation Engineer, Dean C. Muckel, Junior Civil Engineer, and H. W. Kistner, who assisted in the preparation of the manuscript, and A. Lincoln Fellows, Senior Irrigation Engineer, who edited it.

The advice and assistance of Harold Conkling, Deputy State Engineer, is recognized. Acknowledgment is made of the assistance rendered by F. C. Ebert, Jarret Oliver, and K. R. Melin of the United States Geological Survey. W. P. Rowe of the Board of Water Commissioners, City of San Bernardino, and M. N. Thompson, Engineer of the Orange County Flood Control District, also rendered valuable assistance.

Acknowledgment is made to A. S. Amaral of the Appleton Land and Water Company for providing the site for the experiment station at Victorville, of the courtesies extended by H. S. Ward of the Arrowhead Springs Company in the Coldwater Canyon Investigations, and to the Los Angeles County Flood Control District and San Gabriel Valley Protective Association for furnishing the site for Baldwin Park Key Station.

Scientific names for native plants were determined at the Herbarium of the University of California.

ORGANIZATION

STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES

EARL LEE KELLY __________ *Director of Public Works*
EDWARD HYATT __________ *State Engineer*

The South Coastal Basin Investigation was conducted under the supervision of

HAROLD CONKLING
Deputy State Engineer

ORGANIZATION

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF AGRICULTURAL ENGINEERING
DIVISION OF IRRIGATION

Cooperating in
South Coastal Basin Investigation

W. W. McLaughlin ------------------------------ *Chief of Division*

This report was prepared by
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Colin A. Taylor ---------------------- *Assistant Irrigation Engineer*

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CONSUMPTIVE USE OF WATER BY NATIVE PLANTS GROWING IN MOIST AREAS IN SOUTHERN CALIFORNIA

By Harry F. Blaney *

CHAPTER I

INTRODUCTION AND SUMMARY

INTRODUCTION

In southern California the natural water supply is exceedingly limited, while the demands for water are great and its value is high. In some sections the value of continuous-flow gravity water ranges from $100,000 to as much as $200,000 per second-foot,** depending upon its use. Both present and future agricultural, domestic, and industrial development depends upon the adequacy of the water supply. Under these circumstances it is economically important to utilize the available water supply to the fullest extent. For this reason federal, state, county, city, and other agencies are working along lines to determine ways and means by which water, now wasted, may be conserved for beneficial use.

The Bureau of Agricultural Engineering in cooperation with various agencies is making studies to determine the contributions of rainfall to the ground water of valley floors, consumptive use of water by plant life on both irrigated and nonirrigated lands, irrigation water requirements of different crops, replenishment of underground storage of water by spreading, evaporation losses, and noneconomic use of water by native plants growing in moist areas. This report deals with the consumptive use of water by various types of indigenous vegetation commonly found in meadows and swamps and along stream beds, evaporation losses from soils without vegetative growth in areas of high water table, and evaporation from free water surfaces.

In considering the adequacy of public water supplies in the past, too little attention has been given to use of water by noncrop plants. In most instances such plants are so located that they get their supplies of water before settled communities get theirs, and therefore such use must be considered in estimating water available for other purposes.

For areas where large amounts of money are spent to develop and deliver water for irrigation at heavy annual cost to the irrigators, the water that could be saved by preventing the growth of uneconomic plants may be reckoned as approximating in value that of an equal amount of water in storage. For citrus fruits the cost of water is frequently as high as $15 to $20 per acre-foot and in some instances it is much higher. Tules, willows, and alders growing in irrigation canals, drainage ditches or stream channels or on their banks are usually exposed in narrow strips to sun and wind so that their consumption of

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* Irrigation Engineer, Division of Irrigation, Bureau of Agricultural Engineering, U. S. Department of Agriculture.

** State of California Department of Public Works Bulletin No. 36, Cost of Irrigation Water in California, by Harry F. Blaney and Martin R. Huberty. (1930.)

water is very high. Lining canals to check seepage losses and diverting stream flows into conduits conserve water by eliminating losses due to such aquatic growths as well as by decreasing the seepage.

In many instances irrigation and domestic supplies are obtained by diverting water from the lower reaches of canyons, the bottoms of which usually are covered with vegetation. The amount of water lost through consumptive use by that vegetation may be of considerable importance where the flow of the stream is relatively small and studies have therefore been undertaken to measure such losses.

Evaporation records from standard Weather Bureau pans are valuable in estimating evaporation losses from reservoirs and consumptive use of water by native vegetation growing in moist areas. Very few data have been published on evaporation in southern California, accordingly all available records are included in this report. Among these are those kept by the Bureau of Agricultural Engineering at several stations in cooperation with the State Engineer of California and those kept in other localities by local agencies.

SUMMARY

Commencing in 1929 and continuing thereafter investigations of evaporation and transpiration losses in moist areas have been conducted by the Division of Irrigation, Bureau of Agricultural Engineering, United States Department of Agriculture, in cooperation with the Division of Water Resources, Department of Public Works, State of California, and other agencies. Stations were established at Santa Ana, Prado, San Bernardino, Victorville, Coldwater Canyon and Baldwin Park. The results obtained are summarized in the following discussion.

Santa Ana, Prado, and San Bernardino Stations

Data regarding evaporation from bare uncultivated soil and use of water by noneconomic native growth found in moist areas in Santa Ana River Valley have been collected for the three-year period immediately preceding May 1, 1932. Results of the first year's work have already been published.* Investigations were conducted at three stations, although the greater part of the work was done at Santa Ana, with smaller stations at San Bernardino, 50 miles distant, and at Prado, midway between the other two. The Prado station was established a year after the others and work there is being continued. The other two stations have been dismantled. The soil at the Santa Ana station is classed as a Hanford fine sandy loam** and that at San Bernardino as Chino silt loam. The work at Prado did not include soil moisture studies and the soil class was not determined.

The investigation included studies of evaporation from soil, consumptive use of water by salt grass and Bermuda grass in tanks with predetermined water levels, use of water by tules and cat-tails in submerged soil, and by willow and wire rush. Some experiments in evaporation from water surfaces also were included. Soil evaporation and use of water studies were carried on at Santa Ana in unbroken columns of soil in 12 tanks and with disturbed soil in three tanks. All soil moisture

* California State Department of Public Works Bulletin No. 33, Rainfall Penetration and Consumptive Use of Water in the Santa Ana River Valley and Coastal Plain, by Harry F. Blaney, C. A. Taylor, and A. A. Young.

** Soil Survey of the Anaheim Area, California. Bureau of Soils, U. S. Department of Agriculture.

experiments were carried on in triplicate to average errors and the effects of soil differences. The following summaries and conclusions are given from the data obtained during the investigation:

1. Mariotte tanks were used with all soil tanks to supply and maintain a constant water table in the soil. Their value lies in the ease with which periodic measurements of water used may be made as they are automatic in operation. Great care is necessary to protect the Mariotte tank against temperature changes or from leakage of air into the tank or the connecting pipe system.

2. Evaporation tests from bare soil were conducted with both disturbed and undisturbed soil in tanks, separately. No evaporation occurred from tanks of undisturbed soil having a water table 4 feet below the surface. When the water table was raised to 3 feet from the soil surface the evaporation averaged 0.1 acre-inch per acre per month. Tanks of undisturbed soil having water tables at a depth of 2 feet lost an average of 0.445 acre-inch per acre per month for 15 months. In contrast with losses from undisturbed soil, three tanks filled with disturbed soil having a 2-foot depth to water level had a mean monthly loss by evaporation of 1.599 acre-inches per acre, while the average loss from undisturbed soil for the same period was 0.404 acre-inch per acre, or about 25 per cent. In disturbed soil the opportunity for evaporation was greater as the soil contained more moisture. Evaporation from undisturbed soil is more comparable to that lost under field conditions than is that from disturbed soil. These data indicate that there will be no evaporation from the light textured soils of the Hanford series when the water table is 4 feet or more below the ground surface.

3. Use of water by both salt grass and Bermuda grass was influenced by the availability of moisture in the soil and the depth to water table. Grasses in tanks having the highest water tables used the most water. During the year ending April 30, 1932, salt grass grown in tanks having water tables 1 foot in depth used water at the rate of 42.75 acre-inches per acre; with a 2-foot depth, 36.23 acre-inches; and with a 5-foot depth, 22.12 acre-inches per acre. In general, the ratio of the use of water to depth of water table by Bermuda grass was about the same as that of salt grass. From these data, it is concluded that use of water by these grasses is not excessive and does not exceed the amount that would be used by many cultivated crops grown under the same conditions of soil moisture.

4. Consumptive use of water by tules or cat-tails grown in tanks in exposed locations is not closely indicative of the true use by these plants growing in their natural environment. Growths in exposed tanks are subject to greater solar radiation, lower humidity and greater wind movement conditions than are found under natural swamp conditions; and use of water by swamp growth transplanted to exposed locations is inordinately high. Numerous instances of tules in tanks using an acre-inch or more of water per 24 hours at the Santa Ana station and an extreme use of 3.6 acre-inches per acre per 24 hours at Prado were noted. Taken as a percentage of evaporation from a standard Weather Bureau pan the use of water by tules or cat-tails in exposed tanks varied from 168.3 per cent for cat-tails at Santa Ana to 451.7 per cent for triangular stem tules at Prado. From other experiments by the Bureau of Agricultural Engineering it is evident that

if the size of tanks was extended to swamp areas the consumptive use would decrease to a relatively small fraction of that used by exposed tanks. Very little is known as to the proper factor to be applied, but a limited investigation indicates that consumptive use of water by tules or cat-tails in densely grown natural swamp areas may be as low as 30 per cent of the consumptive use by similar growth in isolated tanks having extreme exposure to the elements.

5. Willow uses more water than either of the two wild grasses with which tests were made. A single clump of willow used 52.71 acre-inches per acre with a water table at a depth of 2 feet during an eleven-month period. This was 83.5 per cent of the evaporation from a standard Weather Bureau pan. The willow was fully exposed and the consumptive use may have been higher than would be the case from an area of equal size in a willow thicket. As a moist area noneconomic growth, the willow is responsible for waste of water which might otherwise be put to a more beneficial use. On the other hand, willows will grow in gravelly river bottoms where they furnish protection against erosion. Any benefit obtained by removal of such protection to increase the water supply may be offset by damage by floods carrying sand and gravel into valuable farm communities. No data are available indicating a factor for reduction of consumptive use by willows grown in exposed and isolated tanks to that used by natural growth in large areas.

6. Wire rush grows in a limited area in the Santa Ana Valley where high ground water exists. Its consumptive use measured from a 2-foot water table is high, exceeding that from grasses or willow. In July, 1931, it amounted to 13.75 acre-inches per acre, which was 2.8 times the amount used by salt grass during the same period and growing at the same location. As far as is known, wire rush has no value for live stock and the water it consumes is an economic loss. No data exists for determination of a factor to reduce consumptive use from tank growth to that by natural field growth, but some factor should be applied.

7. Soil tests were made to determine mechanical analysis, moisture equivalent, porosity, and apparent specific gravity of soils in tanks. About 20 per cent of the soil at the Santa Ana station was fine enough to pass a No. 200 screen. Soil in the San Bernardino tanks was considerably finer. Moisture-equivalent values as determined at Santa Ana were not constant, varying from 5.8 to 13.0 per cent in different tanks. The moisture equivalent of the top foot of soil at San Bernardino was about 30 per cent, or nearly twice that of the subsoil at a depth of 3 feet. Porosity tests of soil in tanks show an average of 40.2 per cent at Santa Ana and 47.4 per cent at San Bernardino.

8. Specific yield and specific retention in relation to high water tables, the sum of the two equaling the total porosity, also were determined. Each of these varies with the depth to the water table, the greater yield occurring with the least depth, and the greater retention with the greater depth. Porosity of the disturbed soil is about the same as in the undisturbed soil, but the specific yield is much less and specific retention is correspondingly greater. In the Chino silt loam at San Bernardino, the specific yield is small in comparison with the specific retention. The percentages measured as specific yield and

specific retention are apparent rather than real, as they apply only to conditions of high water table. True values can be obtained only when measured from a high column of soil, disregarding the fringe of capillary moisture.

9. Alkali deposits occurred on the surface of several soil moisture tanks at the Santa Ana station, depending in amount on the depth to water table in the tank. Much of this alkali was originally present in the soil, but it was increased by the small amounts in solution in the water consumed. During the first two seasons, when the soil tanks were covered during rain storms, the concentration of alkali on the surface increased month by month. During the third season, much of the surface deposit was carried back into the soil by rainfall penetration, causing a redistribution. Chemical analyses of soils taken from the tanks at the end of the investigation show a high pH value and where the water table was close to the tank surface a very high concentration of salts in the top inch of soil. As salt grass is alkali resistant it is doubtful if the rate of transpiration was affected.

Alkali was very much less in amount at the San Bernardino station, and no deposits occurred on the tank surfaces. Water used in the tests was from an artesian well and was relatively pure. The distribution of salts was greater in the top soil, decreasing in amounts toward the water tables. The same was true of the pH values.

Victorville Station

In November, 1930, an experiment station was established near Victorville for the purpose of measuring evaporation and transpiration losses from moist areas along the Mojave River and for recording meteorological data. The work was correlated with the stream flow measurements being made by the U. S. Geological Survey to determine the consumptive use of water between gaging stations at several locations on the river.

The experiment station was located in and on the bank of a small cienaga on the east side of the Mojave River. The equipment consisted of three tule tanks, a standard Weather Bureau evaporation pan, an anemometer, a set of standard maximum and minimum thermometers and a thermograph housed in a standard shelter, a rain gage and a ground well. Previous investigations regarding consumptive use of water by native vegetation along stream channels* indicate that if data from tanks are to be used in estimating losses from larger areas under field conditions, the tanks should be set in a field of natural growth similar to that in the tanks. Two tule tanks were therefore placed in the swamp, one 2 feet in diameter and the other 6 feet in diameter. A third tule tank, similar to those used at the Santa Ana, Prado, and San Bernardino stations, was set in the ground on the bank for the purpose of demonstrating the effect of exposure on the use of water by plants grown in tanks. The standard Weather Bureau evaporation pan was also placed on the bank with similar exposure.

Observations were made on evaporation, consumptive use of water from tules, wind movement, rainfall, and temperatures from February 1, 1931, to February 28, 1933. The results indicate the following conclusions:

* California State Department of Public Works Bulletin No. 33, Rainfall Penetration and Consumptive Use of Water in the Santa Ana River Valley and Coastal Plain, by Harry F. Blaney, C. A. Taylor, and A. A. Young. Chapter 4.

1. Based on the 25-month period of record, the mean annual consumptive use of water by tules growing in a tank 6 feet in diameter, located in a swamp with natural conditions replicated, was found to be 78.5 acre-inches per acre.

2. For the same period, the mean annual evaporation from a standard Weather Bureau pan located on the bank near the swamp was 82.5 inches. By applying a conversion coefficient of 0.7 to this value, the mean annual evaporation from a lake surface is indicated to be 58 inches.

3. The ratio of the mean annual consumptive use of water by the tules to the mean annual evaporation from the standard Weather Bureau pan for the period of record is 0.95.

4. Based on the mean record for the two growing seasons from May to October, inclusive, the evaporation from a lake surface is indicated to be 40 inches, while for the same period the consumptive use of water by tules would be 62 acre-inches per acre. This exceeds the loss by evaporation from the free water surface of a reservoir by 22 inches.

5. The investigation demonstrates the impracticability of applying to field conditions records of tests made in isolated tanks of tules grown apart from their natural environment.

Coldwater Canyon Investigations

The investigation into the losses occurring along the stream channels above the usual points of diversion was started in Coldwater Canyon near San Bernardino in 1931 and continued through 1932. The combined evaporation and transpiration by the native vegetation growing in the canyon was determined by accurately measuring the water at various points along the channel. The controls were on bed rock so that the amount of water entering the upper end of each section of channel was known as well as the amount leaving each section.

The losses from two sections of the canyon are reported, the average elevation above sea level of one being 2400 feet and of the other 2800 feet. The average width of the canyon bottom fill in the lower section is 49 feet, and in the upper section it is 44 feet.

The results of this study show a loss from the lower section of the canyon of 72 acre-inches per 1000 feet of canyon for the six-month period from May to October, inclusive, 1932. This is at the rate of 64 acre-inches per acre of canyon bottom fill. For the same period in the upper section of canyon, the loss was found to be at the rate of 50 acre-inches per acre of canyon bottom fill.

The evaporation from the water surface in the stream is shown to be only a small part of the total loss by evaporation and transpiration. The water surface of this stream is almost completely shaded and the evaporation rate would be greater in open areas where the water surface is exposed to the sun. The maximum loss in the canyon occurred during the month of August, 1932, being at the average rate of 0.44 acre-inch per acre per day in the lower section, and 0.35 acre-inch per acre per day in the upper section. In October the average rate of loss was 0.26 acre-inch per acre per day in the lower section and 0.20 acre-inch per acre per day in the upper section.

Enough water is consumed during the growing season along each mile of canyon similar to the lower section to meet the annual irrigation requirements of approximately 16 acres of citrus. For the upper section, the loss in each mile would meet the irrigation requirements of 11 acres of citrus.

Evaporation from Free Water Surfaces

The Bureau of Agricultural Engineering has been keeping evaporation records at several stations in southern California in cooperation with the State Division of Water Resources, since 1928. Other agencies also have been making observations. These agencies do not always use the same type of evaporation pan and results from the different types are not comparable. For this reason a cooperative, experimental key station has been established at Baldwin Park for the purpose of correlating the data being collected by the various organizations and for determining factors that may be used to reduce the observations on various types of evaporation pans to a comparable basis. This investigation is expected to continue for several years, until sufficient data are available for the purpose.

The Los Angeles County Flood Control District, the San Gabriel Valley Protective Association, the Pasadena Water Department, the California State Division of Water Resources, and the United States Geological Survey are cooperating with the Division of Irrigation, U. S. Bureau of Agricultural Engineering, in conducting this investigation. Three types of evaporation pans have been installed at the station:

1. Standard Weather Bureau pan, 4 feet in diameter by 10 inches deep, set upon a wooden platform above ground.

2. U. S. Bureau of Agricultural Engineering type, 6 feet in diameter by 3 feet deep, set 2.75 feet in the ground.

3. Los Angeles County Flood Control District type, 2 feet in diameter by 3 feet deep, set 2.75 feet in the ground.

Records of evaporation from free water surfaces in pans and tanks, collected by various agencies in southern California, are tabulated in Chapter V.

With few exceptions all records of evaporation are comparatively recent, the majority being obtained since 1929. The oldest record available, that at Pomona, was of short duration—from 1903 to 1905. One record was begun at South Haiwee Reservoir, Inyo County, in 1924, and one at Fairmont Reservoir in Antelope Valley in 1923 by the City of Los Angeles. Both records are continuous to the present date. The longest record available is at Chula Vista, San Diego County, maintained by the U. S. Weather Bureau continuously since 1918.

CHAPTER II

INVESTIGATIONS IN THE SANTA ANA RIVER VALLEY AND COASTAL PLAIN

By A. A. Young *

This chapter deals with the consumptive use of water in the Santa Ana River basin by various types of moist area native vegetation commonly found along stream beds, swamps and cienagas, and the evaporation from moist soil without vegetative growth.

As originally outlined the plan of the investigation was to determine by tank experiments the use of water by wild grasses, and evaporation from bare soil in moist areas. Two experiment stations were established, one at Santa Ana and one at San Bernardino in 1929, and a third, at Prado, was added in the following year. In the vicinity of each are certain areas with relatively high ground water supporting moist area native growth from which samples were selected for transplanting into tanks for study.

A progress report giving results of studies at Santa Ana and San Bernardino stations of consumptive use of water by salt grass and Bermuda grass, and evaporation from uncultivated bare soil for the year ending May 1, 1930, has been published.** Since that bulletin was written several changes and additions have been made to the original set-up and the experiments have been extended to include the measurement of consumptive use of water by round stem tules and triangular stem tules, cat-tails, wire rush and willows grown in tanks. These studies were continued for an additional two years following the published progress report in 1930, and the data assembled during that period are presented herewith as a final report† of the investigations made.

SANTA ANA STATION

Description of Site

Following a survey of western Orange County early in 1929, in which a study was made of soil type and soil moisture conditions, a small plot of ground was selected as the site for the Santa Ana experiment station for studies of consumptive use of water by moist area vegetation. The plot is in a level 10-acre field of small native vegetation, 4 miles west of Santa Ana and about 7 miles inland from the coast. It is free from windbreaks and shade and is generally suitable in regard to soil, climatic conditions, and exposure to the elements for the studies undertaken. The station ground is 50 by 100 feet and is surrounded by a tight woven wire fence for protection. Plate I is a general plan of the station showing the arrangement and uses of the various tanks.

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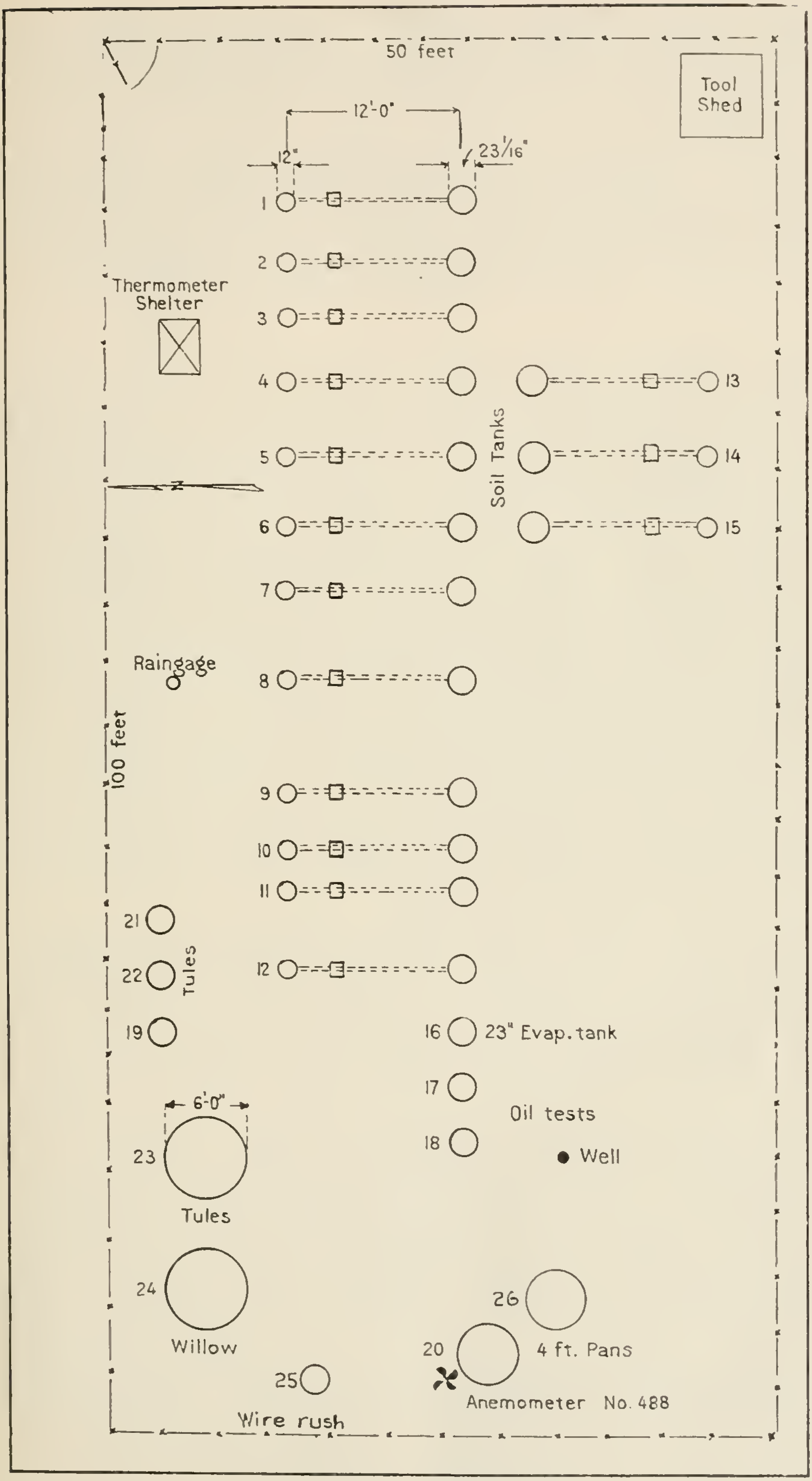
* Assistant Irrigation Engineer, Division of Irrigation, Bureau of Agricultural Engineering, U. S. Department of Agriculture.

** Part II. Bulletin No. 33, Rainfall Penetration and Consumptive Use of Water in the Santa Ana River Valley and Coastal Plain. 1930. State of California, Department of Public Works, Division of Water Resources.

† Credit is due to Dean C. Muckel, Junior Civil Engineer, Bureau of Agricultural Engineering, for valuable assistance in collection of data from October, 1930, to December, 1931, and in preparation of the report.

PLATE I



PLAN OF SANTA ANA STATION.

The climatic conditions at this point are representative of the coastal climate of southern California. Summers are warm and dry while winters are moderate. Coastal fogs are of frequent occurrence and tend to modify evaporation from water surfaces and transpiration losses by plants.

Soil at the station is of alluvial origin, classified as Hanford fine sandy loam which grades into coarse yellow sand at a depth of 6 to 7 feet.* It is probably lacking in humus and contains a small amount of alkali although not enough to affect the growth of the type of vegetation under investigation. An ample supply of good water for use in the experiment tanks was found at a depth of a few feet.

Station Equipment

The equipment first installed early in 1929 consisted of 12 soil tanks, each connected to a Mariotte supply tank, a set of maximum and minimum thermometers and a thermograph set in an instrument shelter, a standard rain gage, a standard Weather Bureau evaporation pan, a circular sunken evaporation tank of the same diameter as the soil tanks and a shallow well with a hand pump to supply water for the various tanks. Later, two anemometers and three additional soil tanks with Mariotte control were added, making 15 soil tanks in all.

Soil tanks are of the double type with an annular space between the inner and outer shell. The inner tank, $23\frac{1}{16}$ inches in diameter by 6 feet in depth, is suspended in the outer tank by means of a heavy angle-iron rim around the top. The bottom of the inner tank is removable and bolted in place by long rods to the supporting top rim. The inner tank holds soil, and the outer is a reservoir for water which passes into the soil through perforations in the tank wall and in the bottom plate. Each soil tank unit is connected by a pipe to a Mariotte supply tank which regulates the height of the water table in the annular space between the inner and outer tank walls and supplies water to the tank growth as needed.

From time to time additional tanks of simple construction were added in which tules, cat-tails, willows and wire rush were grown in order to measure consumptive use of water by each variety. One tule tank and one tank for willows were each 6 feet in diameter by 3 feet deep. Smaller tanks, used for other swamp growth, were each $25\frac{1}{2}$ inches in diameter by 2.7 feet deep. Each of the 6-foot tanks used water in such quantities that it was necessary to provide them with supply tanks equipped with automatic feed control to provide water as needed, and at the same time hold the water level in the crop tank at a constant level. This could have been accomplished by Mariotte control, but in this case a needle valve operated by a float was found satisfactory. When the water surface in the crop tank dropped, due to transpiration and evaporation losses, the float dropped also, opening the needle valve and admitting more water. When the water surface returned to its original level, the valve closed and the flow ceased. A water glass and a graduated scale on the side of the supply tank allowed readings of amounts of water withdrawn. This type of control has been in use at all three stations during the investigations.

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* Soil Survey of the Anaheim Area, California. Bureau of Soils, U. S. Department of Agriculture.

The evaporation pan was set upon a wooden grillage in accordance with instructions issued by the United States Weather Bureau for pans of this type. Evaporation losses were measured by a hook gage graduated to thousandths of a foot and mounted on the side of the pan. At the northwest corner of the grillage an anemometer was mounted on a stand so that the level of the cups was about 12 inches above the top of the pan and about 24 inches above the ground surface. Originally, a second anemometer was set 12 inches above the ground surface, midway in the row of soil tanks, to measure ground wind, but it was used only during the first year of the investigation.

Method of Filling Soil Tanks

Heretofore a method frequently used for placing soil in experiment tanks has been to separate layers of soil as excavated from a trench and place them in the tank in the same order as originally found in the ground. This process broke up the soil structure, increased the volume, and changed the density. If tamped into the tank, alternate layers of loose and dense material resulted, with structural arrangements of soil particles entirely different from the original. Soil moisture experiments with soil so placed have not always proved satisfactory. To rectify this condition the first tanks used in this investigation were filled without materially changing the original soil structure. The plan followed was to fill each tank by forcing the bottomless inner shell over a core of soil of the same diameter of the tank until full, at the same time excavating around the tank shell as the filling proceeded.

At first use was made of a heavy screw jack resting upon a crib of timber blocks, which in turn rested upon the angle-iron rim, with the jack working against an overhead cable anchored in the ground on each side of the excavation. As the tank sank into the soil under the pressure, a gradually increasing pile of cribbing was used to support the jack against the cable. The anchors to which the cable was fastened were of a type generally used to anchor guy wires and were set in auger holes bored in the ground.

Friction of soil against the outside of the tank was relieved by excavating around the tank as the work proceeded. This excavation generally kept a few inches ahead of the cutting edge of the tank, cutting a core slightly larger than the tank diameter, the core being shaved to the proper size as the cutting edge of the tank moved downward.

As the tank gradually filled, the skin friction on the inside rapidly increased, tending to cause compression in the soil. After the first two or three attempts, it was found that the tank shell would slide over the trimmed core of soil more readily if a sharp blow was given at the top of the tank, using a short piece of timber as a driver. This impact broke the bond of the inside friction, resulting in less tendency toward soil compression and allowed increased speed in the work. A few of the last tanks to be filled were driven over the trimmed core of soil by impact alone.

When the inner tank shell was filled, the soil column was cut off by jacking the bottom plate across the bottom edge of the tank and bolting it to the angle-iron rim at the top. The whole was then hoisted above the ground by chain block and tripod. The outer shell was then set in place in the excavation, and the inner shell with its soil content was lowered into the outer, where it hung suspended from the heavy iron rim around the top.

As a means of comparing results of evaporation from similar soil placed in tanks by different methods, three tanks of the same size as those described were filled with loose soil taken from an excavation made to a depth of 6 feet. In making the excavation each foot of soil removed was kept separate from the others and placed in the tanks in the original order, foot by foot. Before the tank was completely filled, it was flooded with water to compact and settle the material in a uniform manner. Water was added from time to time until it drained from the bottom through a pipe connection. Very little settlement occurred after the initial settlement and there is no doubt as to this method producing a more uniform soil density than is obtained by placing and tamping the soil in layers.

The Mariotte Tank

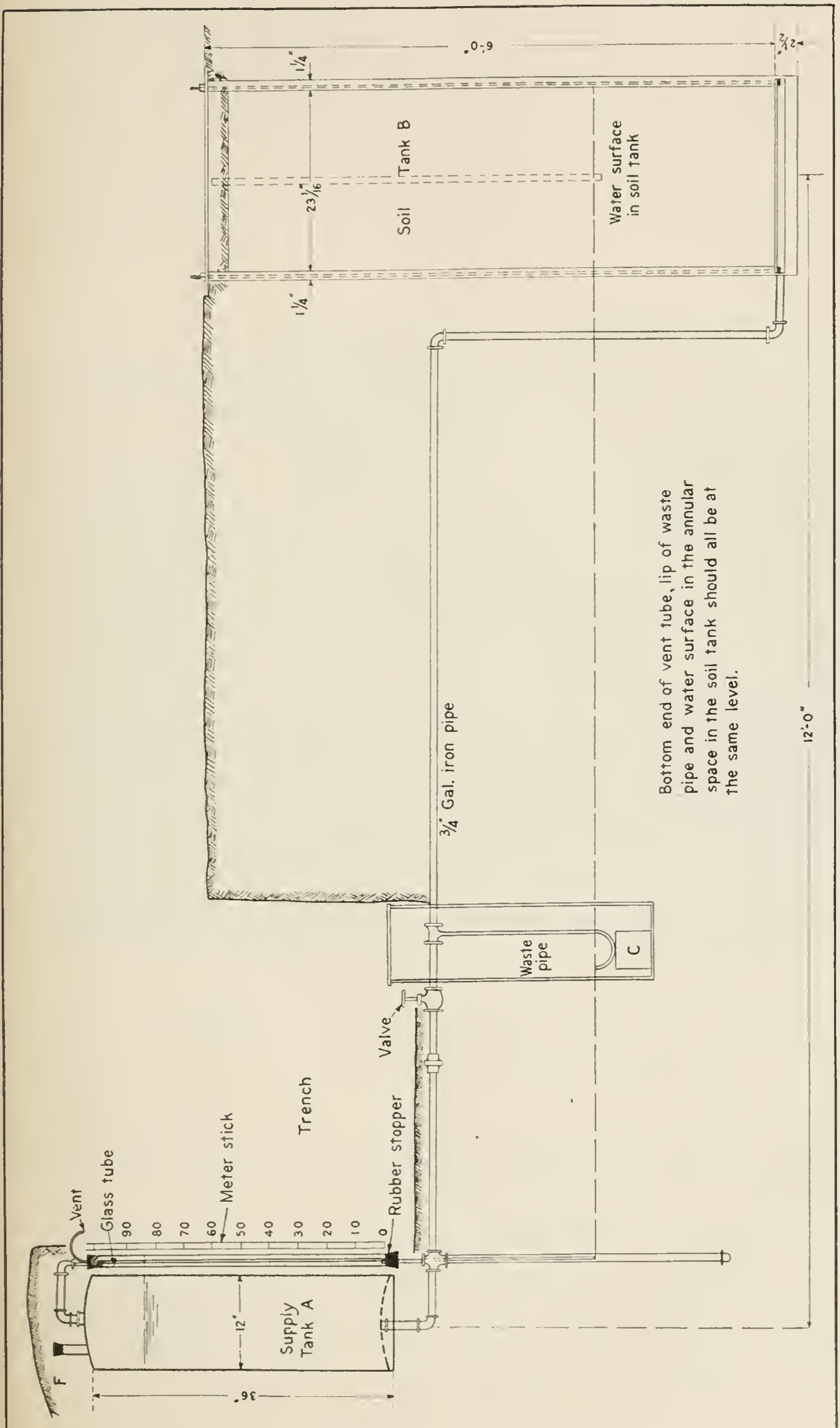
This device consists essentially of a supply tank equipped on the principle of the Mariotte flask to supply water to the soil tank through a connecting pipe. A 12- by 36-inch galvanized-iron range boiler, chosen because of its solid construction, rigidity of its connections, and practicability of keeping it air-tight, was found satisfactory for the purpose. Mounted upon the side of the supply tank is a vertical length of glass tubing, each end of which is fitted with a rubber stopper perforated to admit a small connecting pipe. The lower pipe connects with the supply pipe between the Mariotte tank and the soil tank, while the upper connects with the top of the supply tank. Upon the glass tube is mounted a meter stick or scale upon which differences in daily readings determine the amount of water withdrawn. A valve in the connecting pipe makes it possible to shut off the flow of water when the supply tank is being refilled. A waste pipe also is set into the connecting pipe to discharge excess water from the soil tank into a receiving vessel. The lip of the waste pipe is set at the level of the water in the soil tank. The tank equipment is shown in Plate II.

A vent tube of small diameter passes through the rubber stopper at the top of the glass gage. This tube is open at both ends and the level of the soil water is determined by the elevation of the bottom end of the vent. In Plate II, the water table in the soil tank is shown as being at such a depth that it is necessary to extend the vent tube downward into an extension well below the supply pipe.

Previous experience has determined that variations in temperature cause changes in the vapor pressure in the Mariotte tank above the water surface, causing fluctuations in the water level. Every effort was made, therefore, to insulate the Mariotte tanks against temperature changes. The Santa Ana Mariotte tanks were completely buried in the ground except for a small entrance provided with a narrow doorway for making readings of the graduated scale. They were further protected from the cooling effect of rainfall on the surrounding soil by a galvanized iron roof, beneath which was free circulation of air.

For the benefit of those who may be interested in the theory of operation of the Mariotte tank, a brief description follows. The vent tube provides the Mariotte control feature which maintains a constant water level in the connected soil tank. In operation, the Mariotte tank is filled with water and the valve in the connecting pipe is opened,

PLATE II



MARIOTTE TANK CONNECTED TO SOIL TANK TO MAINTAIN A CONSTANT WATER LEVEL IN THE SOIL AND SUPPLY WATER EVAPORATED OR TRANSPIRED, SANTA ANA STATION 1929-1932.

allowing water to flow to the soil tank. As the water level drops in the supply tank a partial vacuum is formed above the water surface and the water drops in the vent tube from the original level to a point depending upon the degree of vacuum established. This point is determined by the difference in the pressure heads, due to atmospheric pressure and the partial vacuum in the supply tank. Water will continue to fall in the vent tube, but at a greater rate than in the Mariotte tank, until the pressure head corresponding to the atmospheric pressure minus the pressure head caused by the partial vacuum is balanced by a column of water equal to the difference in elevation between the water surface in the Mariotte tank and the bottom of the vent. Water will then stand in the vent at the bottom of the tube with the pressure at this point atmospheric.

If the water continues to flow, air will enter the glass gage through the vent tube, bubbling upward through the water in the gage to enter the top of the supply tank. Water will continue to rise in the soil tank up to the level of the lower end of the vent, at which point the atmospheric pressure in the soil tank and the bottom of the vent tube is the same. As there is no difference in pressure and both points are at the same level, there is no head to cause further flow and bubbling will cease. When the water table in the soil falls below the bottom of the vent, the balance of pressures is again disturbed and a flow of water will again start from the Mariotte tank, replacing the amount used.

Some of the difficulties in the accurate use of the Mariotte tank should not be overlooked. As the partial vacuum in the tank must be maintained at all times, pipe connections must be air-tight. Air leaks through the many joints in the system disturb the balance of pressure necessary for automatic control. Thorough insulation against temperature changes inside the tank have been previously mentioned. Such changes cause expansion or contraction of the tank itself, of the water in the tank and also of the air in the chamber above the water. The combined result is to cause changes in the vapor pressure with a resulting influence upon effective regulation.

Water in the glass tube will fall with an increase in temperature in the Mariotte tank, and readings on the scale taken at this time will be erroneous. A test of the effect of temperature on scale readings showed that an increase of 30° F. in air temperature caused a fall of 1 cm. in the water surface in the glass gage. The temperature change inside the Mariotte tank during the test was not measured. When the temperature returned to the starting point the water in the gage returned to its original position. If the gage readings are taken at an early morning hour each day, the difference in the readings will represent a true rate of loss as early morning temperature changes are too small to affect vapor pressure. Readings taken at other times of the day may be in error unless complete insulation of the supply tank is effected.

SAN BERNARDINO STATION

Description of Site

In choosing a site for tank experiments in the upper Santa Ana River Valley, a small plot on the grounds of the Antil Pumping Plant of the San Bernardino Water Department,* about 1 mile east of town,

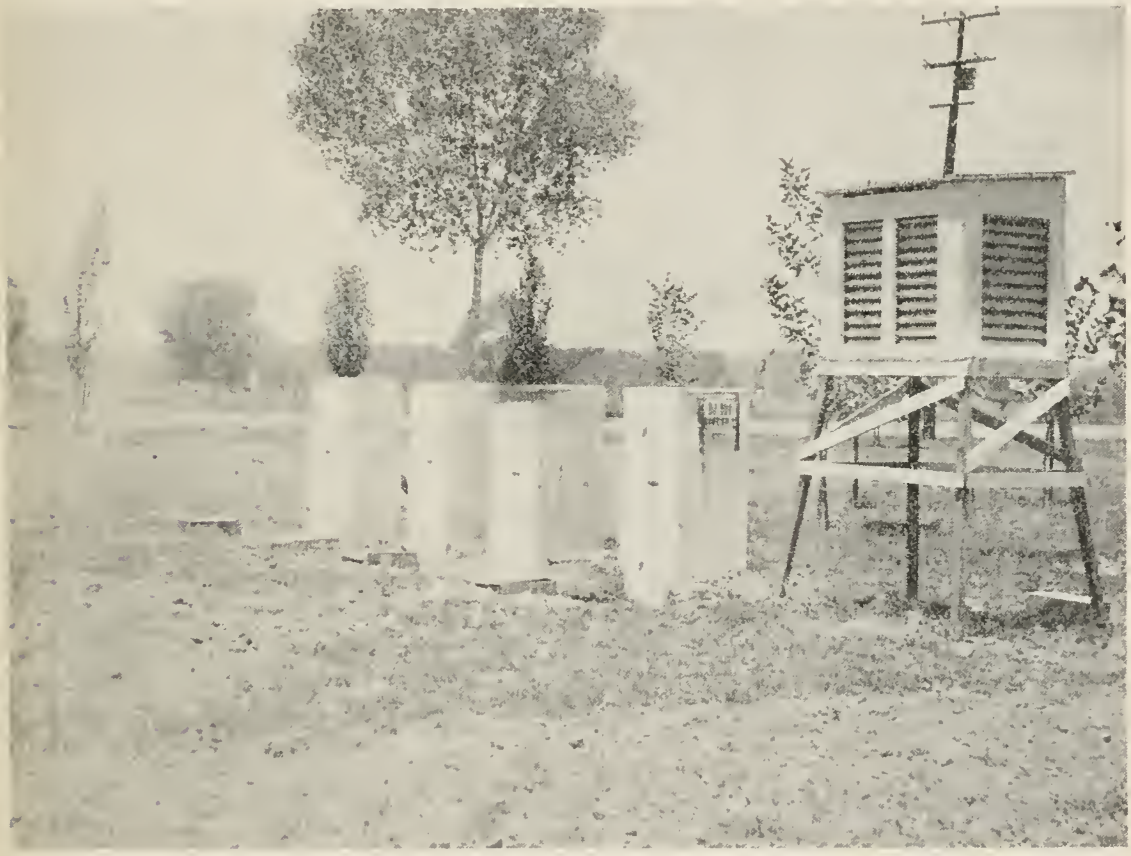
* The Municipal Water Department of the City of San Bernardino, through the courtesy of William Starke, assisted in maintaining this station.

was selected after a study of soil and ground-water conditions in the vicinity. The plot lies in a level field of Bermuda grass, at some distance from any buildings, and has excellent exposure.

Climatic conditions at this point are representative of the interior climate of southern California, and summers are hot and dry. Winter temperatures are lower than at the Santa Ana station, and rainfall is greater.

Soil used in the experiment tanks was taken in place at the station site and is classified as Chino silt loam.* Although the location of the station is in an area of high ground water, no evidence of alkali appeared on the tank surfaces during the 3 years of operation. Fluc-

PLATE III



BOARD HOUSING FOR MARIOTTE TANKS AT SAN BERNARDINO.

tuations of ground water level, varying from $2\frac{1}{2}$ to 6 feet from the surface, occur each year, being lowest during the summer months. The station is supplied with artesian water from the city pumps.

Station Equipment

Tank equipment at the San Bernardino station is similar to that at Santa Ana, although not the same in number of tanks. Four soil tanks, each $23\frac{1}{16}$ inches in diameter, were set with their tops level with the ground surface. Because of existing high ground water, these are 40 inches in depth instead of 6 feet. Each tank is connected with a Mariotte supply tank to furnish water to the soil tank as needed and to maintain a constant water level in the soil.

* Soil Survey of the Riverside Area, California. Bureau of Soils, U. S. Department of Agriculture.

Because of ground water conditions, it was not deemed advisable to set the Mariotte tanks underground for protection from temperature changes as at Santa Ana. Instead, each tank was placed above ground enclosed in a white painted board shelter. This is shown in Plate III. Each shelter box has a narrow doorway opening before the glass gage and a hinged top to allow access for refilling the tank when empty. To provide insulation against temperature changes as much as possible, the space between the tank and the sides of the box are filled with wood shavings and the tank is wrapped with asbestos paper.

Evaporation was measured from a standard Weather Bureau pan mounted on a timber grill and from a ground tank $23\frac{1}{16}$ inches in diameter by 2.7 feet in depth. This tank was set with the rim 3 inches above the ground surface and the water surface was held near the ground level. All evaporation readings were obtained with a hook gage equipped with a vernier reading to thousandths of a foot. A four-cup anemometer was mounted on the platform of the pan, with the cups about 12 inches above the top of the pan.

A single tank, $23\frac{1}{16}$ inches in diameter by 2.7 feet in depth, was used in which consumptive use of water by round stem tules in submerged soil was measured. It was set in the ground with about 3 inches of the rim exposed and connected to a supply tank through a float arrangement, previously described. A glass gage and a graduated scale mounted on the side of the supply tank allowed measurements of water withdrawn for plant use.

Additional equipment consisted of maximum and minimum thermometers housed in a standard shelter and an 8-inch rain gage:

PRADO STATION

Description of Site

A small station was established near Prado on the Santa Ana River, midway between Santa Ana and San Bernardino, during the summer of 1930, for collection of meteorological records, measurement of evaporation from a water surface, and consumptive use of water by triangular stem tules. The site is on slightly sloping ground near the lower end of the Prado basin and is fully exposed to sun and wind.

The climate is intermediate between the interior climate at the San Bernardino station and the coastal climate at Santa Ana, as it is tempered by the ocean breezes blowing through the Santa Ana canyon into the Prado basin. This station was operated in cooperation with the U. S. Geological Survey.

Station Equipment

The Prado station is equipped with a standard Weather Bureau evaporation pan, a ground tank growing tules for measurement of consumptive use of water, a thermograph housed in a standard shelter, a rain gage, and an anemometer. The evaporation pan and the tule tank are each equipped with a supply tank connection operating through a float valve arrangement to supply and maintain a constant water level in the pan or the tank. Use of water in each case is measured on the chart of a water stage recorder mounted with a float in the supply tank. This arrangement operates satisfactorily, the hourly rate of use being computed from the chart. A barograph also is used at intervals. The station is protected from intrusion by a high wire fence with a gate, which is kept locked.

METEOROLOGICAL RECORDS

The three experiment stations just described are spaced at nearly equal intervals of about 25 miles along the Santa Ana River. While the distances between the stations are not great, the topography of the area is such as to cause material differences in climate. The Santa Ana River Valley is divided into two distinct basins, known as the upper and lower, connected by the lower Santa Ana canyon. The Santa Ana station lies on the coastal plain of Orange County below the canyon and has a distinctly coastal climate characterized by ocean breezes and light summer fogs, both of which modify the summer temperatures. The Prado station, in Prado basin, Riverside County, is in the lower part of the upper basin at the upper end of the canyon. It is slightly remote from the coast but not far enough away to be removed entirely beyond the effect of the coastal breeze. The principal difference is the absence of coastal fog, with some increase in temperature. The San Bernardino station, San Bernardino County, in the upper basin, is removed farther from the effect of ocean modifying influences. The climate is classed as interior and the temperature is higher in summer than at either of the other two stations.

The prevailing winds are from the southwest, off the ocean, and pass through the Santa Ana canyon by the Prado station. The total yearly wind movements here and at Santa Ana are about equal, but during the summer months the greatest movement occurs at Prado. This condition combined with higher summer temperature results in a higher rate of evaporation than at the other stations.

Rainfall is deficient throughout the whole of the Santa Ana River basin except in the higher mountain districts, and occurs almost entirely between November and April, inclusive. Other months are almost devoid of precipitation.

Meteorological data for the three stations for the period of the investigation, showing monthly mean maximum, mean minimum and mean temperatures, rainfall, and wind movement in miles per month are given in Tables 1 to 3, inclusive. Rainfall at Santa Ana and San Bernardino is shown for storm periods in Tables 4 and 5.

TABLE 1

MONTHLY TEMPERATURES, RAINFALL, AND MILES OF WIND MOVEMENT AT SANTA ANA STATION

Month	Temperature, degrees Fahrenheit					Rainfall in inches	Wind movement in miles
	Mean maximum	Mean minimum	Mean	Maxi-mum	Mini-mum		
1929—							
May	74	51	63	91	41	0.03	----------
June	76	53	65	95	43	.11	----------
July	81	60	71	89	52	----------	----------
August	85	60	73	96	51	----------	----------
September	79	58	69	98	42	.35	1,695
October	80	52	66	101	36	----------	1,745
November	77	41	59	91	33	----------	1,806
December	72	41	57	86	30	----------	1,547
1930—							
January	62	40	51	76	30	5.55	1,743
February	66	44	55	87	33	.55	1,682
March	68	46	57	89	33	2.99	2,212
April	72	47	60	88	39	.80	1,970
May	70	48	59	83	40	1.23	2,228
June	75	55	65	88	47	.02	1,871
July	81	57	69	95	48	----------	1,671
August	82	59	71	93	51	----------	1,518
September	77	54	66	90	48	.02	1,381
October	80	47	64	95	39	.07	1,322
November	77	43	60	95	30	1.47	1,534
December	70	36	53	82	24	----------	1,389
1931—							
January	68	40	54	85	30	3.82	1,382
February	68	45	57	75	49	2.28	1,378
March	76	42	59	92	33	.03	1,830
April	76	49	63	88	41	2.68	1,736
May	77	56	67	92	50	.67	1,781
June	81	56	69	99	49	.07	1,670
July	85	64	75	94	57	----------	1,656
August	84	62	73	96	56	.43	1,415
September	84	55	70	97	43	.29	1,201
October	79	50	65	97	39	.09	1,121
November	68	42	55	83	28	1 69	1,223
December	63	37	50	73	30	4.70	1,136
1932—							
January	61	37	49	77	30	2.04	1,335
February	62	40	51	87	29	4.53	1,371
March	69	41	55	87	33	----------	1,510
April	72	42	57	89	35	.35	1,659

TABLE 2

MONTHLY TEMPERATURES, RAINFALL AND MILES OF WIND MOVEMENT AT PRADO STATION

Month	Temperature, degrees Fahrenheit					Rainfall in inches	Wind movement in miles
	Mean maximum	Mean minimum	Mean	Maxi-mum	Mini-mum		
1930—							
June	81	49	65	102	40	----------	----------
July	92	52	72	106	42	----------	2,034
August	90	55	73	100	47	----------	1,858
September	82	50	66	103	41	----------	1,540
October	82	41	62	101	28	0.27	1,232
November	77	39	58	98	25	1.43	1,438
December	----------	----------	----------	----------	----------	----------	1,950
1931—							
January	----------	----------	----------	----------	----------	2.47	1,738
February	----------	----------	----------	----------	----------	3.53	979
March	----------	----------	----------	----------	----------	.09	1,373
April	----------	----------	----------	----------	----------	2.17	1,646
May	80	52	66	94	43	.55	1,970
June	85	53	69	100	46	----------	1,840
July	94	63	79	105	53	----------	2,240
August	93	61	77	106	53	.16	1,922
September	89	52	71	102	41	.15	1,496
October	81	49	65	95	39	1.89	1,249
November	69	37	53	93	23	2.69	1,257
December	----------	----------	----------	----------	----------	4.77	1,223
1932—							
January	----------	----------	----------	----------	----------	2.29	1,679
February	----------	----------	----------	----------	----------	5.29	1,217
March	----------	----------	----------	----------	----------	.12	1,512
April	----------	----------	----------	----------	----------	.82	1,313
May	----------	----------	----------	----------	----------	----------	2,116
June	82	50	66	102	43	----------	2,285
July	85	54	70	92	45	----------	2,418
August	88	54	71	102	44	----------	2,304
September	84	54	69	98	49	----------	1,892
October	79	47	63	92	32	.73	1,743
November	83	39	61	93	29	----------	1,398
December	65	34	50	85	27	----------	1,578

TABLE 3

MONTHLY TEMPERATURES, RAINFALL AND MILES OF WIND MOVEMENT AT SAN BERNARDINO STATION

Month	Temperature, degrees Fahrenheit					Rainfall in inches	Wind movement in miles
	Mean maximum	Mean minimum	Mean	Maximum	Minimum		
1929—							
May	82	47	65	94	37	----------	----------
June	88	50	69	108	39	0.12	----------
July	95	57	76	106	49	----------	----------
August	98	60	79	106	51	----------	----------
September	88	55	72	107	41	.53	1,012
October	85	46	66	98	31	----------	1,183
November	80	34	57	91	26	----------	1,589
December	75	33	54	85	25	----------	1,255
1930—							
January	61	36	49	76	24	4.71	1,434
February	74	38	56	87	31	1.06	1,357
March	70	41	56	88	28	3.99	1,864
April	77	45	61	95	35	1.33	1,143
May	74	43	59	95	34	1.76	947
June	86	52	69	101	42	----------	900
July	96	54	75	106	43	----------	679
August	95	57	76	104	50	----------	879
September	84	50	67	102	42	----------	895
October	82	44	63	94	34	1.24	1,086
November	77	39	58	90	28	2.08	1,257
December	72	27	50	79	19	----------	----------
1931—							
January	68	35	52	82	25	2.15	----------
February	66	40	53	73	30	3.73	----------
March	76	37	57	92	24	.60	----------
April	79	44	62	94	35	2.73	----------
May	83	52	68	95	42	.89	----------
June	86	53	70	101	46	.06	748
July	98	62	80	107	53	----------	798
August	95	61	78	108	51	1.57	890
September	89	51	70	99	40	.24	816
October	81	47	64	100	37	1.14	797
November	69	37	53	93	23	3.17	1,177
December	----------	----------	----------	----------	----------	3.59	1,013
1932—							
January	----------	----------	----------	----------	----------	2.61	902
February	----------	----------	----------	----------	----------	5.99	1,168
March	----------	----------	----------	----------	----------	.20	1,391
April	----------	----------	----------	----------	----------	.72	1,391

TABLE 4
RAINFALL BY STORMS AT SANTA ANA STATION

1929-30		1930-31		1931-32	
Storm period	Rainfall in inches	Storm period	Rainfall in inches	Storm period	Rainfall in inches
1930—		1930—		1931—	
Jan. 5-6	0.80	Oct. 8-9	0.07	Oct. 1	0.01
Jan. 9-19	4.27	Nov. 13-17	.65	Oct. 8	.02
Jan. 26-27	.48	Nov. 26-29	.82	Oct. 17-19	.06
Feb. 20-22	.45			Nov. 1-2	.03
Feb. 26-27	.10	1931—		Nov. 7-11	.20
Mar. 3-5	.41	Jan. 1	.40	Nov. 14-15	.83
Mar. 13-18	2.51	Jan. 5-8	2.49	Nov. 26-27	.63
Mar. 29	.07	Jan. 13	.10	Dec. 8	1.49
April 29-30	.80	Jan. 23	.03	Dec. 10-11	.16
May 1-4	1.19	Jan. 30-31	.80	Dec. 14	.50
May 8	.02	Feb. 3-4	1.82	Dec. 20-25	.87
May 16	.02	Feb. 6	.04	Dec. 29-31	1.68
June 20	.02	Feb. 8	.01		
Sept. 30	.02	Feb. 10-12	.41	1932—	
		Mar. 11	.03	Jan. 1-3	.23
		April 21-27	2.68	Jan. 12-15	.78
		May 24-25	.67	Jan. 26	.03
		June 4-5	.05	Jan. 31	1.00
		June 25	.02	Feb. 1-9	3.26
		Aug. 12	.02	Feb. 13-18	1.27
		Aug. 28	.41	April 24-26	.35
		Sept. 2-3	.02		
		Sept. 24-25	.04		
		Sept. 30	.23		
Totals, October 1 to September 30	11.16		11.81		13.40

TABLE 5
RAINFALL BY STORMS AT SAN BERNARDINO STATION

1929-30		1930-31		1931-32	
Storm period	Rainfall in inches	Storm period	Rainfall in inches	Storm period	Rainfall in inches
1930—		1930—		1931—	
Jan. 5-14	4.23	Oct. 8-10	1.24	Oct. 1	0.13
Jan. 26-27	.48	Nov. 13-17	1.45	Oct. 18	1.01
Feb. 19-26	1.06	Nov. 26-27	.63	Nov. 7	.02
Mar. 4-5	.48			Nov. 10-11	.16
Mar. 14-16	2.39	1931—		Nov. 14-15	1.35
Mar. 30-31	1.12	Jan. 1-2	.83	Nov. 19	.25
April 13-14	.02	Jan. 5	.33	Nov. 26-27	.99
April 28-30	1.31	Jan. 7-8	.69	Nov. 30	.40
May 1-4	1.54	Jan. 31	.30	Dec. 8	1.02
May 8	.11	Feb. 1	.35	Dec. 10-11	.42
May 17-18	.11	Feb. 4-6	2.28	Dec. 14	.23
		Feb. 8	.05	Dec. 20-21	.21
		Feb. 11-15	.67	Dec. 25	.36
		Feb. 19	.38	Dec. 27-28	1.35
		Mar. 24	.60		
		April 22-29	2.73	1932—	
		May 25-26	.89	Jan. 1	.34
		June 5	.06	Jan. 12-13	.40
		Aug. 10-11	.36	Jan. 15	.49
		Aug. 28-29	1.21	Jan. 26	.06
		Sept. 2	.09	Jan. 31	1.32
		Sept. 25	.09	Feb. 1	.53
		Sept. 30	.06	Feb. 6-9	2.95
				Feb. 13-18	2.47
				Feb. 29	.04
				Mar. 2	.01
				Mar. 14	.19
				April 24-27	.72
Totals, October 1 to September 30	12.85		15.29		17.42

OPERATION OF TANKS

Sources of Errors in Tank Experiments

In conducting investigations of the consumptive use of water by plant life two methods, each of which has certain advantages when used under the proper conditions, are available to the investigator. These are as follows:

1. Determination of consumptive use by field-grown crops by studying soil samples taken with a soil tube.
2. Quantitative measurements of consumptive use by crops grown in tanks.

Both methods have been used since studies were first begun in this field, but as knowledge of the subject increased there have been improvements in both method and equipment. The practice of taking field soil samples at various depths by means of the soil tube for determination of soil moisture is applicable to practically all conditions of soil and crop, and consumptive use of water data may be derived from results so obtained. Similar results may be obtained by measurement of water applied to crops grown in tanks. On account of limitations in the size of tanks that may be used in experimental work, such experiments generally include only field or other crops having limited root systems.

Previous investigators have approved the tank method of studying consumptive use of water, though it is subject to some errors which must be overcome as far as possible to secure applicable results. Hence, it is necessary to have some knowledge of the various sources of error. The factors influencing transpiration determinations with rooted plants in tanks as sources of experimental errors have been outlined by Kiesselbach* as follows:

1. Character of potometer and contents.
    a. Limitation of amount of soil.
        1. Through size of potometer.
        2. Through number of plants grown in potometer.
    b. Limitation of fertility of soil.
    c. Improper distribution of soil moisture.
    d. Evaporation from surface of soil.
    e. Entrance of rain water.
    f. Exposure of potometer and consequent effect on soil temperature.
    g. Unintentional lack of uniformity in soil.
2. Environment.
    a. Testing under unnatural habitat.
3. The plant.
    a. Plant individuality.
        1. Insufficient number of replications.
        2. Disease and injury.
    b. Stage of maturity.
        1. Insufficient development.
4. Errors due to methods of computation.
5. The personal element in drawing conclusions.

These factors apply also to transpiration plus soil evaporation, which is termed consumptive use of water or sometimes use of water. In the investigation reported herein a number of these sources of error were anticipated and efforts were made to minimize them by the selection of tanks of sufficient size to provide soil capacity for proper growth of the types of vegetation chosen for study, by the method of filling the tanks with undisturbed soil and by protection from exposure to

* Transpiration as a Factor in Crop Production, Nebraska Agricultural Experiment Station Research Bulletin No. 6, by T. A. Kiesselbach. 1916.

diurnal changes of temperature by setting all tanks in the ground with the tops level with the ground surface. The growth in any tank should not exceed the number of plants of the same crop ordinarily grown in an equal area under normal field conditions. Not only should the area per plant be maintained but also the volume of soil available for plant roots is important. In tanks having high water tables the soil volume is sometimes limited, curtailing growth of the root system and likewise affecting the aerial growth. Moreover, a small volume of available soil will soon lose its fertility if heavily cropped. This is especially true of any investigation extending over more than one crop year when the soil in the tank is unchanged. A sufficient lack of soil fertility may result in a higher water requirement per unit of dry matter produced and be the cause of a considerable source of error.

A further error also exists when the spread of area of foliage grown in a tank exceeds the tank area. Cases of this kind are found when the growth droops or spreads beyond the tank limits. In such a case computation of consumptive use per unit of tank area gives an amount in excess of the true consumptive use as the crop area is in excess of the tank area.

Experimental records of consumptive use of water by plant growth in tanks include evaporation from the soil as well as water transpired through the stomata of the plant leaf. To the agriculturist and others interested in determining the amount of irrigation water which should be applied to soil in order to produce a normal crop, a separation of the water losses into evaporation and transpiration is not important and the water requirement of a crop as determined by experiment generally includes both soil evaporation and plant transpiration. In making such experiments, evaporation and transpiration can not readily be separated from each other except through the use of methods that are inapplicable to field conditions. Evaporation from soil tanks having the same climatic exposure varies with the degree of soil saturation, soil texture, and crop shading. In the tanks used in the experiments described herein both the degree of crop shading and the soil moisture at the tank surface varied greatly. Both are greatest for those tanks having the highest water tables. It is evident, therefore, that it is not proper to subtract soil evaporation from consumptive use of water by the crop to arrive at the transpiration alone.

Lack of natural environment is also an important source of error in conducting consumptive use of water studies by the tank method. As transpiration and evaporation are closely related to climatic conditions, tank experiments with crops must be conducted where the experimental growths can be maintained in their natural environment. Experiments with field crops should be carried on in fields of the same crop variety, those with grasses should be in meadows where the same kind of grass has a natural growth and experiments with swamp growth must be conducted in a swamp area where humidity is high, to obtain results that are at all comparable with actual swamp consumptive use.

Santa Ana Station

Because of errors which might occur in the use of water by evaporation or consumptive use of water by crops in different soil tanks, it was thought best to operate all tanks in sets of three, the depth to water level and variety and age of crop being identical in each. Twelve tanks were filled with undisturbed soil and three with loose soil settled in water. Complete installation data on tanks in use at the Santa Ana station, giving the diameter, the use made, period covered by test, content, and depth to water table are shown for each tank in Table 6.

TABLE 6

INSTALLATION DATA ON TANKS USED AT SANTA ANA STATION

Tank number[1]	Diameter of tank in inches	Purpose of tank	Period of test		Content of tank	Depth to water table in feet
			Beginning	Ending		
1-2-3	23 1/16	Evaporation	May, 1929	Oct., 1929	Bare soil	4
1-2-3	23 1/16	Evaporation	Oct., 1929	Oct., 1930	Bare soil	3
1-2-3	23 1/16	Use of water	Oct., 1930	April, 1932	Salt grass	3
4-5-6	23 1/16	Evaporation	May, 1929	Oct., 1930	Bare soil	2
4-5-6	23 1/16	Use of water	Oct., 1930	April, 1932	Salt grass	2
7-8-9	23 1/16	Use of water	May, 1929	Oct., 1930	Salt grass	2
7-8-9	23 1/16	Use of water	Oct., 1930	April, 1932	Salt grass	1
10-11-12	23 1/16	Use of water	May, 1929	Oct., 1930	Salt grass	4
10-11-12	23 1/16	Use of water	Oct., 1930	April, 1932	Salt grass	5
13-14-15	23 1/16	Evaporation	July, 1929	Oct., 1930	Bare soil	2
13-14-15	23 1/16	Use of water	Oct., 1930	April, 1932	Salt grass	2
16	23 1/16	Evaporation	May, 1929	April, 1932	Free water surface	
17[2]	23 1/16	Evaporation	Aug., 1929	May, 1930	Water covered with oil film	
18[2]	23 1/16	Evaporation	Aug., 1929	May, 1930	Water covered with oil film	
19	25 1/2	Use of water	Aug., 1929	April, 1932	Round stem tules in water	
20	48	Evaporation	May, 1929	April, 1932	Free water surface	
21	25 1/2	Use of water	May, 1930	April, 1932	Triangular stem tules in water	
22	25 1/2	Use of water	May, 1930	April, 1932	Cat-tails in water	
23	72	Use of water	May, 1930	April, 1932	Round stem tules in water	
24	72	Use of water	May, 1930	April, 1932	Willow	2
25	25 1/2	Use of water	Aug., 1930	April, 1932	Wire rush	2
26	48	Evaporation	May, 1931	April, 1932	Five per cent sodium chloride solution	

[1] Undisturbed soil was used in Tanks Nos. 1 to 12, inclusive; disturbed soil in Tanks Nos. 13, 14, and 15.
[2] Results of these experiments are published in State of California, Department of Public Works Bulletin No. 33.

When the station was first installed, in 1929, four tanks had an original growth of salt grass growing on the column of soil enclosed in them, two others had salt grass transplanted in them, and the rest had bare surfaces. Use of water by salt grass and evaporation from bare, uncultivated soil was measured from these tanks from May, 1929, to October, 1930, when several changes in water levels were made and all bare-soil tanks had salt grass transplanted in them. The new grass did not make good growth at first, and until growth began in the following spring the recorded use of water was largely due to soil evaporation rather than to consumptive use by the transplanted grass. No further changes were made in the crop grown or in the depth to water table in any soil tank after the changes noted in October, 1930.

For reasons which will be given later, measurements of evaporation from bare, uncultivated soil surfaces in Tanks Nos. 1, 2, and 3 were begun with an initial water table depth of 4 feet and were continued thus throughout the summer of 1929. It soon became evident that this water-table depth was greater than the limit of capillary rise of the soil moisture. This was evidenced in part by the lack of soil moisture in surface soil and proved beyond doubt by the fact that there was no withdrawal of water from the Mariotte supply tanks during a five-month period which included the warmest months of the year.

In October following the period during which no evaporation occurred the water-table levels were raised from 4 to 3 feet from the surface and the evaporation test was continued. There was immediate response in loss of water from the supply tanks, but indications were that the large initial losses from the Mariotte tank were partly absorbed by the dry soil as capillary moisture, and that only a small part was lost by soil evaporation. This adjustment of soil moisture continued for a period of four to six weeks until the capillary demand was satisfied, after which a small but rather uniform rate of evaporation continued.

The evaporation test with water tables at a 3-foot level continued for the following 12-month period to October, 1930, at which time a number of changes in depth to water tables in some tanks were made and all soil evaporation tanks were transplanted to salt grass. It was rather hard to get this started and in some cases light surface irrigations were applied as the tank surfaces were generally quite dry. Moreover, the time of year was not the best for starting new growth and the grass was slow in developing a root system. Consequently the recorded use of water during the winter or dormant season by those tanks in which grass was newly transplanted was almost entirely caused by evaporation from the soil surface rather than by consumptive use. The increase in use of water beginning in March, following transplanting, shows definitely that this was the end of the dormant period for the salt grass in this set of tanks.

The second set of tanks, Nos. 4, 5, and 6, containing undisturbed soil, were first used for measurement of evaporation from the soil surface with the water table at a depth of 2 feet. As this depth was well within the limit of capillary rise, evaporation began immediately after the soil received water and continued until October, 1930, when the soil evaporation tests were completed. The first two months of record in 1929 showed a high rate of loss from the Mariotte supply tank, which may be accounted for as adjustment and increase of moisture held in the soil following establishment of a fixed water table. Such losses were observed in every case where the water table was raised to a higher level.

Immediately following completion of the evaporation test, the tanks in this set were transplanted to salt grass, the water table remaining unchanged. As with the first set of tanks, the grass was slow to start and some early surface irrigation was necessary. Consequently, the water used during the following winter when the grass was in the dormant stage was almost entirely soil evaporation. Increase in growth began in the following February and these tanks were soon covered with a luxuriant growth of grass which completely shaded their soil surfaces. Records were made until April 30, 1932, when the investigation was completed.

The third set, including Tanks Nos. 7, 8, and 9, was first operated with a 2-foot water table, but with salt grass sod instead of bare surfaces. Tank No. 9 was the only one to have an original crop of grass at the outset. In this tank the grass root system was fully developed and remained undisturbed, except where the shell of the tank cut off lateral roots as it was forced into the ground. The other two tanks were bare, and it was necessary to transplant grass and develop root systems before the maximum use of water was attained. The transplanted grass showed a very heavy and healthy growth of 6 inches or more. Tank No. 9, on the other hand, had a heavy mat of short stemmed grass which did not compare in height with the new growth.

Records were kept of the consumptive use of water under these conditions from May, 1929, to October, 1930, when the water table was raised from 2 feet to 1 foot, remaining at this level until the end of the investigation. From the very beginning, these tanks had moist soil surfaces on which accumulations of powdery alkali occurred, and with the rise in the water table, this became more pronounced. The concentration, however, was not sufficient to cause injury to the salt grass, which increased in height and density with the higher water table.

Tanks Nos. 10, 11, and 12, comprising the fourth set, were covered with the original salt grass sod found growing on the surface when the tanks were filled, and therefore had fully developed root systems from the beginning. From the first this growth was very dry and sparse and did not increase in density when additional water was supplied. The initial water table was at a depth of 4 feet and consumptive use of water measurements were made under these conditions from May, 1929. to October, 1930, when the water table was lowered to 5 feet. At this depth the experiment was continued until the investigation was completed. As the water table was always below the limit of capillary rise, the tank surfaces remained dry in contrast with others which were always moist. In consequence, there was little or no soil evaporation and no surface deposit of alkali.

Tanks Nos. 13, 14, and 15 were installed during the summer of 1929, for the purpose of comparing evaporation from soil in tanks filled by different methods. The comparisons were to be with Tanks Nos. 4, 5, and 6, previously described. Each set had the same depth to water, the same bare surfaces, and contained the same type of soil, except that Tanks Nos. 4, 5, and 6 contained undisturbed soil, while Nos. 13, 14, and 15 were loosely filled.

These comparisons of evaporation from soils of different structural arrangement were continued until October, 1930. At this time the soil evaporation studies were discontinued and all bare tanks were transplanted to salt grass for further comparative studies. After both sets of tanks were transplanted to salt grass, the comparison was continued without changes in depth of water tables until the investigation was discontinued. Both sets of tanks produced good growths of grass, although that grown in the loose soil was not as heavy as that grown in the undisturbed soil.

In addition to use of soil tanks with Mariotte connections for evaporation and consumptive use of water studies, several tanks of simple design were used for growths of tules, willows, and wire rush. As tules are aquatic plants accustomed to grow in swamps with their roots submerged, the tanks in which they were grown were maintained with water tables about 2 inches above the soil level. The height of the water table was determined by an index point in each tank. In the smaller tanks the water table was raised to the index point each morning by using a measured amount of water. In larger tanks this involved a greater amount of work and supply tanks were operated to maintain the proper water level and supply water as used. In the willow and wire rush tanks, the water table was kept 2 feet below the soil surface with slight fluctuations.

San Bernardino Station

The four tanks used at the Antil Plant of the San Bernardino Water Department were installed for measurement of consumptive use of water by Bermuda grass, of which there was a heavy crop growing in the yard in which the tanks were set. As the tanks were filled with undisturbed soil each had a good stand of grass with root systems fully developed from the beginning of the investigation. At this station tanks were operated in duplicate, one pair having a depth of water table of 3 feet and the other of 2 feet below the soil surface. These depths were unchanged throughout the investigation. Each soil tank was connected to a Mariotte supply tank from which the daily amounts of water used were measured.

Besides the four soil tanks, one tank of round stem tules was maintained to determine the consumptive use by this growth. This tule tank was connected with a supply tank through a float valve to supply water as needed and hold the water table at an index point about 2 inches above the soil level. Installation data giving the number of tanks, periods of use, and content of each tank are shown in Table 7.

TABLE 7

INSTALLATION DATA FOR TANKS USED AT SAN BERNARDINO STATION

Tank number[1]	Diameter of tank in inches	Purpose of tank	Period of test		Content of tank	Depth to water table in feet
			Beginning	Ending		
1–2	23 1/16	Use of water	May, 1929	Jan., 1932	Bermuda grass	3
3–4	23 1/16	Use of water	May, 1929	Jan., 1932	Bermuda grass	2
5	23 1/16	Evaporation	May, 1929	April, 1932	Free water surface	
6	23 1/16	Use of water	April, 1930	April, 1932	Round stem tules in water	
7	48	Evaporation	May, 1929	April, 1932	Free water surface	

[1] Undisturbed Chino silt loam soil used in Bermuda grass tanks.

Prado Station*

Only one crop tank has been used at the Prado station in determination of consumptive use of water. This tank contains a dense growth of triangular stem tules grown in submerged soil as at the other stations. A supply tank is used in connection with the tule tank, the connection being made through a float valve. Measurement of water withdrawn from the supply tank is shown on recorder charts by means of a water stage recorder, and weekly or semiweekly visits are made to the station to replenish the water supply and renew the charts. This station is still in operation and will be continued.

Protection from Rainfall

During the wet seasons of 1929–30 and 1930–31, covers were provided for all soil tanks to prevent changes in soil moisture content due to rainfall. The covers (Plate IV) were of light metal, circular in design and with sloping tops, and were set on legs a few inches high to allow full circulation of air over the protected tank surface. While it was impossible to keep all rainfall from the tanks because of absence from the station at the exact beginning of each storm, they were set as

* The United States Geological Survey, cooperated in maintaining this station through the courtesy of F. C. Ebert.

soon as possible and removed when the rain ceased. The amount of additional moisture the tanks received from rainfall was negligible and was soon evaporated.

There is objection to using covers as the shade they give reduces both evaporation and transpiration. At the time they were used, however, both evaporation and transpiration were at a minimum on account of overcast sky and increased humidity. Also, because covers were raised above the soil tanks by the legs on which they stood, normal air movements were not restricted.

Beginning with the 1931–32 rainy season, it was decided to have all soil tanks exposed to rainfall and covers were not used as during

PLATE IV

CIRCULAR METAL COVERS TO PROTECT SOIL TANKS FROM RAINFALL WHILE ALLOWING FREE CIRCULATION OF AIR OVER THE TANK SURFACE.

the two previous seasons. Under these conditions each rain changed the water content of the soil. The additional soil moisture was disposed of by evaporation and transpiration or the excess drained off through the overflow outlet to be caught and measured in a container.

On account of changes in soil moisture, withdrawals of water from the Mariotte tanks did not give a correct index of consumptive use by the soil tanks. Recourse to taking soil moisture samples from each tank at the beginning of each month was therefore necessary. Consumptive use was computed as the algebraic sum of the change in soil moisture, rainfall during the period, water drawn from the supply tank, and waste water measured in the overflow containers. Certain inaccuracies inherent to this method could not be avoided. Probably the most important of these was caused by inability to obtain soil moisture samples immediately above the water table in the soil tank. This soil was saturated to such an extent that it could not be held in the soil tube, and the samples obtained indicated less moisture than actually existed.

Since tanks were protected from rainfall during the first two years and exposed during the third year, results from tank studies are not entirely comparable. Greater evaporation occurred from tanks subject to rainfall, both from the soil surface and from moisture intercepted by the grass. On a heavy growth of grass, the latter item might be considerable during an entire season. There was every reason to suppose that consumptive use of water by crops grown in tanks exposed to rainfall during the wet season would exceed that used in tanks protected from rain, and the records show this to be true.

SOIL ALKALI IN TANKS

Most western soils contain alkali salts in various amounts and the soil at the Santa Ana station was no exception. As the station was primarily for the investigation of consumptive use of water by salt grass, which is tolerant of a considerable concentration of salts, no effect on the rate of transpiration was expected. Several tanks were used for soil evaporation studies, and it is probable that in a few of these gradual deposition of alkali on the tank surface had some influence in reducing the amount of evaporation. The greatest evaporation from any tanks occurred from those holding disturbed soil, although the most alkali was evident on their surfaces.

As the processes of evaporation and transpiration continued month after month, the original amount of alkali in the soil was increased by constant addition of water to the soil tanks. This water was obtained at the station from a shallow well and chemical analysis showed it to be relatively free from injurious salts and in every way suitable for tank use. Water used in the experimental work at the San Bernardino station was supplied from an artesian well and was even better for the purpose than that at Santa Ana. Samples of water from the annular spaces of a number of tanks at both stations also were analyzed and the results of both analyses are shown in parts per million in Table 8. The carbonates are entirely lacking in both water supplies and bicarbonates and sulphates are the principal salts. No accumulation of salts is shown in the water of the annular space as they are carried into the soil for distribution. Apparently water used at the Santa Ana station is fair and the San Bernardino supply is good for irrigation.

TABLE 8

ANALYSES OF STATION WATER SUPPLIES AND WATER FROM ANNULAR SPACES OF SOIL MOISTURE TANKS AT SANTA ANA AND SAN BERNARDINO STATIONS[1]

Station	Source of sample	Classification of salts in parts per million						
		Cl	CO_3	HCO_3	SO_4	Ca	Mg	Na
Santa Ana	Shallow well	55	0	220	100	78	40	25
Santa Ana	Shallow well	57	0	317	98	81	27	76
Santa Ana	Tank No. 2	130	0	88	170	54	37	70
Santa Ana	Tank No. 5	62	18	73	66	18	12	75
Santa Ana	Tank No. 8	36	27	70	55	18	10	75
Santa Ana	Tank No. 11	41	21	137	53	20	10	85
Santa Ana	Tank No. 14	61	30	140	95	24	15	117
San Bernardino	Artesian well	19	0	156	42	38	30	10
San Bernardino	Tank No. 2	17	0	152	57	40	38	0
San Bernardino	Tank No. 4	25	0	178	33	38	36	0

[1] Samples for analysis were collected during October, 1930, except the second well sample at Santa Ana which was taken in January, 1932.

The migration of alkali salts through the soil, either upward or downward, is dependent upon the movement of soil water, in both direction and amount. In the presence of a water table within the reach of capillary action, this movement ordinarily is upward and when there is high evaporation there is a rapid concentration of salts at or near the surface. If the movement of salts was always in one direction, many fields would soon be ruined for production of crops. Fortunately, heavy rains and the surface application of irrigation water tend to carry the salts downward.

In the soil tanks at Santa Ana, soil alkali accumulated during the dry season on the surface of those tanks having high water tables. In some cases white deposits were noticeable. During the wet season of 1931–32, these deposits were carried downward into the soil by penetration of rainfall, and as the tanks were dismantled in May, 1932, much of the alkali had little opportunity to return to the surface. Exceptions occurred in Tanks Nos. 7, 8, and 9, in which the water tables were but 1 foot from the surface and a high concentration of salts was redeposited

TABLE 9

ALKALI SALT CONCENTRATIONS AND pH VALUES OF COMPOSITE SOIL SAMPLES FROM VARIOUS DEPTHS IN SOIL MOISTURE TANKS AT THE SANTA ANA AND SAN BERNARDINO STATIONS[1]

Station	Tank number	Depth to water table, in feet	Depth to composite sample, in inches	pH value	Classification of salts in parts per million of dry soil			
					Carbonate ion CO_3	Bicarbonate ion HCO_3	Chloride ion Cl	Sulphate SO_4
Santa Ana	1-2-3	3	0–1	8.4	0	145	130	0
Santa Ana	1-2-3	3	6–7	8.8	20	170	50	0
Santa Ana	1-2-3	3	12–13	9.9	240	145	60	
Santa Ana	1-2-3	3	24–25	10.4	540	300	130	
Santa Ana	1-2-3	3	36–37	10.5	480	240	100	
Santa Ana	4-5-6	2	0–1	8.7	20	300	240	
Santa Ana	4-5-6	2	6–7	10.5	625	300	100	
Santa Ana	4-5-6	2	12–13	10.6	600	300	100	
Santa Ana	4-5-6	2	24–25	10.3	420	300	140	
Santa Ana	7-8-9	1	0–1	10.3	3,200	1,560	1,000	
Santa Ana	7-8-9	1	6–7	10.3	660	420	250	
Santa Ana	7-8-9	1	12–13	10.1	420	300	200	
Santa Ana	10-11-12	5	0–1	8.5	0	275	200	
Santa Ana	10-11-12	5	6–7	10.2	420	240	80	
Santa Ana	10-11-12	5	12–13	10.4	420	240	80	
Santa Ana	10-11-12	5	24–25	9.7	300	180	550	
Santa Ana	10-11-12	5	36–37	8.6	0	180	350	
Santa Ana	10-11-12	5	48–49	8.7	0	220	140	
Santa Ana	13-14-15	2	0–1	9.6	180	600	300	135
Santa Ana	13-14-15	2	6–7	10.2	300	520	100	135
Santa Ana	13-14-15	2	12–13	10.2	360	260	140	175
San Bernardino	2	3	0–1	9.0	215	740	130	
San Bernardino	2	3	6–7	9.6	240	700	200	
San Bernardino	2	3	12–13	8.2	0	260	90	
San Bernardino	2	3	24–25	7.5	0	155	80	
San Bernardino	2	3	36–37	7.4	0	85	50	
San Bernardino	4	2	0–1	8.9	95	790	70	
San Bernardino	4	2	6–7	8.5	35	445	130	
San Bernardino	4	2	12–13	8.7	0	300	60	
San Bernardino	4	2	24–25	7.9	0	180	50	

[1] Samples for analysis were collected during June, 1932.

in the top inch of soil. About two months after the last heavy rain in the spring of 1932, samples of horizontal sections of soil in various tanks were collected for chemical analysis. The results of these analyses are shown in Table 9. The salts shown are predominately sodium salts, and extracts from the high carbonate soils were all black, indicating black alkali. There was no calcium present in the solution, due to the high content of the carbonate ion. Also, the amount of sulphates present is of no importance. The pH values at the Santa Ana station are very high, ranging from 8.4 to 10.6. These values indicate a highly alkaline reaction.

In the tanks of undisturbed soil where depth to water table was 2, 3, or 5 feet, the surface concentration of salts in the top inch of soil was not excessive. With a water table 1 foot from the surface, there was an extremely heavy deposit of salts in the top inch, measuring as high as 3200 parts per million of carbonate. In general, greater deposits occurred at or near the surface in those tanks having the highest water tables. The same was true at the San Bernardino station, although the bicarbonates exceeded the carbonates in amount, which was the opposite of the Santa Ana condition. The pH values do not indicate an excessively alkaline reaction.

CONSUMPTIVE USE OF WATER

Evaporation from Soil Surfaces in Tanks

In making studies of evaporation from bare soils at the Santa Ana station, distribution of soil moisture under natural conditions as found at the station site determined the initial maximum depth to the water table in the first set of tanks. In excavating around the tanks as they were filled, the upper 15 inches of soil was observed to be moist from previous rains, while the soil from 15 to 30 inches in depth was found to be extremely dry. Below this dry belt was capillary moisture arising from the perched water table found at a depth of 6 to 7 feet. It was evident, therefore, that the limit of capillary rise in undisturbed soil with which the tanks were filled was the difference between the depth to the water table and the lower limit of the dry area, or slightly less than 4 feet. This measure was, therefore, adopted as the depth to the lowest water tables in the soil evaporation tanks. From this 4-foot water table, no soil evaporation occurred at any time during the warm summer months between May and October. Data regarding weekly amounts of evaporation from soil surfaces obtained at the Santa Ana station, where water tables were at different depths, are found in Table 11. Monthly data relating to the same tanks are given in Tables 13 and 14.

No losses by evaporation occurred when the water table was at a depth of 4 feet, but there were small losses when it was raised to 3 feet and still greater losses at 2-foot depths, confirming the initial conclusion that the limit of capillary rise was about 4 feet. For a six-month period during the winter of 1929–30, when evaporation was at its lowest, the total evaporation from the tanks having 3-foot water tables averaged but 0.913 acre-inch per acre. For the same period, evaporation from tanks having water tables at a 2-foot depth was 1.775 acre-inches per acre.

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In order to have a comparison of evaporations from both disturbed and undisturbed soils, further tests were carried on with soil loosely settled in water as the tanks were filled. Differences due to the methods of filling the tanks became apparent immediately at the outset. Although both sets of tanks had water tables at the same depth, the moisture content in the loosely filled soil was enough to keep the soil surface moist, while the surface in tanks of undisturbed soil was dry.

For comparison of monthly records of soil evaporation under the two conditions of soil structure, further reference is made to Tables 13 and 14, which show the monthly use of water by all tanks. For the same six-month winter period of 1929–30, during which evaporation from undisturbed soil having a 2-foot depth to the water table was 1.775 acre-inches per acre, the disturbed soil with the same water table evaporated 6.889 acre-inches per acre, or nearly four times as much.

In applying the results of these experiments to field conditions, it is obvious that only data secured from experiments with undisturbed soil should be used, and that measurements of evaporation from disturbed soil do not represent a true criterion for natural soil moisture losses. The large difference in the rate of evaporation for disturbed and undisturbed soils, indicates the advisability of further experimental work of this character. It also seems to cast doubt on the accuracy of results of some previous experiments along the same line.

Use of Water by Salt Grass

Salt grass (*Distichlis spicata*) is most often found in somewhat alkalied areas of shallow water table, the limit of depth from which the roots may draw moisture depending upon the soil type. In various investigations the limiting depth to water at which it has been found has varied. In one small locality with heavy soil, in the lower Santa Ana River basin, it was observed where the ground water was at a depth of 11 to 12 feet, but in general the limiting depth in lighter soils is about 6 feet. Moreover, it was found to exist only in those areas that were classified by the United States Bureau of Soils as containing some alkali.

The growth of the plant is spread by means of a thick creeping root stalk within the upper few inches of soil from which finer roots extend downward in search of moisture. The stiff, light green leaves rise from each joint of the root stalk and sometimes spread to form a considerable sod. The grass has a distinctly salty taste and, although it is sometimes used for pasture, stock do not thrive on it. The growing period in southern California is from February to December and although the grass dies or becomes dormant in the winter, there is some discharge from the water table throughout the winter months. Salt grass is not an excessive user of water. Its habit of growth in alkali soils has caused the plant to protect itself against toxic effects of alkali salts by a decreased rate of transpiration.

Until recent years, the area devoted to salt grass in the lower Santa Ana River basin has been considerable, but the advent of drainage systems and extension of the cultivated area has crowded out the salt grass from a number of districts. Various salt-grass areas still exist, however, especially where the ground water continues to remain near the surface. This investigation was begun to measure the consumptive use of water by salt grass for comparison with use of water by other wild growths in order to determine the net draft on the ground water supply by native vegetation.

In experiments with salt grass grown in tanks at the Santa Ana station, distribution of moisture above the water table was determined by means of soil-moisture samples. Depth to water in the different tanks ranged from 1 to 5 feet. Reference to Table 10 shows the average soil moisture in the top foot of soil, when the water table was 1 foot from the ground surface, to be 27.1 per cent and that it decreased rapidly until the water table was 3 feet in depth, or near the limit of the capillary rise. With the water table below 3 feet there was little difference in the moisture content of the top foot of soil.

It is evident, then, that there was greater soil evaporation in the tanks having the highest water tables. In the same tanks there was also greater transpiration because of a heavier crop of grass, due, in turn, to a higher moisture content. As consumptive use of water includes both soil evaporation and plant transpiration, it follows that plant growth in tanks having the highest water tables has the higher

TABLE 10

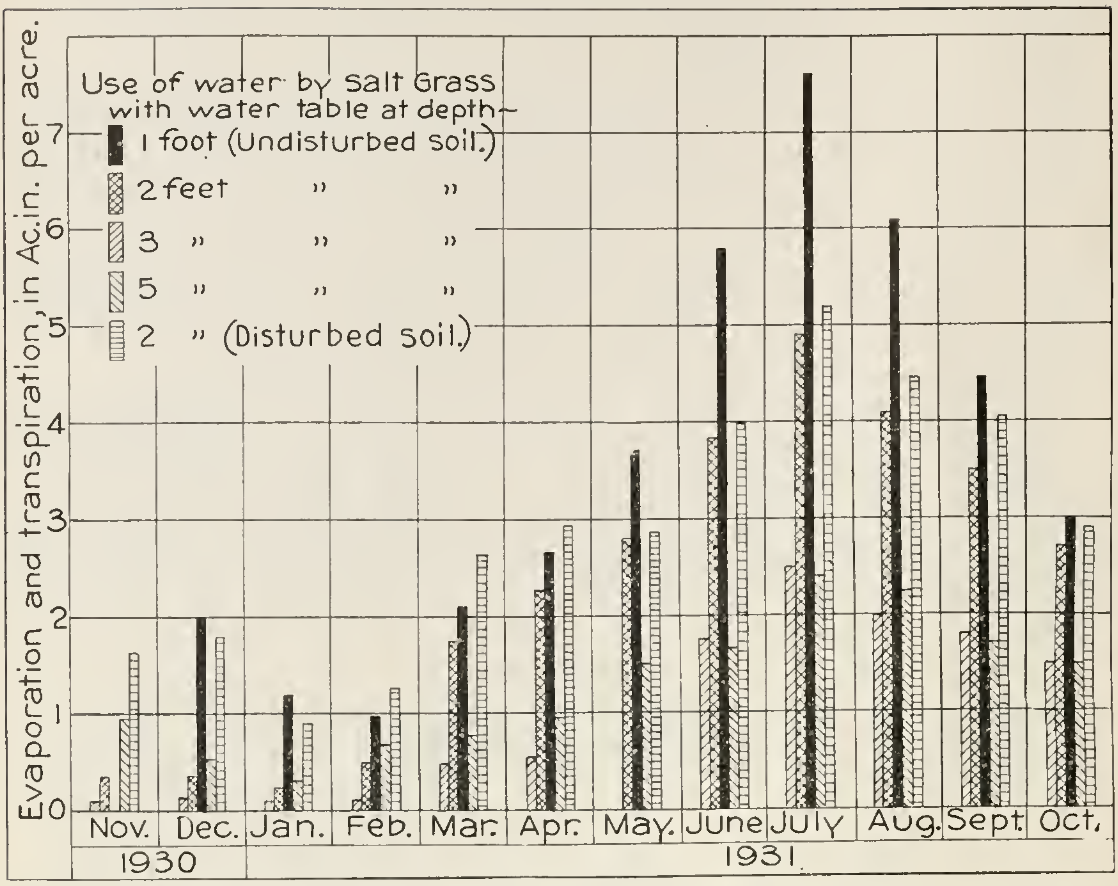
RELATION OF SOIL MOISTURE TO DEPTH OF WATER TABLE IN TANKS AT SANTA ANA STATION

Depth of sample in feet	Average soil moisture content in per cent			
	Depth to water table in soil tanks, in feet			
	1	2	3	5
1	27.1	15.5	6.7	7.6
2		21.3	9.7	10.7
3			21.4	18.7
4				20.5
5				29.5

consumptive use. This is indicated in Plate V, which shows a comparison of monthly use of water by each set of salt grass tanks. The set having the highest water table, shown by the solid bar, used the most water. It will be noted that bars representing tanks of disturbed soil show a greater use of water than do tanks of undisturbed soil, when both have the same depth to water table.

The draft of salt grass on the ground water supply depends upon the depth to the water table and the soil structure. This may be estimated by comparison with results of tank experiments made during this investigation. When an irrigated area is extended to include uncultivated lands, the resulting net draft on the ground water supply is the difference between the amount of water required by cultivated crops and by the indigenous growth which the cultivation replaces. If the cultivated crop uses no more water than the native growth in the same area, no depletion results because of the change. Practical experience and scientific experiments have indicated the necessary water requirements of crops, but little information is available as to the consumptive use of water by noneconomic plant life.

PLATE V



MONTHLY USE OF WATER BY SALT GRASS IN TANKS HAVING VARIOUS DEPTHS TO WATER TABLE.

Although the presence of salt grass is always an indicator of ground water, these experiments have demonstrated that its consumptive use is not excessive when compared with water requirements of many cultivated crops. In general, farming operations are conducted on water-free soil of sufficient depth to allow ample root development. The average depth to free water naturally varies with each locality, but a minimum of 5 or 6 feet is considered a safe depth for many field crops. For the 12-month period ending April 30, 1932, salt grass grown in tanks having a depth of 5 feet to water table, used an average of about 22 acre-inches of water, including rainfall. During this period, conditions were the same as in natural salt-grass areas. This consumptive use is no more than that used by various crops of low water requirement, and is less than amounts required by alfalfa, citrus, or walnuts. In tanks having a water-table depth of 2 feet, the 12-month consumptive use for the same period was about 36 acre-inches per acre, which is sufficient, with careful management, to produce a fair crop of alfalfa. In most salt-grass areas in the Santa Ana basin the ground water occurs at depths exceeding 4 feet and the average seasonal draft is, therefore, low. It is concluded, therefore, that the yearly water requirement of salt grass in this area is generally less than that of cropped lands.

Data on the weekly use of water by salt grass at the Santa Ana station from May 7, 1929, to November 3, 1931, are given in Tables 11 and 12. On the latter date, readings at the station were discontinued, e

'ith fixed water table four feet)w the ground surface			Bare soil with fixed water table two feet below the ground surface			
Tank No. 11	Tank No. 12	Mean	Tank No. 13	Tank No. 14	Tank No. 15	Mean
0 000	0 180	0 095	----------	----------	----------	----------
000	.277	.117	----------	----------	----------	----------
000	.127	.060	----------	----------	----------	----------
.000	.096	.042	----------	----------	----------	----------
.022	.097	.057	----------	----------	----------	----------
021	.179	.088	----------	----------	----------	----------
.115	.234	.138	----------	----------	----------	----------
.191	.519	.311	----------	----------	----------	----------
333	.482	.344	----------	----------	----------	----------
265	366	.315	----------	----------	----------	----------
444	587	.482	----------	----------	----------	----------
462	.636	.621	----------	----------	----------	----------
551	.823	.790	----------	----------	----------	----------
508	.944	.742	----------	----------	----------	----------
508	.870	.716	0.254	0 449	0 353	0.352
.439	.373	.620	.848	.866	1 465	1.060
.579	.561	.518	.542	824	1 197	.854
593	.689	.657	.392	.738	1 336	.822
.308	.625	.512	.488	.514	749	.584
.466	.276	.419	.552	450	685	.562
273	270	.295	.318	524	546	.463
.138	.515	.352	.531	479	748	586
445	737	.574	.572	372	696	.547
243	.646	.431	.499	502	.588	.530
259	.487	.326	.490	385	546	.474
147	.343	.188	.403	438	641	.494
297	.123	.278	.511	.417	.600	.509
196	.021	.186	435	.385	492	.437
173	.000	.139	403	.309	.491	.401
177	.000	.139	371	310	395	.359
.138	.036	.148	295	.245	.197	.246
107	.070	.131	.159	.266	.324	.250
138	.022	.109	.128	246	175	.183
099	.222	.172	211	192	386	.263
114	.117	.136	.286	267	.363	.305
148	.095	.169	272	287	277	.273
043	.063	.063	.137	234	.085	.152
000	.010	.021	.063	.140	.097	.100
000	.011	.039	.137	288	.160	.195
021	.010	.067	.042	235	.160	.146
053	.000	.046	.106	.277	.181	.188
.125	.032	.095	.126	211	.256	.198
063	.010	.081	.148	171	.255	.191
127	.021	105	.169	.265	.203	.212
095	.000	.081	.181	203	331	.238
074	.000	.046	.203	.448	.159	.270
084	.074	.091	.192	320	201	.238
201	.064	.209	.234	288	.385	.302
159	.115	.172	.256	320	.330	.302
148	159	.251	290	.394	.417	.367
276	.190	.297	.278	331	.341	.317
212	212	.240	.299	351	471	.374
191	.168	.198	299	246	.268	271
180	.170	.247	.332	278	.394	.335
179	.168	246	.437	.373	416	.409
306	233	.318	.362	.426	534	.441
305	180	.320	.383	471	578	.477
295	222	.342	.373	.449	524	.449
255	222	.329	340	309	.426	358
319	243	.335	.361	202	439	.331
329	274	.381	.394	.277	589	.420
306	316	.391	.405	342	514	.420
404	349	.470	.405	406	.503	.438
382	371	.463	.459	514	727	.567
.456	360	.488	415	128	514	.452
318	382	.467	.426	469	621	.505
445	284	.395	.395	405	.438	413
318	.284	.332	.321	352	.383	.352
276	349	.413	.375	427	535	.446
349	338	.438	427	427	514	.456
414	320	.418	.386	437	.492	.438
265	267	.322	.342	288	405	.345
339	244	.328	.322	247	.352	.307
286	233	.300	.311	299	.394	.335

TABLE 11

RECORD OF WEEKLY EVAPORATION FROM SOIL AND USE OF WATER BY SALT GRASS IN TANKS AT SANTA ANA, CALIFORNIA, MAY, 1929, TO SEPTEMBER, 1930[1]

Evaporation from bare soil and use of water by salt grass in acre-inches per acre

Week ending	Bare soil with fixed water table three feet below the ground surface				Bare soil with fixed water table two feet below the ground surface			
	Tank No. 1	Tank No. 2	Tank No. 3	Mean	Tank No. 4	Tank No. 5	Tank No. 6	Mean
1929—								
May 7	No evaporation from Tanks Nos. 1, 2 and 3 with water table at depth of four feet, May 1 to October 1, 1929				0.689	0.660	0.274	0.541
May 14					.561	.597	.253	.470
May 21					.445	.523	.232	.400
May 28					.359	.450	.223	.344
June 4					.275	.449	.210	.311
June 11					.296	.449	.136	.294
June 18					.233	.355	.158	.249
June 25					.222	.323	.115	.220
July 2					.232	.251	.180	.221
July 9					.085	.229	.168	.161
July 16					.190	.188	.180	.186
July 23					.169	.177	.147	.164
July 30					.180	.167	.169	.172
Aug. 6					.169	.293	.136	.199
Aug. 13					.170	.251	.158	.193
Aug. 20					.158	.249	.126	.178
Aug. 27					.157	.218	.157	.177
Sept. 3					.159	.241	.155	.185
Sept. 10					.158	.261	.184	.201
Spet. 17					.094	.177	.020	.097
Sept. 24					.032	.136	.084	.084
Oct. 1					.105	.157	.105	.122
Oct. 8	0.115	0.890	0.413	0.473	.127	.166	.073	.122
Oct. 15	.084	.306	.499	.296	.126	.156	.084	.122
Oct. 22	.084	.180	.254	.173	.106	.125	.106	.112
Oct. 29	.074	.064	.095	.078	.147	.178	.115	.147
Nov. 5	.075	.106	.180	.120	.127	.187	.096	.137
Nov. 12	.105	.053	.064	.074	.126	.156	.095	.126
Nov. 19	.074	.084	.126	.095	.106	.135	.095	.112
Nov. 26	.084	.032	.042	.053	.127	.104	.096	.109
Dec. 3	.074	.084	.094	.084	.075	.137	.064	.092
Dec. 10	.064	.031	.074	.056	.053	.074	.074	.067
Dec. 17	.063	.043	.085	.064	.053	.063	.042	.053
Dec. 24	.053	.000	.021	.025	.106	.104	.096	.101
Dec. 31	.074	.000	.075	.050	.063	.116	.063	.081
1930—								
Jan. 7	.074	.000	.032	.035	.116	.105	.074	.098
Jan. 14	.074	.000	.042	.039	.074	.074	.073	.074
Jan. 21	.011	.000	.010	.007	.031	.010	.032	.024
Jan. 28	.010	.000	.032	.014	.021	.000	.042	.021
Feb. 4	.010	.000	.010	.007	.032	.043	.032	.036
Feb. 11	.032	.000	.021	.018	.021	.031	.021	.024
Feb. 18	.031	.000	.021	.017	.052	.063	.063	.059
Feb. 25	.021	.000	.021	.014	.074	.042	.063	.060
Mar. 4	.064	.000	.022	.029	.021	.021	.042	.028
Mar. 11	.043	.000	.042	.028	.031	.043	.042	.039
Mar. 18	.021	.000	.021	.014	.064	.074	.032	.057
Mar. 25	.021	.000	.032	.018	.010	.041	.031	.027
April 1	.021	.000	.052	.024	.053	.064	.042	.053
April 8	.021	.000	.000	.007	.032	.063	.064	.053
April 15	.000	.000	.053	.018	.063	.115	.021	.066
April 22	.021	.000	.031	.017	.074	.095	.073	.081
April 29	.000	.000	.032	.011	.084	.178	.063	.108
May 6	.084	.021	.032	.046	.143	.116	.116	.135
May 13	.042	.011	.042	.032	.063	.053	.063	.060
May 20	.010	.000	.052	.021	.074	.105	.053	.077
May 27	.032	.011	.021	.021	.042	.104	.031	.059
June 3	.000	.000	.000	.000	.095	.116	.063	.091
June 10	.011	.011	.032	.018	.073	.126	.064	.088
June 17	.000	.000	.000	.000	.105	.145	.084	.111
June 24	.042	.000	.011	.018	.105	.105	.084	.098
July 1	.022	.010	.000	.011	.074	.146	.053	.091
July 8	.011	.021	.000	.010	.095	.156	.094	.115
July 15	.042	.021	.063	.042	.095	.094	.084	.091
July 22	.021	.000	.063	.028	.095	.125	.085	.102
July 29	.064	.032	.084	.060	.137	.125	.126	.129
Aug. 5	.010	.000	.053	.021	.105	.125	.053	.094
Aug. 12	.042	.000	.032	.025	.116	.136	.094	.115
Aug. 19	.042	.000	.000	.014	.084	.137	.074	.098
Aug. 26	.042	.000	.042	.028	.105	.135	.073	.104
Sept. 2	.033	.000	.011	.015	.086	.157	.085	.109
Sept. 9	.126	.000	.042	.056	.127	.177	.095	.133
Sept. 16	.021	.000	.042	.021	.074	.137	.105	.105
Sept. 23	.032	.000	.073	.035	.094	.104	.074	.091
Sept. 30	.031	.000	.074	.035	.095	.125	.084	.101

Week ending	Salt grass with fixed water table two feet below the ground surface				Salt grass with fixed water table four feet below the ground surface				Bare soil with fixed water table two feet below the ground surface			
	Tank No. 7	Tank No. 8	Tank No. 9	Mean	Tank No. 10	Tank No. 11	Tank No. 12	Mean	Tank No. 13	Tank No. 14	Tank No. 15	Mean
1929—												
May 7	0.296	0.862	0.699	0.619	0.105	0.000	0.180	0.095	------	------	------	------
May 14	.275	.561	1.003	.613	.074	.000	.277	.117	------	------	------	------
May 21	.275	.293	.624	.397	.053	.000	.127	.060	------	------	------	------
May 28	.371	.429	.741	.514	.032	.000	.096	.042	------	------	------	------
June 4	.626	.481	1.111	.739	.053	.022	.097	.057	------	------	------	------
June 11	.964	.398	1.007	.790	.063	.021	.179	.088	------	------	------	------
June 18	.975	.670	.975	.873	.064	.115	.234	.138	------	------	------	------
June 25	1.632	1.167	1.461	1.420	.223	.191	.519	.311	------	------	------	------
July 2	1.281	1.178	1.154	1.204	.216	.333	.482	.344	------	------	------	------
July 9	1.217	1.251	1.132	1.200	.314	.265	.366	.315	------	------	------	------
July 16	1.282	1.442	1.323	1.349	.414	.444	.587	.482	------	------	------	------
July 23	1.325	1.462	1.335	1.374	.764	.462	.636	.621	------	------	------	------
July 30	1.208	1.315	1.176	1.233	.996	.551	.823	.790	------	------	------	------
Aug. 6	1.154	1.283	1.334	1.257	.773	.508	.944	.742	------	------	------	------
Aug. 13	1.048	1.271	1.166	1.162	.770	.508	.870	.716	0.254	0.449	0.353	0.352
Aug. 20	1.165	1.314	1.282	1.254	1.049	.439	.373	.620	.848	.866	1.465	1.060
Aug. 27	1.101	1.314	1.227	1.214	.413	.579	.561	.518	.542	.824	1.197	.854
Sept. 3	1.144	1.430	1.292	1.289	.690	.593	.689	.657	.392	.738	1.336	.822
Sept. 10	.744	.840	.868	.817	.604	.308	.625	.512	.488	.514	.749	.584
Spet. 17	.816	.945	.890	.884	.514	.466	.276	.419	.552	.450	.685	.562
Sept. 24	.646	.661	.605	.637	.343	.273	.270	.295	.318	.524	.546	.463
Oct. 1	.785	.881	.838	.835	.403	.138	.515	.352	.531	.479	.748	.586
Oct. 8	.890	.998	.933	.940	.540	.445	.737	.574	.572	.372	.696	.547
Oct. 15	.667	.735	.689	.697	.403	.243	.646	.431	.499	.502	.588	.530
Oct. 22	.669	.735	.689	.698	.233	.259	.487	.326	.490	.385	.546	.474
Oct. 29	.837	.840	.817	.831	.073	.147	.343	.188	.403	.438	.641	.494
Nov. 5	.848	.923	.784	.852	.414	.297	.123	.278	.511	.417	.600	.509
Nov. 12	.636	.661	.572	.623	.340	.196	.021	.186	.435	.385	.492	.437
Nov. 19	.647	.713	.593	.651	.243	.173	.000	.139	.403	.309	.491	.401
Nov. 26	.521	.565	.478	.521	.240	.177	.000	.139	.371	.310	.395	.359
Dec. 3	.413	.429	.392	.411	.270	.138	.036	.148	.295	.245	.197	.246
Dec. 10	.317	.324	.265	.302	.217	.107	.070	.131	.159	.266	.324	.250
Dec. 17	.285	.313	.307	.302	.166	.138	.022	.109	.128	.246	.175	.183
Dec. 24	.434	.471	.434	.446	.196	.099	.222	.172	.211	.192	.386	.263
Dec. 31	.435	.460	.392	.129	.176	.114	.117	.136	.286	.267	.363	.305
1930—												
Jan. 7	.297	.345	.329	.324	.265	.148	.095	.169	.272	.287	.277	.273
Jan. 14	.148	.031	.127	.102	.084	.043	.063	.063	.137	.234	.085	.152
Jan. 21	.137	.000	.063	.067	.052	.000	.010	.021	.063	.140	.097	.100
Jan. 28	.192	.105	.148	.148	.106	.000	.011	.039	.137	.288	.160	.195
Feb. 4	.243	.250	.244	.246	.169	.021	.010	.067	.042	.235	.160	.146
Feb. 11	.211	.187	.169	.189	.084	.053	.000	.046	.106	.277	.181	.188
Feb. 18	.286	.313	.318	.306	.127	.125	.032	.095	.126	.211	.256	.198
Feb. 25	.222	.136	.148	.169	.169	.063	.010	.081	.148	.171	.255	.191
Mar. 4	.201	.188	.211	.200	.168	.127	.021	.105	.169	.265	.203	.212
Mar. 11	.265	.281	.275	.274	.147	.095	.000	.081	.181	.203	.331	.238
Mar. 18	.223	.229	.233	.228	.063	.074	.000	.046	.203	.448	.159	.270
Mar. 25	.328	.387	.392	.369	.116	.084	.074	.091	.192	.320	.201	.238
April 1	.435	.491	.520	.482	.361	.201	.064	.209	.234	.288	.385	.302
April 8	.499	.544	.539	.527	.243	.159	.115	.172	.256	.320	.330	.302
April 15	.540	.650	.732	.641	.446	.148	.159	.251	.290	.394	.417	.367
April 22	.668	.800	.943	.804	.424	.276	.190	.297	.278	.331	.341	.317
April 29	.678	.756	.921	.785	.297	.212	.212	.240	.299	.351	.471	.374
May 6	.382	.386	.478	.415	.234	.191	.168	.198	.299	.246	.268	.271
May 13	.647	.713	.764	.708	.392	.180	.170	.247	.332	.278	.394	.335
May 20	.721	.788	.953	.821	.393	.179	.168	.246	.437	.373	.416	.409
May 27	.953	1.062	1.048	1.021	.415	.306	.233	.318	.362	.426	.534	.441
June 3	.954	1.050	.995	1.000	.476	.305	.180	.320	.383	.471	.578	.477
June 10	1.134	1.231	1.228	1.198	.510	.295	.222	.342	.373	.449	.524	.449
June 17	.890	.944	.890	.908	.510	.255	.222	.329	.340	.309	.426	.358
June 24	.974	1.051	.964	.996	.444	.319	.243	.335	.361	.202	.439	.334
July 1	1.174	1.336	1.227	1.246	.540	.329	.274	.381	.394	.277	.589	.420
July 8	1.133	1.272	1.217	1.207	.552	.306	.316	.391	.405	.342	.514	.420
July 15	1.521	1.703	1.579	1.601	.656	.404	.349	.470	.405	.406	.503	.438
July 22	1.454	1.555	1.505	1.505	.637	.382	.371	.463	.459	.514	.727	.567
July 29	1.155	1.513	1.398	1.355	.647	.456	.360	.488	.415	.428	.514	.452
Aug. 5	1.303	1.597	1.452	1.451	.700	.318	.382	.467	.426	.469	.621	.505
Aug. 12	1.228	1.125	1.187	1.180	.457	.445	.284	.395	.395	.405	.438	.413
Aug. 19	1.068	1.167	1.123	1.119	.393	.318	.284	.332	.321	.352	.383	.352
Aug. 26	1.453	1.578	1.527	1.519	.615	.276	.349	.413	.375	.427	.535	.446
Sept. 2	1.312	1.410	1.389	1.370	.626	.349	.338	.438	.427	.427	.514	.456
Sept. 9	1.250	1.314	1.314	1.293	.520	.414	.320	.418	.386	.437	.492	.438
Sept. 16	.996	1.050	1.049	1.032	.435	.265	.267	.322	.342	.288	.405	.345
Sept. 23	.891	.966	.953	.937	.402	.339	.244	.328	.322	.247	.352	.307
Sept. 30	.828	.891	.818	.846	.382	.286	.233	.300	.311	.299	.394	.335

[1] All tanks covered during rains. Tanks Nos. 1 to 12, inclusive, contain undisturbed soil. Tanks Nos. 13 to 15, inclusive, contain disturbed soil.

TABLE 12

RECORD OF WEEKLY USE OF WATER BY SALT GRASS IN TANKS AT SANTA ANA, CALIFORNIA, OCTOBER, 1930, TO NOVEMBER, 1931[1]

Week ending	Use of water by salt grass in acre-inches per acre																			
	Salt grass with fixed water table three feet below the ground surface				Salt grass with fixed water table two feet below the ground surface				Salt grass with fixed water table one foot below the ground surface				Salt grass with fixed water table five feet below the ground surface				Salt grass with fixed water table two feet below the ground surface			
	Tank No. 1	Tank No. 2	Tank No. 3	Mean	Tank No. 4	Tank No. 5	Tank No. 6	Mean	Tank No. 7	Tank No. 8	Tank No. 9	Mean	Tank No. 10	Tank No. 11	Tank No. 12	Mean	Tank No. 13	Tank No. 14	Tank No. 15	Mean
1930—																				
Oct. 7	0 022	0 021	0 021	0 021	0 063	0 084	0.063	0 070	----	----	----	----	----	----	----	----	0 268	0 244	0 266	0 259
Oct. 14	063	021	032	039	095	156	116	.122	----	----	----	----	----	----	----	----	310	319	299	.309
Oct. 21	063	011	021	032	085	063	.063	070	----	----	----	----	----	----	----	----	267	.244	.322	.278
Oct. 28	.052	00	00	017	063	084	.126	091	----	----	----	----	----	----	----	----	.276	.288	320	.295
Nov. 4	.064	00	00	021	096	116	.032	081	----	----	----	----	----	----	----	----	311	.395	406	.371
Nov. 11	.031	00	00	010	084	094	.063	080	----	----	----	----	----	----	----	----	.278	.395	405	359
Nov. 18	.085	00	00	028	127	136	094	109	0 668	0 649	0 605	0 641	0 264	0 159	0.234	0 219	449	439	427	.438
Nov. 25	.094	00	00	031	084	073	064	074	656	880	646	727	.213	.213	.200	209	391	.481	492	.455
Dec. 2	.032	.00	.021	018	032	011	031	025	551	685	509	582	.191	.221	095	.169	181	.298	256	.245
Dec. 9	075	00	032	036	084	074	053	070	478	482	605	522	148	105	180	144	.321	.395	.374	.363
Dec. 16	044	00	021	022	042	031	063	.045	424	409	445	426	158	095	126	126	.320	471	406	399
Dec. 23	032	021	063	039	095	053	.063	070	446	692	509	549	.213	115	106	145	383	588	.513	.495
Dec. 30	053	021	010	.028	105	146	116	.122	317	344	327	.329	.074	084	074	077	374	492	.395	420
1931—																				
Jan. 6	.042	021	011	025	073	063	042	059	180	083	234	166	.095	063	.096	.085	236	235	234	.235
Jan. 13	021	00	021	014	042	021	053	.039	232	230	275	246	.073	052	.126	084	159	128	084	.124
Jan. 20	011	00	063	025	042	053	031	042	253	283	275	270	.074	053	.052	.060	191	192	159	181
Jan. 27	042	021	042	035	063	104	043	070	318	376	411	.368	.042	084	.131	086	235	224	256	.238
Feb. 3	011	00	021	011	053	137	042	077	285	230	.266	260	.107	----	148	.127	267	235	.299	.267
Feb. 10	010	00	011	007	063	094	126	.094	180	021	211	137	.202	----	.148	.175	159	.140	.160	.153
Feb. 17	011	00	00	004	117	198	042	119	222	199	.274	.232	.224	----	.095	.160	266	.362	.364	.331
Feb. 24	021	021	073	038	105	219	052	125	318	355	.359	.344	.180	----	148	164	329	.342	503	.391
Mar. 3	063	148	158	123	170	.281	----	226	372	397	423	397	213	074	191	159	393	459	.695	516
Mar. 10	063	137	064	088	264	408	----	.336	425	418	425	423	.234	148	063	.148	493	.589	867	.650
Mar. 17	073	042	126	080	244	399	----	.322	392	335	424	.384	.191	180	159	177	437	556	685	.559
Mar. 24	158	074	105	112	303	492	----	.398	476	493	530	500	.190	191	169	183	524	589	663	.592
Mar. 31	265	116	032	138	403	807	----	605	561	629	635	608	.191	147	181	173	567	.610	652	610
April 7	----	085	095	090	530	757	201	.496	625	619	699	648	.415	138	117	223	599	.654	739	.664
April 14	----	.126	169	148	647	955	275	626	753	777	880	803	.477	212	159	283	718	.769	910	.799
April 21	----	159	243	201	688	1 019	371	693	806	829	901	845	488	.275	148	304	759	.844	867	823
April 28	----	.116	064	090	477	431	255	388	350	345	287	327	169	095	00	.088	577	535	480	531
May 5	----	----	----	----	.328	397	.192	.306	360	252	381	331	.213	202	----	.208	371	373	364	369
May 12	----	----	----	----	593	862	327	594	615	894	912	807	.351	245	----	298	557	535	600	564
May 19	----	----	----	----	698	.997	456	717	742	1 072	1 038	.951	435	.318	----	377	729	674	791	.731
May 26	----	----	----	----	752	912	.510	725	806	975	933	905	.404	371	----	388	718	706	865	.763
June 2	709	.116	.074	300	732	987	552	.757	901	1 262	1 132	1 098	433	222	084	246	792	611	941	781
June 9	.583	.116	128	276	679	817	508	668	817	1 031	912	920	478	126	201	268	.727	654	856	.746
June 16	636	.117	.212	.322	774	966	.604	781	1 048	1 303	1 101	1 151	563	232	.147	314	.824	717	1 037	859
June 23	763	.339	.179	427	944	1 219	794	986	1 387	1 725	1 536	1 549	645	403	200	.416	.908	824	1 348	1 027
June 30	826	.371	666	621	1 163	1 419	911	1 164	1 769	1 923	1 727	1 806	.774	509	551	611	1.015	.985	1 486	1 162
July 7	646	.360	.602	536	1 038	1 251	890	1 060	1 568	1 650	1 546	1 588	688	340	413	480	1 005	1 006	1 401	1 137
July 14	637	457	614	569	1 028	1 272	869	1.056	1 642	1 756	1.674	1.691	839	457	445	580	1.026	973	1 346	1 115
July 21	509	509	572	530	1 060	1 252	912	1 075	1 685	1 702	1 675	1 687	.711	456	426	.531	1 080	1 060	1 454	1 198
July 28	.678	552	635	622	1 164	1 387	.995	1.182	1 845	1 818	1 824	1 829	838	.572	404	605	1 111	1 048	1 369	1 176
Aug. 4	520	561	561	547	1 102	1 251	943	1 099	1 707	1 577	1 601	1.628	721	488	389	533	1 134	983	1 348	1 155
Aug. 11	467	477	487	477	923	1 062	.839	.941	1 409	1 347	1 389	1.382	594	.413	.456	.488	984	.855	1 153	.997
Aug. 18	.318	393	404	372	710	806	679	732	1 282	1 018	1 060	1 120	.520	393	.338	417	866	728	930	.841
Aug. 25	.530	.552	615	566	1 059	1 293	.857	1 070	1 747	1 618	1 717	1.694	.751	456	467	.558	1 025	919	1 411	1.118
Sept. 1	382	372	308	354	891	997	.753	.880	1 302	1 051	1 155	1 169	550	349	.668	522	1 144	889	1 069	1 034
Sept. 8	424	404	424	417	837	978	721	845	1 240	1 061	1 240	1 180	563	360	244	389	1 261	673	1 047	.994
Sept. 15	458	425	424	436	859	999	742	.867	1 218	1 051	1 134	1 134	635	457	254	449	1 145	856	1 036	1.012
Sept. 22	.466	393	403	421	815	914	720	.816	1 081	966	1 039	1 029	456	351	307	371	973	759	995	909
Sept. 29	.414	.391	402	402	783	831	646	753	974	819	732	842	550	295	286	377	899	792	888	860
Oct. 6	.403	382	360	382	784	839	658	760	837	682	763	.761	508	338	.285	377	866	739	878	.828
Oct. 13	.329	318	361	336	572	629	519	573	722	619	710	684	.572	316	294	394	664	600	556	607
Oct. 20	.338	.328	256	307	552	534	552	546	658	555	625	613	444	244	254	.314	.643	556	589	596
Oct. 27	.286	285	317	296	477	525	370	457	530	503	542	525	.327	274	234	278	557	492	512	.520
Nov. 3	.361	329	371	354	709	799	594	701	783	713	784	760	393	.316	226	.312	771	610	770	.717

[1] Tanks Nos. 1 to 15 inclusive covered during rains. Tanks Nos. 1 to 12, inclusive, contained undisturbed soil; Nos. 13 to 15, inclusive, contained disturbed soil.

TABLE 13

SUMMARY SHOWING MONTHLY USE OF WATER BY SALT GRASS AND TULES AND EVAPORATION FROM SOIL AND WATER SURFACES, MAY, 1929, TO APRIL, 1930, IN TANKS AT SANTA ANA, CALIFORNIA[1]

Tank No.	Content of tank	Depth to water table, in feet	Diameter of tank, in inches	Amount of water used in inches of depth												Number of months of record	Total amount used, in inches	Per cent of	
				May	June	July	August	September	October	November	December	January	February	March	April			Tank No. 16	Tank No. 20
1	Bare soil	4-3	23 1/16	No evaporation from Tanks Nos. 1, 2				(2)	0.399	0.370	0.275	0.179	0 148	0.085	0 084	7			
2	Bare soil	4-3	23 1/16	and 3 with water table at depth of four				(2)	1 493	338	074	.000	000	.000	000	7			
3	Bare soil	4-3	23 1/16	feet, May 1 to October 1, 1929				(2)	1.399	443	.265	.126	074	.137	.137	7			
Mean	Bare soil	4-3	23 1/16					(2)	1 097	384	205	.102	074	074	074	7	2 010	7 7	6.7
4	Bare soil	2	23 1/16	2 160	1 099	0 709	0 696	0 474	559	444	339	.242	189	148	316	12			
5	Bare soil	2	23 1/16	2 418	1 555	.908	1 084	815	708	552	.462	.200	.189	.201	535	12			
6	Bare soil	2	23 1/16	1 076	663	727	651	453	.421	.371	.307	.242	179	147	.263	12			
Mean	Bare soil	2	23 1/16	1 885	1 106	.781	810	.581	563	456	.369	.228	186	.165	.371	12	7.501	11.2	10 6
7	Salt grass sod	2	23 1/16	1 440	4 916	5 530	5 019	3 319	3 413	2 662	1 630	.858	984	1 293	2.502	12			
8	Salt grass sod	2	23 1/16	2 417	3 296	5 964	5 908	3.737	3 696	2 861	1 736	.554	896	1 441	2 862	12			
9	Salt grass sod	2	23 1/16	3 501	4 978	5 410	5 666	3 571	3 447	2 458	1 557	.752	867	1.473	3 326	12			
Mean	Salt grass sod	2	23 1/16	2 453	4.397	5 635	5 531	3 542	3 519	2 660	1 641	.721	.916	1 402	2 897	12	35 314	56 0	50.0
10	Salt grass sod	4	23 1/16	.275	477	2 714	3 451	1 907	1.377	1 326	.914	.549	612	.729	1 463	12			
11	Salt grass sod	4	23 1/16	000	592	1 865	2 330	1 408	1 164	869	.521	.191	.347	454	.837	12			
12	Salt grass sod	4	23 1/16	702	1 304	2 714	3 097	1 792	2 457	.117	.467	.189	042	.148	.719	12			
Mean	Salt grass sod	4	23 1/16	.326	.791	2 431	2 959	1.702	1 666	.771	.634	.310	334	.444	1 006	12	13.374	21 4	19.0
13	Bare soil	2	23 1/16				1 834	2.069	2 221	1 695	.911	.651	454	862	1.219	9			
14	Bare soil	2	23 1/16				2 792	2.256	1 857	1.431	1 067	1.067	1 829	1 418	1 460	9			
15	Bare soil	2	23 1/16				4 223	3.038	2.770	1.957	1.263	.673	.916	1 118	1 677	9			
Mean	Bare soil	2	23 1/16				2 950	2 454	2 283	1 694	1 080	.797	733	1 133	1 452	9	14 576	36 2	32.5
16	Water in circular sunken tank[3]		23 1/16	5 574	7.910	8.196	8.328	5 762	5.640	4 884	3 060	1.860	2 436	3 384	4 968	11¾	62.002	100 0	91.0
19	Round stem tules in submerged soil[4]		25 1/2				23.460	23.750	28.380	23 350	11.300	1.860	3.610	6 020	17.590	9	139.320	345 5	309.7
20	Water in standard Weather Bureau pan		48	8.394	8 234	8 892	8 904	5.654	6 060	5.256	3 444	2 280	2 872	4 476	6 048	12	70.514	110.4	100.0

[1] Tanks Nos. 1 to 12, inclusive, contained undisturbed soil; tanks Nos. 13 to 15, inclusive, contained disturbed soil. All tanks covered during rains.
[2] Water table raised from four to three feet, October 1, 1929.
[3] Record began May 8, 1929.
[4] Not applicable to field conditions.

TABLE 14

SUMMARY SHOWING MONTHLY USE OF WATER BY SALT GRASS, TULES, CAT-TAILS, WILLOWS, AND WIRE RUSH, AND EVAPORATION FROM SOIL AND WATER SURFACES, MAY, 1930, TO APRIL, 1931, IN TANKS AT SANTA ANA, CALIFORNIA[3] [5]

Tank No.	Content of tank	Depth to water table, in feet	Diameter of tank, in inches	Amount of water used in inches of depth												Number of months of record	Total amount used, in inches	Per cent of	
				May	June	July	August	September	October	November	December	January	February	March	April			Tank No. 16	Tank No. 20
1	Bare soil planted to salt grass October, 1930	3	23 1 16	0 147	0 075	0 138	0 158	0 221	0 232	0 274	0 204	0 116	0 074	0 601		11			
2	Bare soil planted to salt grass October, 1930	3	23 1 16	043	021	074	000	000	053	000	042	043	084	454	0 517	12	(6)		
3	Bare soil planted to salt grass October, 1930	3	23 1 16	147	043	242	095	242	074	021	126	158	168	401	571	12			
Mean	Bare soil planted to salt grass October, 1930	3	23 1 16	112	046	151	.084	154	120	098	.124	.106	109	485	544	12			
4	Bare soil planted to salt grass October, 1930	2	23 1/16	358	368	485	422	422	349	380	336	.221	444	1 267	2 426	12			
5	Bare soil planted to salt grass October, 1930	2	23 1/16	398	564	573	586	595	429	388	314	305	730	2 231	3 214	12			
6	Bare soil planted to salt grass October, 1930	2	23 1 16	284	295	421	326	390	368	285	295	169	336		1 145	11			
Mean	Bare soil planted to salt grass October, 1930	2	23 1/16	347	409	493	445	.469	.382	351	315	232	503	1 749	2 262	12			
7	Salt grass sod[1]	2-1	23 1/16	3 180	4 426	5 740	5 697	4 314			1 834	1 141	996	2 035	2 618	10			
8	Salt grass sod[1]	2-1	23 1/16	3 485	4 834	6 664	6 056	4 600			2 084	1 129	836	2 084	2 581	10			
9	Salt grass sod[1]	2-1	23 1/16	3 709	4 563	6 281	5 894	4 505			2 066	1 344	1 109	2.247	2 820	10			
Mean	Salt grass sod[1]	2-1	23 1/16	3 458	4 608	6 228	5 882	4 473			1 995	1 205	980	2 122	2 673	10			
10	Salt grass sod[2]	4-5	23 1/16	1 655	2 173	2 726	2 451	1 898		1 187	.635	274	830	891	1 602	11			
11	Salt grass sod[2]	4-5	23 1/16	1 003	1 292	1 707	1 473	1 410		881	430	242		729	773	10			
12	Salt grass sod[2]	4-5	23 1/16	792	1 024	1 545	1 414	1 170		784	.549	.369	508	710	456	11			
Mean	Salt grass sod[2]	4-5	23 1/16	1 150	1 496	1 993	1 779	1 493		.951	538	.295	669	777	.944	11			
13	Bare soil planted to salt grass October, 1930	2	23 1/16	1 600	1 575	1 854	1 699	1 489	1 250	1 407	1 515	.938	1 084	2 191	2 759	12			
14	Bare soil planted to salt grass October, 1930	2	23 1/16	1 590	1 366	1 914	1 792	1 399	1 288	1 741	2 063	896	1 208	2 514	2 909	12			
15	Bare soil planted to salt grass October, 1930	2	23 1/16	1 880	2 138	2 472	2 213	1 782	1 368	1.751	1 805	.882	1 497	3 199	3 081	12			
Mean	Bare soil planted to salt grass October, 1930	2	23 1/16	1 690	1 693	2 080	1 901	1 557	1 302	1 633	1 794	.905	1 263	2 635	2 916	12			
16	Water in circular sunken tank		23 1/16	5 988	6 440	7 824	6.744	5 588	5 032	3 816	3 144	2 194	2 472	5 454	5 212	12	59 908	100 0	90 8
19	Round stem tules in submerged soil[7]		25 1/2	22 565	23 088	28 595	24 793	19 754	18 352	12 955	8 024	3 730	2 365	5 183	8 386	12	177 790	296 8	269 4
20	Water in standard Weather Bureau pan		48	6 792	6 948	8 544	7 392	5 828	5 500	4 262	3 312	2 890	2 736	5 778	6 016	12	65 998	110 2	100 0
21	Triangular stem tules in submerged soil[7]		25 1/2	12 361	15 896	23 286	24 292	21 942	21 012	15 031	6 405	2 894	2 165	5 901	9 789	12	160 974	268 7	243 9
22	Cat-tails in submerged soil[7]		25 1/2	11 875	13 526	16 906	14 924	11 210	10 140	7 427	5 214	3 007	2 100	6 847	7 891	12	111 067	185 4	168 3
23	Round stem tules in submerged soil[7]		72	10 230	12 428	17 211	15 946	13 058	12 043	8 602	3 322	2 587	2 201	8 553	11 508	12	117 689	196 4	178 3
24	Willow[4]	2	72	3 275	4 988	7 343	7 803	6 628	5 359	3 545	2.115		2 005	3 922	5 724	11	52 707	91 3	83 5
25	Wire rush[4]	2	25 1/2				5 735	5 427	5 682	5 031	4 233	2 654	2 956	6 781	7 761	9	46 260	116 7	105 8

[1] Water table raised from two feet to one foot October, 1930.
[2] Water table lowered from four to five feet October, 1930.
[3] Tanks Nos. 1 to 12, inclusive, contain undisturbed soil. Tanks Nos. 13 to 15, inclusive, contain disturbed soil.
[4] Rainfall included in water used but changes in soil moisture on account of rainfall disregarded.
[5] Tanks Nos. 1 to 15, inclusive, covered during rains.
[6] Totals are not given for soil moisture tanks as conditions are not comparable throughout the year due to changing water levels and planting new grass.
[7] Not applicable to field conditions.

TABLE 15

SUMMARY SHOWING MONTHLY USE OF WATER BY SALT GRASS, TULES, CAT-TAILS, WILLOWS AND WIRE RUSH, AND EVAPORATION FROM WATER SURFACES, MAY, 1931, TO APRIL, 1932; IN TANKS AT SANTA ANA, CALIFORNIA[1, 3]

Tank No.	Content of tank	Depth to water table, in feet	Diameter of tank, in inches	Amount of water used in inches of depth												Number of months of record	Total amount used, in inches	Per cent of	
				May	June	July	August	September	October	November	December	January	February	March	April			Tank No. 16	Tank No. 20
1	Salt grass sod	3	23 1/16		3 041	2 725	1 909	1 868	1 558	1 831	1 436	1 834	1 647	2 643	4 166	11			
2	Salt grass sod	3	23 1/16		964	2 153	2 079	1 740	1 483	1 832		2 329	2 132	3 288	3 042	10			
3	Salt grass sod	3	23 1/16		1 238	2 667	2 099	1 770	1 453	1 841	2 445	[4]	1 748	3 652	2 771	10			
Mean	Salt grass sod	3	23 1/16		1 748	2 515	2 029	1 793	1 498	1 835	1 941	2 082	1 842	3 194	3 326	11	23 803	49 8	42 2
4	Salt grass sod	2	23 1/16	2 764	3 815	4 809	4 049	3 549	2 786	2 225	1 604	2 789		2 947	3 475	11			
5	Salt grass sod	2	23 1/16	3 777	4 747	5 771	4 695	3 974	2 990	2 367	1 487	2 424		2 526	3 574	11			
6	Salt grass sod	2	23 1/16	1 814	2 997	4 111	3 552	3 041	2 343	2 266	1 214	1 690	1 950	3 646	3 025	12			
Mean	Salt grass sod	2	23 1/16	2 785	3 853	4 897	4 099	3 521	2 706	2 286	1 435	2 301	1 950	3 040	3 358	12	36 231	67 7	57 3
7	Salt grass sod	1	23 1/16	3 043	5 318	7 546	6 482	4 799	3 202	2 101	2 046	1.628		2 578	4 202	11			
8	Salt grass sod	1	23 1/16	4 044	6 382	7 683	5 707	4 170	2 768	1 782	1 067		1 893	2 212	3 608	11			
9	Salt grass sod	1	23 1/16	3 983	5 636	7 482	6 011	4 420	3 106	1 964	1 191	1 069	1 294	1 740	3 140	12			
Mean	Salt grass sod	1	23 1/16	3 690	5 779	7 570	6 067	4 463	3 025	1 949	1 435	1 349	1 594	2 177	3 650	12	42 748	79 9	67 6
10	Salt grass sod	5	23 1/16	1 637	2 608	3 415	2 744	2 363	1 968	2 066		1.011	2 557	2 164	2 521	11			
11	Salt grass sod	5	23 1/16	1 263	1 312	2 037	1 845	1 558	1 309	1 683	1 547	1 664	1 215	2 720	1 186	12			
12	Salt grass sod	5	23 1/16		1 099	1 814	2 183	1 166	1 154	1 558	1.685	1 538	2 364	2 612	1 733	11			
Mean	Salt grass sod	5	23 1/16	1 450	1 673	2 422	2 257	1 696	1 477	1 769	1 616	1 404	2 045	2 499	1 813	12	22 121	41 3	35 0
13	Salt grass sod	2	23 1/16	2 804	3 731	4 725	4 404	4 684	3 105	2 633	840	1.870	401	2 811	4 017	12			
14	Salt grass sod	2	23 1/16	2 609	3 362	4 514	3 851	3 283	2 676	2 546	1 108	1 055		1 657	4 822	11			
15	Salt grass sod	2	23 1/16	3 164	5 037	6 222	5 152	4 212	2 963	2 288	1 010	1 230	761	2 312	3 886	12			
Mean	Salt grass sod	2	23 1/16	2 859	4 043	5 154	4 469	4 060	2 915	2 489	.986	1.385	581	2 260	4 242	12	35 443	66 2	56.1
16	Water in circular sunken tank		23 1/16	5 746	6 850	8 100	7 102	5 942	4 266	2 734	1 448	1 788	1.602	3 504	4 442	12	53 524	100 0	84.7
19	Round stem tules in submerged soil[5]		25 1/2	17 372	27 057	31 564	25 746	19 372	14 240	6 089		1 267	2 509	6 052	11 717	11	162 985	313 0	266.1
20	Water in standard Weather Bureau pan		48	6 886	8 050	8 904	7 462	6.206	4.698	3 094	1 988	2 376	2 730	4 980	5 858	12	63 232	118 1	100 0
21	Triangular stem tules in submerged soil[5]		25 1/2	17 198	24 777	31 697	30 823	29 382	20 468	6 015	1 971	2 431	1 568	5 830	11 832	12	183 992	343 8	291.0
22	Cat-tails in submerged soil[5]		25 1/2	11 214	14 940	20 208	17 429	14 978	12 055	5 307		1.744	2 397	6 031	11 180	11	117 483	225 6	191.8
23	Round stem tules in submerged soil[5]		72	15 714	19 073	19 681	14 885	12 431	7 304	5 063		1 346	815	4 775	8 717	11	109 804	210 9	179 2
24	Willow[4, 2]	2	72	4 760	4 484	4 602	3 306	2 702	1 476	1 655	705	1 275	1 065	2 850	4 035	12	32 915	61 5	52.1
25	Wire rush[4]	2	25 1/2	8 621	10 304	13 752	12 702	10 729	8 254	4 853			1 583	4 106	8 549	10	83 453	165 9	141 8
26	5% NaCl solution in standard W. B. pan		48	6 334	7 318	8.148	7 018	5 834	4 542	2 698	1 484	2 064	1 902	4 536	5 126	12	57 004	106 5	90.2

[1] Tanks Nos. 1 to 12, inclusive contain undisturbed soil. Tanks Nos. 13 to 15, inclusive, contain disturbed soil.
[2] Willow unhealthy and lost most of its leaves during latter part of the summer.
[3] Tanks Nos. 1 to 15, inclusive, covered during rains prior to December 1, 1931, except during the first half of November, 1931. From December 1, 1931 to May 1, 1932, all tanks were exposed to rainfall.
[4] Rainfall included in water used but changes in soil moisture on account of rainfall disregarded.
[5] Not appplicable to field conditions.

although sufficient data were collected to obtain monthly totals throughout the following spring. Some weekly totals were omitted. Because of changes in depths to water tables in October, 1930, true records could not be obtained pending soil moisture adjustments and data for these periods are not included. At other times accident or failure of the Mariotte tanks to function properly is responsible for omissions.

A complete summary of all work done at the Santa Ana station for each of the three years of the investigation is given in Tables 13, 14 and 15, which show the monthly use of water by all soil and water tanks. Descriptions of contents of tanks are included, and percentages of use of water by each moist area growth with reference to evaporation from water surfaces is likewise tabulated. These data are the most valuable of the report.

Use of Water by Bermuda Grass

Bermuda grass (*Cynodon dactylon*) is a perennial with long, creeping, jointed stems, often several feet in length. It spreads largely by rooting at the nodes, although it also seeds abundantly. Where conditions are favorable it forms a dense turf, frequently becoming a pest in lawns by driving out or smothering other lawn grass. It is found growing wild in many localities, always in exposed places, as it is intolerant of shade. Bermuda grass is not an indicator of ground water, as is salt grass, although the experiments indicate that it may use slightly more water than salt grass when it is available. It is frequently used for pasture and makes good feed for stock.

Excellent conditions for experimenting with Bermuda grass were found at the San Bernardino station. The yard in which the tanks were set was covered with a dense growth of the grass, so that tests of consumptive use of water were made with tank crops surrounded by a natural growth of the same variety. The principal difference between tank and field conditions was in depth to water table. In the tanks, the water table was fixed at definite levels during the three years of record, while the outside ground water fluctuated between 2½ and 6 feet below the ground surface.

Data on weekly use of water by Bermuda grass grown in tanks at San Bernardino are given in Tables 16 and 17. In November, 1931, daily readings at the station were discontinued, because of high ground water entering the tanks through the waste pipes and changing the water levels. Records of weekly and monthly use of water immediately before and after the first week in October, 1930, are not comparable as at this time the grass was maliciously burned off from all four tanks. Previous to the burning, each tank had a heavy crop of grass which used over ½ acre-inch of water per week. Immediately after the burning, this loss was reduced over one-half. As the burning was done in the fall, no recovery was possible until the following spring when new growth appeared on all tanks. In spite of the loss of grass, there was a small but continuous loss of water from each tank throughout the winter months. Plate VI shows the appearance of the grass in the tanks and in the surrounding field before burning took place. Tank growth is shown in the center of the picture as being higher than the surrounding grass.

TABLE 16

RECORD OF WEEKLY USE OF WATER BY BERMUDA GRASS IN TANKS AT SAN BERNARDINO, CALIFORNIA, MAY, 1929, TO SEPTEMBER, 1930[1]

Week ending	Use of water by Bermuda grass, in acre-inches per acre					
	Fixed water table three feet below ground surface			Fixed water table two feet below ground surface		
	Tank No. 1	Tank No. 2	Mean	Tank No. 3	Tank No. 4	Mean
1929—						
May 14	1.155			1.293	1.325	1.309
May 21	1.006			1.112	.964	1.038
May 28	.828			1.081	.869	.975
June 4	1.198			1.621	1.072	1.347
June 11	.879			1.292	.859	1.075
June 18	.828			1.070	.921	.996
June 25	1.558			1.993	1.451	1.722
July 2	1.389			1.653	1.336	1.495
July 9	1.187			1.537	1.314	1.425
July 16	1.175	Note:—Records for tank No. 2 could not be relied upon before October.		1.622	1.356	1.489
July 23	1.497			1.823	1.655	1.739
July 30	1.137			1.315	.964	1.140
Aug. 6	1.490			1.631	1.388	1.510
Aug. 13	1.121			1.601	1.304	1.452
Aug. 20	1.212			1.495	1.281	1.388
Aug. 27	1.098			1.494	1.273	1.383
Sept. 3	1.118			1.548	1.177	1.362
Sept. 10	.688			.837	.869	.853
Sept. 17	.742			1.219	.911	1.065
Sept. 24	.508			.520	.497	.508
Oct. 1	.582			.636	.636	.636
Oct. 8	.656	0.942	0.799	.912	.742	.827
Oct. 15	.901	.403	.652	.667	.645	.656
Oct. 22	.542	.762	.652	.594	.583	.588
Oct. 29	.466	.902	.684	.772	.593	.683
Nov. 5	.406	.540	.473	.317	.286	.301
Nov. 12	.400	.382	.391	.498	.392	.445
Nov. 19	.264	.365	.315	.424	.372	.398
Nov. 26	.232	.261	.246	.327	.349	.338
Dec. 3	.074	.126	.100	.212	.128	.170
Dec. 10	.149	.286	.217	.266	.255	.260
Dec. 17	.200	.127	.164	.212	.137	.175
Dec. 24	.205	.201	.203	.201	.233	.217
Dec. 31	.167	.084	.125	.201	.181	.191

TABLE 16—Continued

RECORD OF WEEKLY USE OF WATER BY BERMUDA GRASS IN TANKS AT SAN BERNARDINO, CALIFORNIA, MAY, 1929, TO SEPTEMBER, 1930[1]

Week ending	Use of water by Bermuda grass, in acre-inches per acre					
	Fixed water table three feet below ground surface			Fixed water table two feet below ground surface		
	Tank No. 1	Tank No. 2	Mean	Tank No. 3	Tank No. 4	Mean
1930—						
Jan. 7	.105	.222	.169	.148	.179	.164
Jan. 14	.139	.188	.163	.190	.116	.153
Jan. 21	.202	.190	.196	.127	.106	.117
Jan. 28	.160	.148	.154	.010	.032	.021
Feb. 4	.044	.180	.112	.064	.042	.053
Feb. 11	.063	.074	.068	.147	.106	.126
Feb. 18	.138	.222	.180	.212	.125	.168
Feb. 25	.265	.232	.249	.276	.297	.287
Mar. 4	.298	.264	.281	.181	.233	.212
Mar. 11	.373	.264	.318	.201	.265	.233
Mar. 18	.285	.106	.196	.074	.191	.132
Mar. 25	.180	.105	.143	.116	.222	.169
April 1	.213	.329	.271	.614	.191	.402
April 8	.211	.201	.206	.561	.223	.392
April 15	.466	.159	.312	.657	.381	.519
April 22	.571	.688	.630	1.039	.901	.970
April 29	.774	.624	.699	.785	.773	.779
May 6	.287	.370	.329	.296	.626	.461
May 13	.362	.370	.366	.255	.317	.286
May 20	.448	.338	.393	.627	.339	.483
May 27	.648	.830	.739	1.058	.794	.926
June 3	.741	.870	.806	1.167	.933	1.050
June 10	1.258	.965	1.112	1.345	1.271	1.308
June 17	.625	.955	.790	1.175	1.208	1.192
June 24	.953	.995	.974	1.219	1.166	1.193
July 1	1.256	1.312	1.284	1.515	1.484	1.500
July 8	1.186	1.334	1.260	1.399	1.271	1.335
July 15	.816	1.441	1.129	1.633	1.398	1.516
July 22	1.452	1.558	1.505	1.578	1.452	1.515
July 29	1.217	1.112	1.165	1.496	1.346	1.421
Aug. 5	.573	----------	----------	1.409	1.071	1.240
Aug. 12	.689	----------	----------	1.093	1.123	1.108
Aug. 19	.974	----------	----------	1.146	.933	1.040
Aug. 26	.994	----------	----------	1.473	1.408	1.441
Sept. 2	.890	1.483	1.187	1.249	1.167	1.208
Sept. 9	.678	.858	.768	1.145	.985	1.065
Sept. 16	.783	1.007	.895	.775	.826	.801
Sept. 23	.468	.531	.500	.753	.561	.657
Sept. 30	.403	.890	.647	.498	.689	.594

[1] All tanks covered during rains. Tanks contain undisturbed soil.

TABLE 17

RECORD OF WEEKLY USE OF WATER BY BERMUDA GRASS IN TANKS AT SAN BERNARDINO, CALIFORNIA, OCTOBER, 1930, TO NOVEMBER, 1931[1]

Week ending	Use of water by Bermuda grass, in acre-inches per acre					
	Fixed water table three feet below ground surface			Fixed water table two feet below ground surface		
	Tank No. 1	Tank No. 2	Mean	Tank No. 3	Tank No. 4	Mean
1930—						
[2]Oct. 7	0.319	0.297	0.308	0.457	0.276	0.367
Oct. 14	.137	.168	.153	.222	.371	.297
Oct. 21	.105	.212	.159	.233	.294	.264
Oct. 28	.096	.127	.112	.340	.224	.282
Nov. 4	.169	.276	.223	.340	.244	.292
Nov. 11	.126	.244	.185	.413	.244	.329
Nov. 18	.083	.294	.189	.202	.202	.202
Nov. 25	.116	.274	.195	.255	.190	.223
Dec. 2	.137	.169	.153	.074	.127	.101
Dec. 9	.116	.181	.149	.170	.126	.148
Dec. 16	.095	.148	.122	.169	.116	.143
Dec. 23	.084	.116	.100	.147	.116	.132
Dec. 30	.148	.073	.111	.105	.136	.121
1931—						
Jan. 6	------	------	------	------	------	------
Jan. 13	------	------	------	------	------	------
Jan. 20	------	------	------	------	------	------
Jan. 27	------	------	------	------	------	------
Feb. 3	------	------	------	.043	.042	.043
Feb. 10	------	------	------	.052	.053	.053
Feb. 17	------	------	------	.147	.021	.084
Feb. 24	------	------	------	.147	.063	.105
Mar. 3	.021	.011	.016	.212	.138	.175
Mar. 10	.042	.042	.042	.402	.307	.355
Mar. 17	.043	.117	.080	.403	.328	.366
Mar. 24	.042	.126	.084	.563	.509	.536
Mar. 31	.021	.095	.058	.562	.434	.498
April 7	.159	.382	.271	.689	.488	.589
April 14	.148	.720	.434	.836	.836	.836
April 21	.264	.668	.466	.911	.837	.874
April 28	.274	.480	.377	.222	.254	.238
May 5	.231	.414	.323	.412	.360	.386
May 12	.392	.499	.446	.985	.710	.848
May 19	.562	.762	.662	1.049	.934	.992
May 26	.435	.743	.589	.860	.711	.786
June 2	.519	.605	.562	.689	.773	.731
June 9	.317	797	.557	.615	.456	.536
June 16	.382	.786	.584	.763	.679	.721
June 23	.795	.817	.806	1.377	1.293	1.335
June 30	1.145	1.389	1.267	1.749	1.516	1.633
July 7	.966	1.409	1.188	1.527	1.409	1.468
July 14	.816	1.633	1.225	1.674	1.687	1.681
July 21	1.420	1.410	1.415	1.876	1.538	1.707
July 28	1.281	1.335	1.308	1.666	1.345	1.506
Aug. 4	.996	1.304	1.150	1.568	1.322	1.445
Aug. 11	.858	1.336	1.097	1.420	1.239	1.330
Aug. 18	.858	.594	.726	1.144	.678	.911
Aug. 25	1.144	1.155	1.150	1.419	1.442	1.431
Sept. 1	.658	.858	.758	.849	.605	.727
Sept. 8	.404	.562	.483	.625	.551	.588
Sept. 15	.563	.679	.621	1.155	.859	1.007
Sept. 22	.806	.655	.731	.836	.784	.810
Sept. 29	.731	.445	.588	.721	.752	.737
Oct. 6	.487	.508	.498	.594	.666	.630
Oct. 13	.424	.615	.520	.583	------	------
Oct. 20	.371	.522	.447	.476	.266	.371
Oct. 27	.435	------	------	.392	.253	.323
Nov. 3	.200	.233	.217	.742	.541	.642
Nov. 10	.306	.212	.259	.297	.425	.361

[1] All tanks covered during rains. Tanks contain undisturbed soil.
[2] Grass burned off tanks.

Plate VII shows a comparison of the consumptive use of water by Bermuda grass and salt grass, and also evaporation from the water surface of a ground tank of the same size as the soil tanks. The ground tank was No. 16 at the Santa Ana station. The water table in each case was 2 feet in depth during the period indicated, and the results

PLATE VI

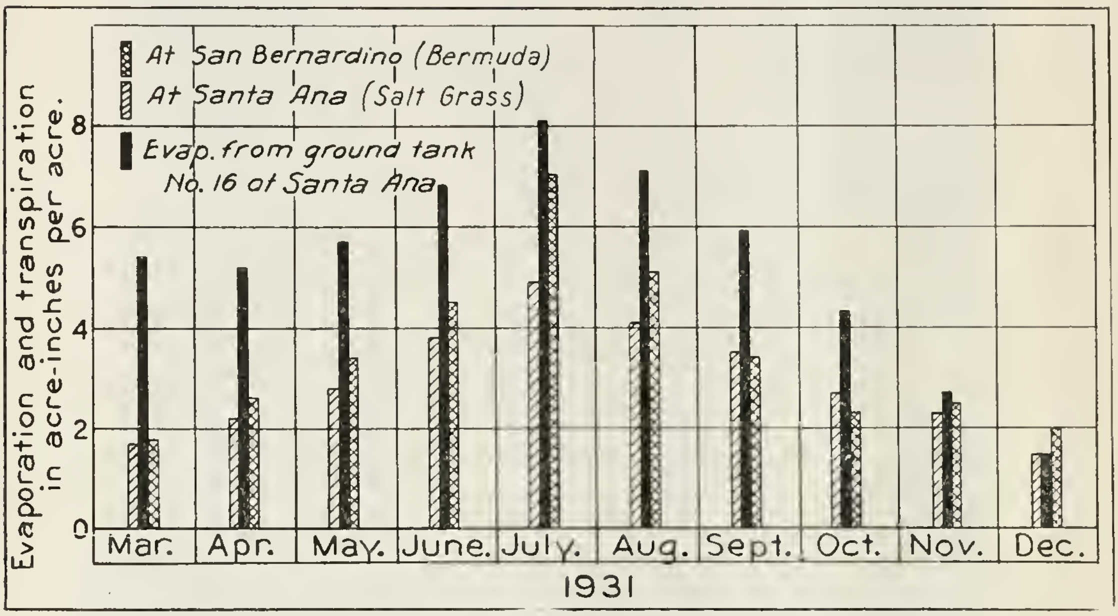
BERMUDA GRASS IN TANKS IN FIELD OF SIMILAR GROWTH AT SAN BERNARDINO. THE TANKS ARE IN THE CENTER OF THE PICTURE SHOWING HEAVIER GROWTH.

given are the averages of three tanks of salt grass and of two tanks of Bermuda grass, respectively. During the period of record the total use of water by salt grass was 29.6 acre-inches per acre, while that by Bermuda grass was 34.7 acre-inches per acre.

Although consumptive use by Bermuda grass is the greater, the maximum 12-month record from May to April during the three years of measurement was but little more than 3 acre-feet per acre in a year when the tanks were protected from rainfall. If there had been no protection consumptive use would have been slightly increased. The San Bernardino district has an interior climate which increases evaporation and consumptive use of water to an amount greater than that in the coastal climate of Orange County, and irrigation requirements also are higher. The use of water by Bermuda grass is probably somewhat higher than the use by citrus, but less than that by alfalfa. Bermuda grass, therefore, does not make an excessive demand upon the ground water supply.

Monthly consumptive use of water by Bermuda grass for the period covered by the investigation is shown in Tables 18, 19 and 20. These tables also show the total use of water for each year, ending April 30. Some months are omitted, but percentages of use for the

PLATE VII



COMPARISON OF USE OF WATER BY BERMUDA GRASS AT SAN BERNARDINO WITH THAT OF SALT GRASS AT SANTA ANA AND EVAPORATION FROM WATER IN TANK NO. 16 AT SANTA ANA.

months of record, based on the evaporation from both the circular sunken evaporation tank and the Weather Bureau pan, separately, are given for the same period. It is through these percentages that comparisons of consumptive use with the same or different crops grown under different climatic conditions may be made.

Use of Water by Tules and Cat-Tails

A study of consumptive use of water by aquatic growth was begun in the summer of 1929 at the Santa Ana station by transplanting rooted plants of round stem tules into a single tank. In the following spring investigation of triangular stem tules and cat-tails was begun at Santa Ana and later one tank of triangular stem tules at Prado and one tank of round stem tules at San Bernardino were included.

The round stem tule or common bulrush (*Scirpus acutus*) is a perennial plant with a round, dark green stem which grows to a height of 6 to 12 feet. It is found in abundance in some sections where water

\CES, MAY, 1929, TO APRIL,

	uary	March	April	Number of months of record	Total amount used	Per cent of Tank No. 5	Per cent of Tank No. 7
1	647	1 136	2 139	12	-------	-------	-------
2	676	.877	1.798	6	-------	-------	-------
)	.662	1.006	1 968	-------	32.526	51.2	45 5
3	742	1 122	3.063	12	-------	-------	-------
4	676	.975	2 373	12	-------	-------	-------
)	709	1 048	2 718	12	37 266	58 6	52 1
5	676	3 912	5 400	12	63 572	100.0	88.9
6	-----	-------	-------	2	13 858	105 3	95.6
7	456	5 016	5 376	12	71 490	112 5	100 0

ER SURFACES, MAY, 1930, TO

	uary	March	April	Number of months of record	Total amount used	Per cent of Tank No. 5	Per cent of Tank No. 7
1	-----	0 169	-------	9	-------	-------	-------
2	-----	.391	2 334	9	-------	-------	-------
)	-----	.280	2 334	10	23 833	49 3	43.0
3	495	2 036	2 700	11	-------	-------	-------
4	211	1.674	2 457	11	-------	-------	-------
)	.353	1 855	2 579	11	31 010	61 3	53.0
5	253	4 953	4 064	12	53 396	100 0	86 7
6	(6)	8 883	13.399	11	170.880	334 1	291.9
7	.058	5 766	4.892	12	61 594	115 4	100 0

TABLE 18

SUMMARY SHOWING MONTHLY USE OF WATER BY BERMUDA GRASS AND EVAPORATION FROM WATER SURFACES, MAY, 1929, TO APRIL, 1930, IN TANKS AT SAN BERNARDINO, CALIFORNIA[1]

Tank No.	Content of tank	Depth to water table, in feet	Diameter of tank, in inches	Amount of water used, in inches of depth												Number of months of record	Total amount used	Per cent of	
				May[2]	June	July	August	September	October	November	December	January	February	March	April			Tank No. 5	Tank No. 7
1	Bermuda grass sod	3	23 1/16	4 280	5 216	5 489	5 345	2 901	2 771	1 255	0 719	0 650	0 647	1 136	2 139	12			
2	Bermuda grass sod	3	23 1/16							1 505	761	886	676	.877	1 798	6			
Mean	Bermuda grass sod	3	23 1/16	4 280	5 216	5 489	5 345	2 901	2 771	1 380	740	768	662	1 006	1 968		32 526	51 2	45 5
3	Bermuda grass sod	2	23 1/16	5 340	6 348	7 144	6 804	3 785	3 061	1 641	1 007	.475	742	1 122	3 063	12			
4	Bermuda grass sod	2	23 1/16	4 840	4 854	5 872	5 660	3 337	2 722	1 410	849	433	676	975	2 373	12			
Mean	Bermuda grass sod	2	23 1/16	5 090	5 601	6 508	6 232	3 561	2 892	1 525	.928	454	709	1 048	2 718	12	37 266	58 6	52 1
5	Water in circular sunken tank		23 1/16	6 090	7 596	8 892	7 740	5 426	5 436	4 704	3 480	2 220	2 676	3 912	5 400	12	63 572	100 0	88.9
6	Bermuda grass in submerged soil		23 1/16				8 296	5 562								2	13 858	105 3	95.6
7	Water in standard Weather Bureau pan		48	7 780	8 892	9 780	8 808	5 690	5 580	4 980	3 816	2 316	3 456	5 016	5 376	12	71 490	112 5	100 0

[1] Tanks contained undisturbed soil. All grass tanks covered during rains.
[2] Records began May 6, 1929, but May totals are proportioned for full month.

TABLE 19

SUMMARY SHOWING MONTHLY USE OF WATER BY BERMUDA GRASS AND TULES AND EVAPORATION FROM WATER SURFACES, MAY, 1930, TO APRIL, 1931, IN TANKS AT SAN BERNARDINO, CALIFORNIA[1, 7]

Tank No.	Content of tank	Depth to water table, in feet	Diameter of tank, in inches	Amount of water used, in inches of depth												Number of months of record	Total amount used	Per cent of	
				May	June	July	August	September	October[2]	November	December	January	February	March	April			Tank No. 5	Tank No. 7
1	Bermuda grass	3	23 1/16	2 031	4 552	4 872	3 898	2 533	0 720	0 526	0 506			0 169		9			
2	Bermuda grass	3	23 1/16	2 163	4 524	5 997		3 625	.963	1 034	593			391	2 334	9			
Mean	Bermuda grass	3	23 1/16	2 097	4 538	5 435	3 898	3.079	842	780	550			280	2 334	10	23 833	49 3	43 0
3	Bermuda grass	2	23 1/16	2 916	5 550	6 710	5 608	3 520	1 337	1 188	623		0 495	2 036	2 700	11			
4	Bermuda grass	2	23 1/16	2 500	5 235	6 135	5 066	3 358	1 261	.890	547		211	1 674	2 457	11			
Mean	Bermuda grass	2	23 1/16	2 708	5 393	6 423	5 337	3 439	1 299	1 039	585		353	1 855	2 579	11	31 010	61 3	53 0
5	Water in circular sunken tank		23 1/16	4 572	5 976	6 804	5 844	5 124	4 860	3 506	2 651	2 789	2 253	4 953	4 064	12	53 396	100 0	86 7
6	Round stem tules in submerged soil[8]		23 1/16	16.935	22 125	30 052	26 108	17 417	[3]13 989	[4]12 560	[5]5 365	4 047	([6])	8 883	13 399	11	170 880	334 1	291 9
7	Water in standard Weather Bureau pan		48	5 496	6.588	8 076	7 536	5 472	5 208	3 768	2 634	3 100	3 058	5.766	4 892	12	61 594	115 4	100 0

[1] Tanks contained undisturbed soil.
[2] Grass burned off Tanks Nos. 1 to 4, October 4, 1930.
[3] Use for November computed from 21-day record.
[4] Use for December computed from 20-day record.
[5] Use for January computed from 25-day record.
[6] Heavy rains ruined record.
[7] All grass tanks covered during rains.
[8] Not applicable to field conditions.

TABLE 20

SUMMARY SHOWING MONTHLY USE OF WATER BY BERMUDA GRASS AND TULES AND EVAPORATION FROM WATER SURFACES, MAY, 1931, TO APRIL, 1932, IN TANKS AT SAN BERNARDINO, CALIFORNIA[1,2]

Tank No.	Content of tank	Depth to water table, in feet	Diameter of tank, in inches	Amount of water used, in inches of depth												Number of months of record	Total amount used	Per cent of	
				May	June	July	August	September	October	November	December	January	February [4]	March [4]	April [4]			Tank No. 5	Tank No. 7
1	Bermuda grass	3	23 1/16	1 959	2 798	5 002	3 931	2 653	1 759	2 456	1.886	1.129				9			
2	Bermuda grass	3	23 1/16	2 759	3 969	6 168	4 813	2 465	1 919	2 204	.757					8			
Mean	Bermuda grass	3	23 1/16	2 359	3 384	5 585	4 372	2 559	1.839	2 330	1 322	1 129				9	24 879	58 3	49.3
3	Bermuda grass	2	23 1/16	3 677	4 780	7 474	5 595	3 528	2 332	2 425	2 057	1 540				9			
4	Bermuda grass	2	23 1/16	3 086	4 304	6 646	4 566	3 306		2 523	1 854	1 573				8			
Mean	Bermuda grass	2	23 1/16	3 382	4 542	7 060	5 081	3 417	2 332	2 474	1 956	1 557				9	31 801	74 5	63 0
5	Water in circular sunken tank		23 1/16	4 850	5.734	6 727	6 886	5 448	4 596	2.674	2.786	3 008	2 892	4 232	5 100	12	54 933	100 0	84 3
6	Round stem tules in submerged soil[5]		23 1/16	18 067	21 705	29 250	23 233	[3]12 876	7 575	5 381	5 050	4 151		5 839	8 795	11	141 922	272 7	228 9
7	Water in standard Weather Bureau pan		48	6.794	7 384	8 918	8 062	5 808	4 812	3 482	2 098	3 126	3 134	5 240	6 276	12	65 134	118 6	100.0

[1] Tanks contained undisturbed soil.
[2] All grass tanks covered during rains prior to December 1, 1931.
[3] Tules eaten off by stock in September.
[4] Heavy rains ruined record for Bermuda grass tanks.
[5] Not applicable to field conditions.

is plentiful and grows with its roots submerged in the shallow water along the edges of stream channels and in swamps. It is a great nuisance in drainage ditches.

The triangular stem tule (*Scirpus olneyi*) is similar to the round stem variety, being an aquatic plant that grows in areas of shallow water. The stems are three cornered and grow with considerable density, but are not generally as tall as the round stem tules. The cat-tail (*Typha latifolia*) is a perennial marsh plant with flat leaves that is frequently classed as a tule, although it belongs to an entirely different family. Its cylindrical head is filled with thousands of small cottony seeds which are spread by the wind. The cat-tail is found wherever there is sluggish water. It spreads rapidly from seed and is hard to eradicate.

Both tules and cat-tails were grown in tanks set in the ground with 2 inches of rim surface exposed. Water was held on the tank surface to a depth of approximately 2 inches so that the roots were entirely submerged. It seems probable that air is supplied to the root systems of growths of this type through the coarse cellular structure of the stems. The surrounding ground surface was free from vegetation during the first season, but later was covered with grass.

All tule or cat-tail tanks were in exposed locations, subject to the full effect of solar radiation and wind movement. In this respect, tules grown at the stations differed from tules in swamps where a certain degree of protection is afforded by increased vegetation and a larger growing area. Consumptive use by swamp growth is partly controlled by greater humidity overlying the swamp area. It is probably true, too, that temperatures within the swamp are lower than those outside. Both factors would combine to cause a lower use of water by swamp plants than by those in exposed tanks.

In general, it appears that aquatic plants in exposed tanks do not attain the maximum height of stalk growth that is found under natural conditions. Tank growth rarely exceeds 5 or 6 feet in height when fully exposed, and more often is less, whereas natural swamp growth of tules or cat-tails frequently grow to a height of 10 or 12 feet. The highest growth occurs in the swamp interior, with shorter stalks around the water's edge. In this respect the outside growth in a swamp is comparable to that in experimental tanks.

To determine whether size of tank had an effect on consumptive use of water, an additional tank, 6 feet in diameter, was transplanted to round stem tules at the Santa Ana station. The density of growth at no time equalled that in the smaller tank and the consumptive use per unit of area was consequently less. A comparison of the data obtained from two tanks for the month of September, 1931, shows that the smaller tank had a density of 87 stems per square foot of tank area, which used water at the rate of 19.37 acre-inches per acre per month, while the larger tank had only 57 stems per square foot of area using 12.43 acre-inches. The exposure of both tanks was identical. Carrying the comparison further to determine the consumptive use per individual stalk indicates that each tule used the same amount of water, regardless of density of growth or size of tank in which it grew. Plate VIII-A shows the 6-foot tule tank, No. 23, with the small tule tank, No. 19, at the right.

PLATE VIII

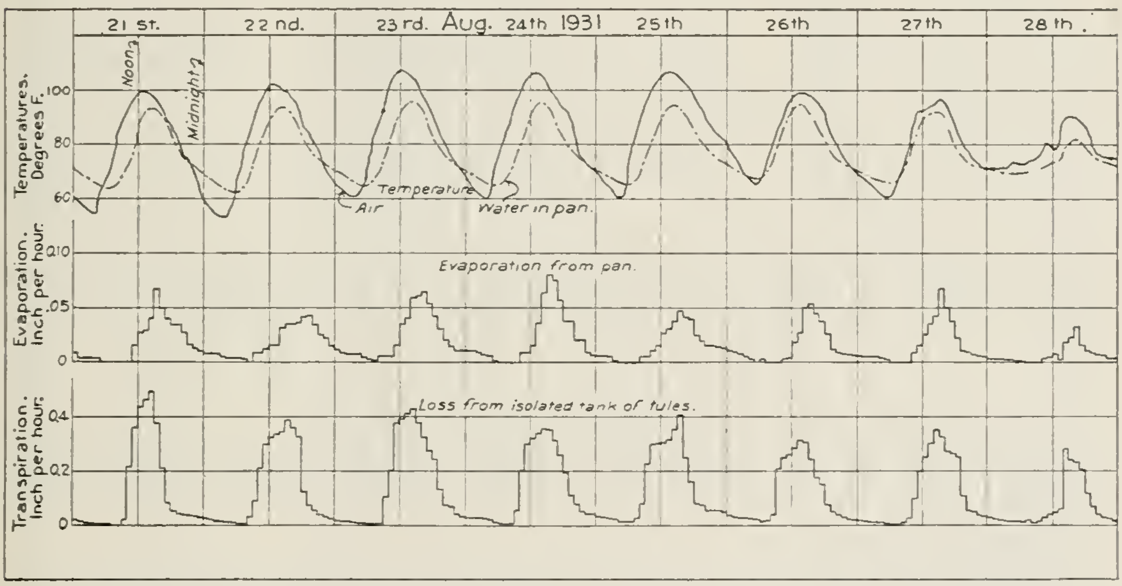
A. TULES GROWING IN TANK SIX FEET IN DIAMETER AT SANTA ANA STATION, 1931, WITH SMALL TANKS OF TULES AND CAT-TAILS AT THE RIGHT.

B. CAT-TAILS GROWING IN SMALL TANK, SANTA ANA STATION, 1931.

C. TULES GROWING IN SMALL TANK, PRADO STATION, 1931.

The cooperative station at Prado was intended principally to determine the rate of use of water by tules in connection with a study of the flow of the Santa Ana River that was being made by the United States Geological Survey. As the station was isolated and daily visits were not practicable, recording devices were attached to both tule tank and Weather Bureau evaporation pan. From the records so obtained the hourly rates of consumptive use and of evaporation have been computed. These are plotted in Plate IX, which shows air and water temperatures, consumptive use of water by tules in an isolated tank, and evaporation from a four-foot pan for each hour of the day from August 21 to August 28, 1931, inclusive. There were periods during the early morning hours when the loss of water was too small to be recorded and evaporation or transpiration, during those hours, has been listed as zero. Characteristic of both evaporation and transpiration is the daily increase or decrease with a rising or falling temperature. The minimum rate occurs near sunrise and the maximum is in the afternoon. Consumptive use is greater than evaporation and responds more readily to sunlight and changes of temperature. The rate of evaporation does not increase rapidly until water in the pan has been warmed

PLATE IX



HOURLY RATE OF USE OF WATER BY TULES, EVAPORATION FROM STANDARD WEATHER BUREAU PAN AND AIR AND WATER TEMPERATURES, PRADO STATION.

by the sun and is relatively slow in comparison with the rate of consumptive use, which increases rapidly, comes to a peak sooner, and declines more quickly.

On the morning of August 28 temperature was less than normal and a light rain occurred shortly after noon. The effect of the rain in deferring the morning increase in consumptive use and in evaporation from water until about 2 p.m. is shown on the chart. The rain was apparently the cause of a small decrease in the rate of evaporation until its effect was overcome by a rise in temperature. In general, the highest air temperature occurred at about 1 or 2 p.m., while the highest water temperature occurred about two hours later. The same interval also is noticeable in minimum temperatures. Observations in other localities have shown that the highest consumptive use of water by tules occurs at approximately the time of highest air temperatures, although such is not the case in this instance.

Coastal winds continuing through several hours each day pass over the Prado station and, in combination with high temperatures, are responsible for a continued increase in both evaporation and transpiration until 3 or 4 o'clock in the afternoon. This accounts for a larger consumptive use than at other localities in the Santa Ana basin.

Because of their exposure and abnormal conditions affecting growth, use of water by tules grown in tanks was excessive. At Santa Ana station, round stem tules used more water than did the triangular stem tules or the cat-tails, their growth being greater in point of density and height of stems. Their consumptive use frequently amounted to more than $1\frac{1}{2}$ inches in depth per day and at one time averaged an inch a day for a period of six weeks. Tules at the Prado station had a higher consumptive use than did those of the same variety at Santa Ana, partly because of slight climatic differences, but also because of differences in height and number of stems. The maximum daily use at Prado was 3.6 acre-inches per acre on a day of high temperature and wind movement.

Intensive investigations near Victorville, undertaken to determine the proper adjustment factor to be used in reducing consumptive use of water by tules grown in tanks to the actual amount used by swamps, are discussed in the following chapter. In this study, one 2-foot tank containing tules was fully exposed to wind and sunshine with a resulting large use of water. A large tank set in a protected area of a swamp used a much smaller amount. Further investigation by the Bureau of Agricultural Engineering in the Sacramento-San Joaquin delta indicates a factor of 0.46 for cat-tails and tules for a 20-day period in August, 1930. Reporting on this and other work, Charles H. Lee* has adopted a tentative factor of 0.50 for making the reduction, admitting that the value may be changed when further data are available. By applying the results of the Victorville investigation to the measured losses from isolated tanks used in southern California, it is found that the adjustment factor ranges in these experiments from 0.29 to 0.55 as shown in Table 21.

While the relation between the water requirement of a crop and evaporation from a water surface during the growing season is not constant, month by month, it is the most practical means of making comparisons of consumptive use, not only from year to year, but between localities having different rates of evaporation. For this purpose the best records for comparison are those of standard Weather Bureau evaporation pans, which are in more general use in investigational work than pans of other sizes or depths. For the Victorville station, where tules were grown in a swamp area, the percentage of consumptive use in the swamp with reference to evaporation from the Weather Bureau pan is computed for an average year, the result being about 95 per cent. In the average year the consumptive use for each month is taken as the average of all records for that month. Neglecting other factors, such as variety, density of growth, and seasonal variations in evaporation and transpiration, this percentage has been applied to evaporation

* Bulletin No. 28, Economic Aspects of a Salt Water Barrier Below Confluence of Sacramento and San Joaquin Rivers, Division of Water Resources, 1931.

records at Santa Ana, Prado, and San Bernardino. In other words, 95 per cent of the evaporation at a station is estimated to be the consumptive use of water by aquatic growth in a natural swamp area in that locality. Having computed the estimated consumptive use in a swamp, the percentage of computed swamp use to the observed tank use, may be determined. This was the method followed in compiling Table 21.

TABLE 21

ESTIMATED CONSUMPTIVE USE OF WATER BY TULES AND CAT-TAILS IN SWAMPS BASED UPON TANK EXPERIMENTS, AND PERCENTAGE OF SWAMP USE TO TANK USE

Station	Tank number	Aquatic growth	Observed consumptive use from exposed tank, in acre-inches per acre per year	Evaporation from Weather Bureau pan, in inches per year	Computed consumptive use from swamp, in acre-inches per acre per year	Swamp consumptive use, in per cent of observed consumptive use
Victorville		Triangular stem tules	272.2	[1]82.5	[1]78.5	28.8
Santa Ana	19	Round stem tules	188.3	66.6	63.4	33.7
Santa Ana	21	Triangular stem tules	172.5	66.6	63.4	36.8
Santa Ana	22	Cat-tails	116.9	66.6	63.4	54.2
Santa Ana	23	Round stem tules	115.4	66.6	63.4	55.0
Prado		Triangular stem tules	251.3	77.4	73.6	29.3
San Bernardino	6	Round stem tules	162.1	66.1	62.9	38.8
Mean percentage						39.5

[1] The observed swamp consumptive use at Victorville is 95.2 per cent of the evaporation from the Weather Bureau pan. This percentage multiplied by the evaporation at each station equals the computed swamp use for that locality.

In the last column of the table there is a large difference in percentages. These are due in part to differences in density of growth in each tank. Disregarding small differences in rates of transpiration, which may exist in different varieties of aquatic growth, the total use of water by adjacent tanks should correspond rather closely, provided that the dry weight of crop matter is nearly the same. Transpiration is nearly proportional to the transpiring area and is consequently more where there is a heavy growth than where the growth is light. Each tank used had different density of growth and a different consumptive use. In Tank No. 22 cat-tails did not spread and produce as thick a growth as is natural in swamp areas, nor did they reach the height of stems found in swamps. The same is true of round stem tules in Tank No. 23. In both cases, the observed consumptive use is less than that of triangular stem tules at Santa Ana or of round stem tules at San Bernardino, and the percentage of computed swamp use to observed tank use is much higher than the average for other tanks. Likewise, consumptive use by tules at Prado is high and its relation to swamp use is correspondingly low.

The results of the tule tank experiments indicate the impracticability of applying to field conditions records of tests made in isolated tanks of tules grown apart from their natural environment.

Use of Water by Willows

Willows are water-loving shrubs or trees found in areas of comparatively high ground water. They often grow in the coarse material forming dry stream channels, where they draw moisture from the underflow. The root system of some varieties includes a long tap root which enables the plant to receive moisture from a water table at a considerable depth. Willows have been observed in a very sandy soil where depth to water table was about 10 feet.

Investigation of consumptive use of water by a single willow (*Salix laevigata*) bush was begun at the Santa Ana station in 1930. The bush consisted of a single clump of 20 stems from one-half to an inch and one-quarter in diameter growing from the same root. The average height was about 7 feet. This bush was transplanted into a metal tank, 6 feet in diameter by 3 feet deep. Measurement of consumptive use was begun in May, 1930, and continued for two years. The spread of bush area was the same as the tank area and consumptive use was computed on that basis. The soil in the tank was bare, consequently the total use includes soil evaporation. Water in the soil stood 2 feet below the surface. As the soil in the tank was shaded by the willow growth and grass and weeds grew up around the tank, evaporation was probably no more than occurs under ordinary conditions of scattered brush growth. Previous experiments with evaporation from disturbed soil having the same water table depth show losses ranging from less than 1 to nearly 3 inches per month, depending upon the season. Evaporation from the willow tank should be relatively small on account of shade and protection due to overhanging branches.

During both years of the investigation stems and leaves of the willow were heavily infested with aphis and the red ants that are found with them. During 1930 the tree was sprayed regularly, every effort being made to control the pest, and apparently no harm was done. In the following year, defoliation began early in the summer and was complete by September, several weeks earlier than is normal. During this period consumptive use records are not for a healthy tree in full leaf. In the following spring of 1932, the third of the investigation, a normal growth of new leaves appeared at the regular time, indicating that no permanent damage to the tree had occurred. Plate X shows the willow growing in a 6-foot tank at Santa Ana in May, 1930, before vegetative growth surrounded the tank.

Soil in the willow tank originally contained some alkali. During the summer months, when evaporation was at a maximum, white alkali was deposited on the tank surface. As the daily amount of water was added to the tank the total amount of alkali increased. These salts went through seasonal changes in location in alternate wet and dry seasons as they were carried down to the water table by winter rains and returned to the surface by summer evaporation. During the period when the tree was losing its leaves alkali was visible on the tank surface, but apparently not to exceed the amount of the previous year when no defoliation occurred. The willow is normally a user of relatively pure water and does not grow where salts are found in high concentration. The defoliation may have been due either to presence of alkali or to infestation.

Consumptive use of water by the willow growth by months is shown in Tables 14 and 15. The maximum monthly use in the year in which the growth was in good condition, amounting to 7.8 acre-inches per acre, occurred in August. In comparison with evaporation from a Weather Bureau pan, consumptive use exceeded evaporation only during the months of August and September. The total use during a period of eleven months, shown in Table 14, was 52.7 acre-inches per

PLATE X

WILLOW TREE GROWING IN 6-FOOT TANK, SANTA ANA STATION, 1931.

acre or 83.5 per cent of the evaporation from a Weather Bureau pan for the same period. It is evident that willows grown in tanks under the conditions of this experiment, are fairly large users of ground water. The amounts used exceed consumptive use by either salt grass or Bermuda grass, but are less than consumptive use by tules under natural swamp conditions.

An adjustment factor has been computed for tules to adjust consumptive use of water by tank growth to similar growth in large areas, but no basis exists for computing the proper factor for use with willows. Because there is a great natural difference in the habits of growth of tules and willows, the same factor will not apply to both. Tules naturally grow in swamp areas, whereas willows are found in scattered areas of dry land, sometimes in isolated clumps, small groups, or in large bodies of brush. Where isolated growth occurs, conditions of temperature, sunlight, and wind movement are the same as for tank growth, and consumptive use is nearly the same in all cases. In dense growths of brush, however, conditions are changed to reduce the factors mentioned and transpiration also is less. In this case, an adjustment factor should be applied to the observed consumptive use by willows grown in tanks to arrive at the correct figure for field conditions. In many instances willows grow as a fringe along water courses, and embankments of ditches. They are also found in large areas interspersed with open places that are sometimes of considerable size. Considering differences in the spread of willow growth it is evident that an adjustment factor is not a constant that can be used under all conditions, but is a variable depending upon density and size of brush. Due to the present lack of data, any factor arrived at must be only an estimate, subject to revision later when further evidence is available. For willow growth in the Santa Ana River basin, which is partly in solid blocks of brush and partly scattering, it is estimated that consumptive use is 75 to 100 per cent of the amount of water necessary for isolated tank growth, with an average of 85 per cent.

Use of Water by Wire Rush

Wire rush (*Juncus balticus*) grows in limited areas of high ground water in the Prado basin where it is found in association with salt grass. In appearance it is a heavy, tough, wire-like grass growing from a thick creeping rootstalk. In places where it was observed, it did not exceed 10 or 12 inches in height. Some of this growth was transplanted into a small tank at the Santa Ana station in the summer of 1930 for the purpose of making a consumptive use of water study, as indications were that it might be a large user of water. During the first year of the study a considerable amount of salt grass was included with the wire rush, but in the following year the heavier growth had crowded out the salt grass.

A fixed water level was maintained at a depth of 2 feet in the tank, although where a natural growth occurred in the fields there were seasonal fluctuations of ground water at greater depths. This depth was the same as that chosen for investigations of consumptive use by salt grass, Bermuda grass, and willows. During the first winter, the wire rush tank was protected from rainfall, as were all soil moisture tanks, but during the second year it was exposed to all rains.

A summary showing monthly use of water by wire rush is given in Tables 14 and 15. The maximum use for any month was 13.75 acre-inches per acre during July, 1931. The total use for a ten-month period was 83.45 acre-inches per acre or 141.8 per cent of the evaporation from a Weather Bureau pan for the same period. In comparison with consumptive use by grasses and willows, the wire rush has appeared to be a heavy user of water and it is fortunate that the area restricted to its growth is limited.

Adjustment Factors

Previous tables have shown weekly or monthly use of water by each growth at the several stations, but Table 22 contains the observed average yearly consumptive use and also an estimated factor for adjustment of such use to consumptive use over large areas. This factor for tules and cat-tails is based upon experiments carried on at Victorville and reported in Chapter III. No experiments have been made to determine a factor for grasses, but conditions of tank growth are so nearly those of the field, that factors for these crops have been taken as 100 per cent. A tentative factor of 85 per cent has been adopted for willow as previously stated.

TABLE 22

SUMMARY OF TANK INVESTIGATIONS SHOWING ESTIMATED ANNUAL CONSUMPTIVE USE OF WATER IN MOIST AREAS

Type of vegetation	Depth to water table, in feet	Location	Length of effective record, in months	Observed average consumptive use, by vegetation in tanks, in acre-inches per acre per year	Estimated factor for adjustment to large areas, in per cent	Estimated annual depth of consumptive use, in acre-inches per acre per year
Bare soil[1]	2	Santa Ana	19	4 7	100 0	4 7
Bare soil[1]	3	Santa Ana	11	1.6	100.0	1.6
Bare soil[1]	4	Santa Ana	5	0.0	100.0	0.0
Salt grass	1	Santa Ana	17	42.1	100.0	42.1
Salt grass	2	Santa Ana	31	36.0	100.0	36.0
Salt grass	3	Santa Ana	11	24.8	100.0	24.8
Salt grass	4	Santa Ana	17	13.2	100.0	13.2
Salt grass	5	Santa Ana	16	19.6	100 0	19.6
Bermuda grass	2	San Bernardino	32	36.2	100 0	36.2
Bermuda grass	3	San Bernardino	31	28.8	100.0	28.8
Round stem tules		San Bernardino	22	162.1	[4]38.8	62.9
Round stem tules[2]		Santa Ana	33	188.3	[4]33.7	63.4
Round stem tules[3]		Santa Ana	24	115.4	[4]55.0	63.4
Cat-tails		Santa Ana	23	116.9	[4]54.2	63.4
Triangular stem tules		Santa Ana	24	172 5	[4]36.8	63.4
Triangular stem tules		Prado	28	251.3	[4]29.3	73.6
Willow	2	Santa Ana	17	52.7	85.0	47.8
Wire rush	2	Santa Ana	19	84.5		

[1] Evaporation from surface of bare soil.
[2] Tules grown in tank 25½ inches in diameter.
[3] Tules grown in tank 6 feet in diameter.
[4] See Table 21.

No data are available for estimating an adjustment factor for wire rush. While the tank in which it grew was not set in a field of similar growth, it was surrounded by grass and weeds. It is possible, since it did not grow in its natural habitat as did the salt grass, that change of environment was responsible for an increased consumptive use as is the case with tules in isolated tanks.

In Table 22 there are also presented estimates, based upon experiments, of the annual drafts upon the ground water by noneconomic native growths found in moist areas in the Santa Ana basin. These estimates are only for those depths to ground water at which the experiments were conducted and are not applicable to other localities with markedly different climatic conditions.

SOIL CHARACTERISTICS

The top soil at the Santa Ana station was overlying a coarse water bearing sand at a depth of 6 to 7 feet. It contained considerable mica and some alkali in quantities not detrimental to the varieties of vegetation used in the investigation. A thin layer of finer than average material lay at a depth of about 4 feet in all Santa Ana tanks, a mechanical analysis of which showed that 29 per cent should be classed as very fine sand and 59 per cent as silt. This fine material was unimportant, as in all tests except one it lay below the water table and could have no effect on capillary rise of moisture or rate of transpiration. In the one case referred to, where it was a few inches above the water table, it apparently had no influence on rate of movement of soil moisture. Soil at the San Bernardino station is classed as Chino silt loam and is relatively free from alkali.

Mechanical Analyses

Mechanical analyses of soil from five tanks at the Santa Ana station and from two tanks at the San Bernardino station were made, and the percentages of different sized soil particles are shown in Table 23. Each sample of soil, representing 1 foot in depth and weighing

TABLE 23

MECHANICAL ANALYSES OF SOIL FROM TANKS AT SANTA ANA AND SAN BERNARDINO STATIONS

Tank number	Depth of sample, in feet	Per cent of material retained on screens of the following sizes					Per cent of material passing screen No. 200
		No. 14	No. 28	No. 48	No. 100	No. 200	
SANTA ANA STATION							
3	1	0	2	14	42	21	21
3	2	0	2	23	46	14	15
3	3	0	1	17	39	21	22
3	4	0	2	13	49	16	20
5	1	0	2	22	43	15	18
5	2	0	1	13	45	19	22
5	3	0	1	12	36	20	31
7	1	0	2	17	42	16	23
7	2	0	1	16	42	18	23
7	3	0	1	14	42	16	27
12	1	0	2	13	35	20	30
12	2	0	1	16	33	21	29
12	3	0	1	18	32	19	30
12	4	0	1	17	47	13	22
12	5	0	3	13	51	20	13
12	6	1	12	45	22	4	16
15	1	0	4	20	47	14	15
15	2	0	2	18	44	18	18
15	3	0	2	16	46	19	17
SAN BERNARDINO STATION							
2	1	0	2	16	28	13	41
2	2	0	2	21	23	13	41
2	3	1	4	18	38	13	26
4	1	0	1	29	30	14	26
4	2	0	1	20	29	19	31

TABLE 24

MOISTURE EQUIVALENTS OF SOIL FROM TANKS AT SANTA ANA AND SAN BERNARDINO STATIONS

Tank number	Depth of sample, in feet	Moisture equivalent in per cent	Tank number	Depth of sample, in feet	Moisture equivalent, in per cent
SANTA ANA STATION			SANTA ANA STATION		
1	1	5.8	11	1	10.4
	2	8.1		2	11.0
	3	8.7		3	12.2
	4	6.2		4	11.9
2	1	6.5	12	1	11.0
	2	8.2		2	13.0
	3	9.4		3	12.3
	4	7.8		4	12.2
3	1	6.6	13[1]	1	6.3
	2	7.1		2	6.2
	3	9.2			
	4	8.9	14[1]	1	6.2
				2	6.7
4	1	7.0			
	2	8.3	15[1]	1	6.5
				2	6.6
5	1	8.3			
	2	9.0	SAN BERNARDINO STATION		
6	1	8.7	1	1	30.6
	2	8.4		2	19.7
				3	15.2
7	1	8.6			
	2	9.0	2	1	31.2
				2	21.4
8	1	10.3		3	16.3
	2	9.8			
			3	1	29.4
9	1	11.4		2	19.8
	2	11.7			
			4	1	28.6
10	1	9.9		2	19.3
	2	12.6			
	3	12.0			
	4	9.4			

[1] Tank Nos. 13, 14 and 15 contained disturbed soil, all others contained soil in place.

about 1000 grams, was air dried and screened to the point of refusal. Results at Santa Ana show that about 40 per cent of the sample was retained on a No. 100 screen and nearly half that amount passed the No. 200 screen.

Soil at the San Bernardino station was finer and a larger percentage passed the No. 200 screen.

Moisture Equivalent

Moisture equivalent is a measure of the value of the moisture retentiveness of a soil and is obtained by subjecting a sample of 30 grams to a constant centrifugal force of 1000 times the force of gravity for a period of 30 minutes. Experiments by many investigators have determined that moisture equivalent is a close measure of the field capacity. It is more easily interpreted as regards soil moisture retention than is possible by separation of soil particles into groups as determined by mechanical analysis. Colloidal matter in the soil, as an important factor in affecting specific yield or specific retention, is not apparent in determinations of mechanical analysis, but does affect the percentage of moisture retained. High moisture equivalents are obtained from fine grained soils containing quantities of colloidal matter, while low values come from coarse materials of low water holding capacity.

Soil moisture samples at the Santa Ana station, outside of soil tanks, show average moisture of 2 to 3 per cent in the upper soil after a long dry period and about 12 per cent four days after a heavy rain. The former percentage is the wilting point for this soil, while the latter is near field capacity. Samples taken from soil tanks show moisture equivalents that approximately agree with field capacities previously determined. This is shown in Table 24 of moisture equivalents, as determined from samples taken from above the water tables in tanks at both Santa Ana and San Bernardino.

Moisture equivalents of Chino silt loam at San Bernardino are higher than at Santa Ana because of fine soil particles, as evidenced in Table 23, and a greater variation occurs at the different depths. The San Bernardino top soil has a high moisture equivalent, while for subsoil it is decreased one-half.

Porosity, Specific Yield, and Specific Retention

At the end of three years of investigation at the Santa Ana station and previous to dismantling the soil tanks, tests were made of the soils in various tanks to determine (1) porosity, (2) specific retention, and (3) specific yield.

Porosity is a measure of the total voids in a soil and is represented as a percentage of the total volume. It varies inversely with the size of soil particles and is greater for clay soils than it is for sand or gravel.

Specific retention is a measure of the water holding capacity of a soil and is recorded as a percentage of the total volume. In determining specific retention, it is necessary to consider the depth to water table, as more water is held in a soil in close proximity to the water table than at several feet above it.

Specific yield is the amount of water which will drain from a soil by gravity. It also is measured as a percentage of the total volume. It is influenced by the size of soil particles and is greater for soils of coarse material than for soils composed of finer grains. It depends also upon the amount of capillary moisture resulting from a high water table. It is evident that both specific retention and specific yield are entirely relative and not altogether functions of the soil, as they depend on the depth to ground water and are different with each change in depth within the capillary fringe. Stearns* says, "Obviously, in any direct test, whether made in the laboratory or in the field, the true specific retention of the material can be ascertained only by using a high column of the material and disregarding the lower part that lies within the capillary fringe." In considering these characteristics, it is obvious that the specific retention is the complement of the specific yield and that the sum of the two is equal to the total porosity.

Water tables in the tanks in which these tests were made were from 2 to 5 feet below the surface, or mostly within the limits of capillary rise, and therefore the specific yield and specific retention as given in this report refer only to the conditions under which the tests were

* Laboratory Tests on Physical Properties of Water Bearing Materials, by Norah D. Stearns. (U. S. Geol. Sur. Water Supply Paper 596-F, p. 138.) 1927.

made. They are not true results as would be found in the absence of a water table. For example, the true specific yield of a soil is measured by the quantity of water which it will yield after it has been saturated and allowed to drain. Where a high water table exists, there can not be complete drainage.

A measure of specific yield is approximated by the difference between the porosity of a soil and its moisture equivalent by volume. This represents the pore space remaining in a soil sample after it has

TABLE 25

COMPARISON OF THE COMPUTED SPECIFIC YIELD OF SOILS IN THE ABSENCE OF A WATER TABLE WITH THE OBSERVED SPECIFIC YIELD OF THE SAME SOILS HAVING HIGH WATER TABLES

Station	Tank number	Porosity, in per cent	Moisture equivalent, in per cent by volume	Specific yield, in per cent	
				Computed (without water table)[1]	Observed (with high water table)[2]
Santa Ana	1	38.3	11.5	26.8	23.0
Santa Ana	2	44.8	13.5	31.3	24.5
Santa Ana	10	39.5	17.4	22.1	15.2
Santa Ana	11	36.4	16.8	19.6	15.5
Santa Ana	[3]14	41.9	9.1	32.8	9.8
San Bernardino	1	43.5	31.2	12.3	9.9
San Bernardino	3	51.3	36.9	14.4	6.6

[1] Computed specific yield equals porosity minus moisture equivalent by volume.
[2] Observed specific yield equals porosity minus specific retention.
[3] Tank No. 14 contained disturbed soil. In all other tanks the original soil column was unbroken.

been centrifuged. To show the difference between the computed specific yield and the observed specific yield as measured in the tank tests, Table 25 has been prepared. Here the porosity as determined by measurement minus the moisture equivalent equals the computed specific yield. In the adjoining column the observed porosity minus the specific retention equals the measured specific yield. The variation in the two values is due entirely to capillary moisture resulting from a high water table.

In making these tests, soil moisture was first determined in each tank and the water content of the soil was computed. Measured quantities of water were poured into the tanks, raising the water level until the soil was saturated. The volume of water required for saturation added to the capillary moisture was then equal to the total pore space, and from this the percentage of porosity was computed. The capillary moisture above the water tables was incapable of further drainage and was, therefore, equal to the specific retention. Specific yield is the difference between total porosity and specific retention. These quantities are given in Table 26 for soils in various tanks at both the Santa Ana and San Bernardino stations.

It is shown in this table that both specific yield and specific retention vary with depth to water. The higher yields occur in those tanks having the shallower water tables. It will be observed that porosity of disturbed soil in Tank No. 14 was close to the average of all tanks, but that the specific retention greatly exceeded that of undisturbed soil.

This accounts for the frequently moist surface in this tank and for the high rate of soil evaporation from disturbed soil. One column of Table 26 includes a check of porosity by computation using the formula

$P = 100 \left(1 - \frac{A_s}{Sp.\,gr.}\right)$, where P is porosity, A_s is apparent specific gravity, and Sp. gr. is the real specific gravity, which has been assumed to have a value of 2.65.

Chino silt loam is composed of finer material than is Hanford fine sandy loam and, therefore, the porosity is greater. The finer material holds a larger proportion of soil moisture which results in an

TABLE 26

POROSITY, SPECIFIC YIELD AND SPECIFIC RETENTION OF SOIL IN TANKS HAVING HIGH WATER TABLES

Station	Tank number	Depth to water table, in feet	Depth of soil tested, in inches	Specific yield, in per cent	Specific retention, in per cent	Observed porosity, in per cent	Computed porosity, in per cent[1]
Santa Ana	1	3	36.0	23.0	15.3	38.3	39.6
Santa Ana	2	3	34.08	24.5	20.3	44.8	36.2
Santa Ana	Mean	3	35.04	23.75	17.8	41.55	37.9
Santa Ana	10	5	61.2	15.2	24.3	39.5	40.4
Santa Ana	11	5	58.44	15.5	20.9	36.4	44.5
Santa Ana	Mean	5	59.82	15.35	22.6	37.95	42.45
Santa Ana	[2]14	2	30.12	9.8	32.1	41.9	46.9
Santa Ana, Mean of all tanks						40.2	41.5
San Bernardino	1	3	34.56	9.9	33.6	43.5	49.8
San Bernardino	3	2	22.2	6.6	44.7	51.3	43.3
San Bernardino, Mean of all tanks						47.4	46.6

[1] Computed by formula: $\text{Porosity} = 100\left(1 - \frac{\text{Apparent specific gravity}}{\text{Real specific gravity}}\right)$

[2] Tank No. 14 contained disturbed soil. In all other tanks, the original soil column was unbroken.

increased specific retention and a smaller specific yield. For tanks having a water-table depth of 3 feet in fine sandy loam, the specific yield averaged 23.75 per cent of the volume of soil tested, but for Chino silt loam, the yield was but 9.9 per cent. The computed porosity of this soil agrees very closely with that found by actual test.

Apparent Specific Gravity

Apparent specific gravity is defined as the ratio of the weight of a unit of dry soil to that of an equal volume of water. It is sometimes called volume weight. It varies with the soil material and is highest for soils having the lowest porosity. It is always less than the real specific gravity.

Apparent specific gravity of the soils in a majority of tanks at both stations was determined for use in computing the equivalent depth of water in inches above the water table in each tank. These determinations were not made until the winter of 1931–32, when it became necessary to measure the change in water content in the soil each month, due to soil moisture increases from rainfall. Determinations were made from samples taken from each foot of depth, using a new soil tube. The weight and volume of each sample was obtained and apparent specific gravity computed by dividing the dry weight of the sample in grams by its volume in cubic centimeters.

There is considerable variation in the results and this may account for some discrepancies in consumptive use by different soil tanks, although the majority of values are close to the mean at each station. Check determinations made at points outside the tanks agree with those in the tanks. Values found in tanks containing disturbed soil are somewhat less than those in undisturbed soil, as might be expected. It will be noticed that the top foot of soil at San Bernardino has a lower apparent specific gravity than the second or third foot. Results of all apparent specific gravity determinations at both stations are given in Table 27.

TABLE 27

APPARENT SPECIFIC GRAVITY OF SOILS IN TANKS AT SANTA ANA AND SAN BERNARDINO STATIONS

Station	Tank number or location of sample	Apparent specific gravity at				
		Depth in feet				Mean
		1	2	3	4	
Santa Ana	1	1.61	1.60	1.58	------	1.60
Santa Ana	2	1.67	1.70	1.70	------	1.69
Santa Ana	5	1.41	1.63	------	------	1.52
Santa Ana	6	1.51	1.46	------	------	1.49
Santa Ana	10	1.56	1.57	1.64	1.53	1.58
Santa Ana	11	1.54	1.40	1.45	1.49	1.47
Santa Ana	12	1.48	1.49	1.44	1.48	1.47
Santa Ana	14	1.34	1.46	1.46	------	1.42
Santa Ana	15	1.42	1.28	------	------	1.35
Santa Ana	5 feet north of Tank No. 1	1.57	1.47	1.44	1.36	1.46
Santa Ana	4 feet south of Tank No. 8	1.50	1.53	------	------	1.52
Santa Ana	5 feet south of Tank No. 12	1.44	1.47	1.57	1.58	1.52
Santa Ana	4 feet north of Tank No. 6	1.49	1.47	1.56	1.44	1.49
Santa Ana	Mean	1.50	1.50	1.54	1.48	1.51
San Bernardino	1	1.35	1.50	1.44	------	1.43
San Bernardino	2	1.33	1.52	1.51	------	1.45
San Bernardino	3	1.37	1.62	------	------	1.50
San Bernardino	4	1.34	1.58	------	------	1.46
San Bernardino	Mean	1.35	1.56	1.48	------	1.46

CHAPTER III

INVESTIGATIONS IN MOJAVE RIVER AREA

By Colin A. Taylor and Harry G. Nickle *

Along the Mojave River there are moist areas where the noneconomic use of water by natural vegetation is considerable. In October, 1930, the State Engineer of California requested that cooperative investigations be undertaken as follows: (1) That the U. S. Bureau of Agricultural Engineering establish an experiment station along the Mojave River near Victorville for the purpose of measuring the evaporation and transpiration losses from moist areas and of recording meteorological data; (2) that the U. S. Geological Survey establish additional gaging stations along the Mojave River, and an effort be made to determine consumptive use of water between stations by stream flow measurements. The work as outlined was started in November, 1930, by the cooperating agencies. Stream flow measurements along the river are still being made, but the experiment station has been discontinued. This chapter presents the data collected at the Victorville experiment station on evaporation and transpiration losses from moist areas along the Mojave River.

The Mojave River** is situated in San Bernardino County, California, and constitutes the chief drainage system of the northern slopes of the San Bernardino Mountains. The mountain headwaters comprise two distinct branches, East Fork, or Deep Creek, and West Fork, which unite at the base of the mountains to form the main river. This junction is known as the Forks. Below it, the river, in its course of 90 miles across the desert plain, receives no surface tributary of consequence, but there is an underground contribution from springs. The course of the river is first northward 30 miles, then northeastward 20 miles, and finally eastward 40 miles. The river ends in dry lakes at an elevation of less than 1000 feet above sea level. The mountain watershed of the river, 217 square miles in area, extends from an elevation of 8000 feet at the summit of the range to 3000 feet at the Forks. The upper portion has heavy precipitation and the main tributaries are never dry where they leave the mountains. In summer the water sinks in the river a short distance below the Forks but appears again as surface flow several miles below, reaching the Upper Narrows at Victorville, 14 miles below the Forks. The surface flow continues through the Lower Narrows 4 miles farther down stream and during the summer again sinks several miles below Oro Grande after supplying several irrigation ditches. The water is then brought to the surface for short distances at a number of other points, these points being farther apart and the flow diminishing in quantity toward the lower

* Prepared by C. A. Taylor, Assistant Irrigation Engineer, and Harry G. Nickle, Junior Hydraulic Engineer, Bureau of Agricultural Engineering, U. S. Department of Agriculture. K. R. Melin of the U. S. Geological Survey assisted in conducting field work.

** Bulletin No. 5. Report on the Utilization of Mojave River for Irrigation in Victor Valley, California. State of California, Department of Engineering. (1918.)

end of the stream. At each point of reappearance the water supports a considerable amount of noneconomic vegetation. In describing these points in the river, Thompson * states:

"Wherever the water is at or close to the surface there is more or less evaporation, not only from the surface streams but also from the ground water supply through direct upward capillary movement and by transpiration from the plants. In some places as summer approaches the evaporation becomes so great that the water is disposed of more rapidly than it reaches the surface, and the stream dwindles and disappears. But even when the stream no longer exists water is generally present a few feet below the surface, except in places where the ground water is not held near the surface by submerged rock "dikes" or dams. As the end of the dry season approaches and evaporation becomes less, more water reaches the surface and the stream becomes wider and deeper and has a greater linear extent. The end of the stream may be seen to advance on cool days and at night and to retreat on warm days."

One of the moist areas adjacent to the river extends for several miles above the Upper Narrows at Victorville. Both surface and underground flow must pass over the bedrock at the Upper Narrows, and the level of the underground water immediately above this obstruction fluctuates little, the water being brought to the surface by the constriction of the channel. The ground water, therefore, is usually at or near the surface over much of the area.

Several flood channels have been cut through this moist area by the river during periods of high water. After careful consideration of possible sites, one of these channels, located on the east side of the river just above the Upper Narrows, was selected as the site of the Victorville station. The only surface water that enters this channel is flood water from the river and flood waters due to torrential rain storms falling upon the adjacent higher areas. The bottom of the channel has been cut down below the general ground-water level, so that there is a free stream flow of the raised water and a swampy area (cienaga) is formed. This channel is about 1600 feet in length and from 10 to 70 feet in width, is not isolated from the main moist area, and contains a dense growth of tules. The outflow from the cienaga joins the main channel of the river at the Narrows. The altitude of the station is about 2700 feet above sea level.

A low earth dam was built at the lower end of the channel chosen and a Parshall measuring flume with a water-stage recorder was installed to measure the outflow. The records obtained are not given in this report but it is believed that when analyzed they may be found useful in correlating the results of the tank experiments presented in this chapter with the stream-flow measurements made by the U. S. Geological Survey in the main channel of Mojave River.

During the latter part of November, 1930, evaporation and transpiration apparatus was established for the purpose of obtaining basic data. Evaporation, temperature, rainfall, and wind movement records were started November 22, 1930, but no tules were planted in the tanks

* "The Mohave Desert Region, California," by David G. Thompson, U. S. Geological Survey Water-supply Paper 578, p. 375.

until January 29, 1931. Records were continued until March 1, 1933, when the station was dismantled.

PROCEDURE

A general view of the moist area above the Upper Narrows is shown in Plate XI. The small flood channel on which the station is located is designated by an X marked on the plate. About midway of the length of this small channel, previously described, a section of the swamp and an area of the adjacent higher ground were inclosed with a fence for protection against animals. The bank is 4 to 5 feet higher than the level of the swamp. The enclosure is approximately 20 feet

PLATE XI

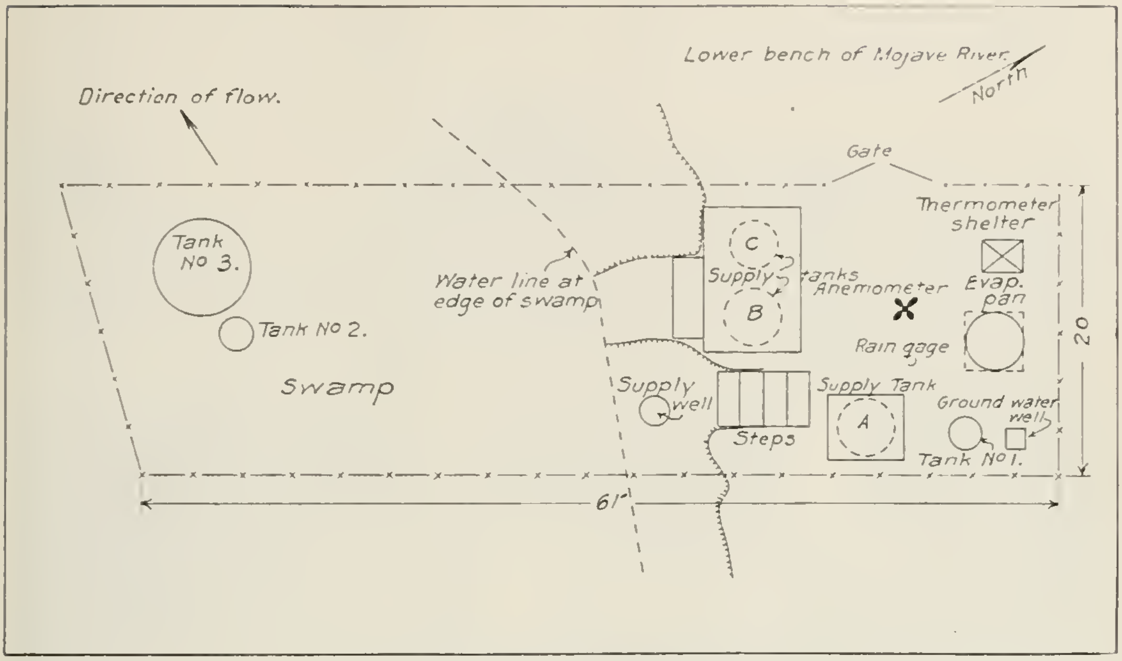
MOIST AREA ALONG THE MOJAVE RIVER ABOVE THE UPPER NARROWS NEAR VICTORVILLE, CALIFORNIA.

by 64 feet and includes space in the swamp for the tule tanks, and space on the bank for a tule tank, supply tanks, a ground water well, and evaporation station equipment. The plan of the station is shown in Plate XII. The equipment consists of three tule tanks, a standard Weather Bureau evaporation pan, a four-cup anemometer, a set of standard maximum and minimum thermometers and a thermograph housed in a standard shelter, a rain gage, and a ground-water well.

Previous investigations by Blaney and Taylor on consumptive use of water by native vegetation along stream channels* indicate that if data from tanks are to be used in estimating losses from larger areas under field conditions, the tanks should be set in a field of natural growth similar to that in the tanks. The native vegetation should completely surround the growth in the tanks so that the exposure is normal. Otherwise it is necessary to use large reduction factors the

* "Bulletin No. 33, Chapter 4, "Rainfall Penetration and Consumptive Use of Water in the Santa Ana River Valley and Coastal Plain," Division of Water Resources, California State Department of Public Works.

PLATE XII



PLAN OF VICTORVILLE STATION.

values of which are diffieult to determine, and which at best can be only very approximate. Therefore, besides the primary purpose of determining the eonsumptive use of water by tules, it was desired to demonstrate the impracticability of attempting to determine their use of water in swamps from experiments eonducted with tules planted in isolated tanks outside their natural environment.

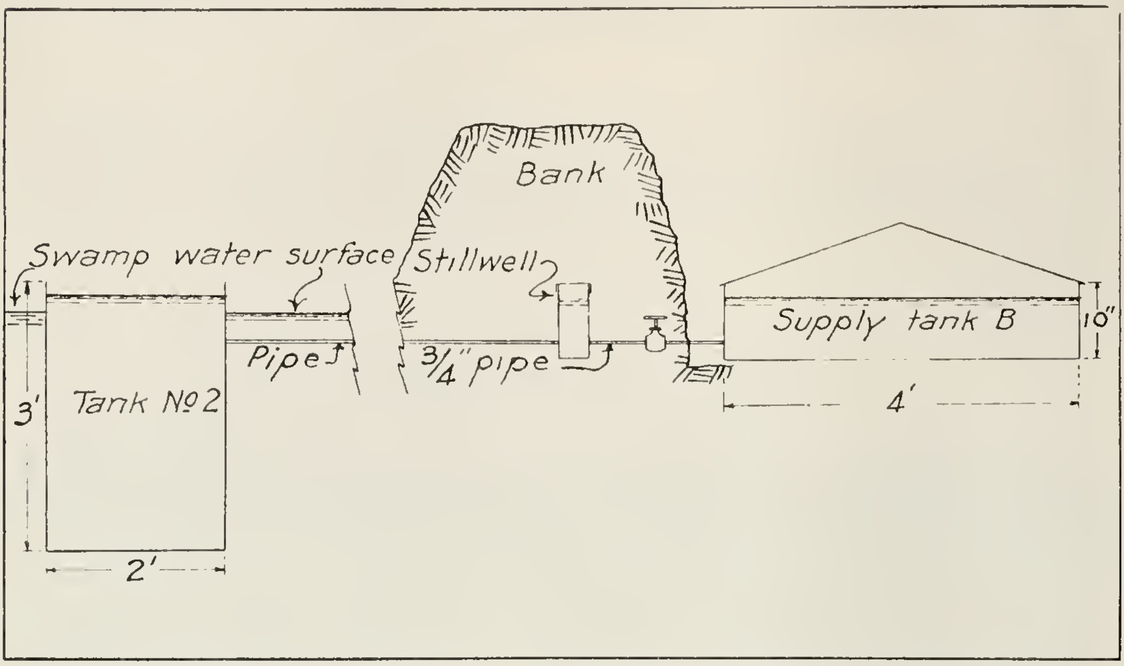
Tule Tank No. 1, 2 feet in diameter and 3 feet deep, was set in the ground on the bank for the purpose of demonstrating the effect of exposure on the use of water by plants grown in tanks. The rim of this tank was set 1 inch above the surrounding ground surface. This tank was filled with soil taken from the swamp. A sparse growth of salt grass around Tank No. 1 did not reach higher than an inch at any time during the season, so that the growth in the tank had a full exposure. The evaporation pan was plaeed on the bank in the standard manner and had good exposure, similar to that of Tank No. 1.

Two tule tanks were placed in the swamp, Tank No. 2 being 2 feet in diameter, and Tank No. 3, 6 feet in diameter. Both tanks are 3 feet deep and set in the swamp 30 feet from the bank. Cradles for the tanks were made of 2-inch redwood planks and supported on piling so that the elevation of the rims of the tanks was approximately 4 inehes above the water surface of the surrounding swamp. Pipe lines were eonnected to the tanks 1 foot below the rim and extended to supply tanks located in a sheltered dug-out in the bank. The tanks were filled with swamp soil.

A ground water well was sunk in the northeast corner of the plot with a easing extending 30 inches below the ground water into a coarse sand. Records of the height of the ground water were kept at this well. but the fluctuations were very slight. The water supply for the various tanks was obtained from a eased well about 2 feet in diameter and 3 feet deep, located near the edge of the swamp.

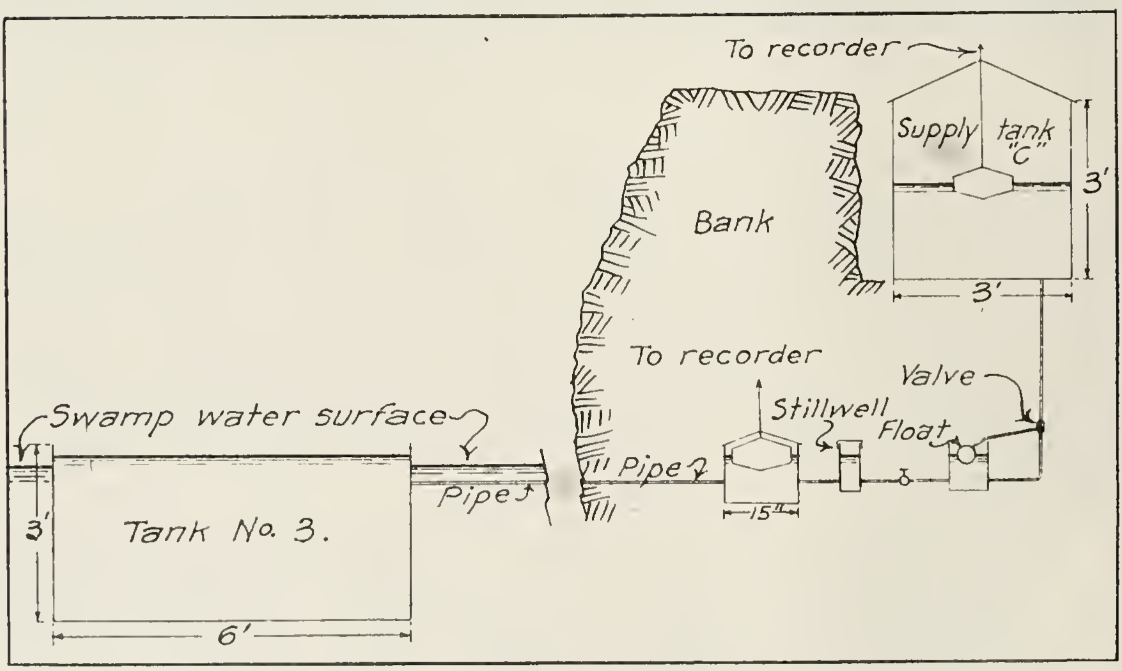
It was necessary to use a supply tank with each tule tank to maintain the water level between narrow limits. Tule Tanks Nos. 1 and 2 are directly connected to separate water supply tanks, 4 feet in diameter and about 1 foot deep. A cone-shaped metal cover with an air vent was fitted over the supply tanks, and a second cover was placed over the supply tanks to eliminate evaporation. With this arrangement the fluctuations in the water surfaces of the tule tanks are reduced by the replenishment of water from the supply tanks. Plate XIII shows

PLATE XIII



ARRANGEMENT FOR TANK NO. 2 TO SUPPLY WATER AND TO MEASURE AMOUNT OF EVAPORATION AND TRANSPIRATION.

PLATE XIV



ARRANGEMENT FOR TANK NO. 3 TO REGULATE SUPPLY OF WATER AND TO MEASURE AMOUNT OF EVAPORATION AND TRANSPIRATION.

PLATE XV

A. GENERAL VIEW OF VICTORVILLE STATION, TAKEN OCTOBER 31, 1931.

B. VIEW TAKEN OCTOBER 31, 1931, OF SWAMP WHERE TWO TANKS WERE LOCATED, THE STADIA ROD BEING HELD BETWEEN THE TWO TANKS.

the arrangement to supply water for tule Tank No. 2 and also the still well for measuring the amount of water used. Because of the volume of water required to supply tule Tank No. 3, a different arrangement was necessary there. This tank was supplied through an automatic float-valve feed connected to a supply tank of larger capacity. Plate XIV shows the arrangement for regulating the supply of water and measuring the amount used in tule Tank No. 3.

Beginning November 22, 1930, Tanks Nos. 1, 2, and 3 were maintained with free water surfaces until January 29, 1931, when they were planted with tules (*Scirpus olneyi*). During the installation of the equipment, the old tules around the tanks were broken down and the tanks were not completely surrounded with new growth until about May, 1931. Prior to May 15 the side exposure of Tank No. 2 was somewhat greater than that of Tank No. 3 but after that date the surrounding growth completely hid the rims of both tanks and thereafter the exposure of the tules in Tanks Nos. 2 and 3 was similar to that of the natural swamp tules.

PLATE XVI

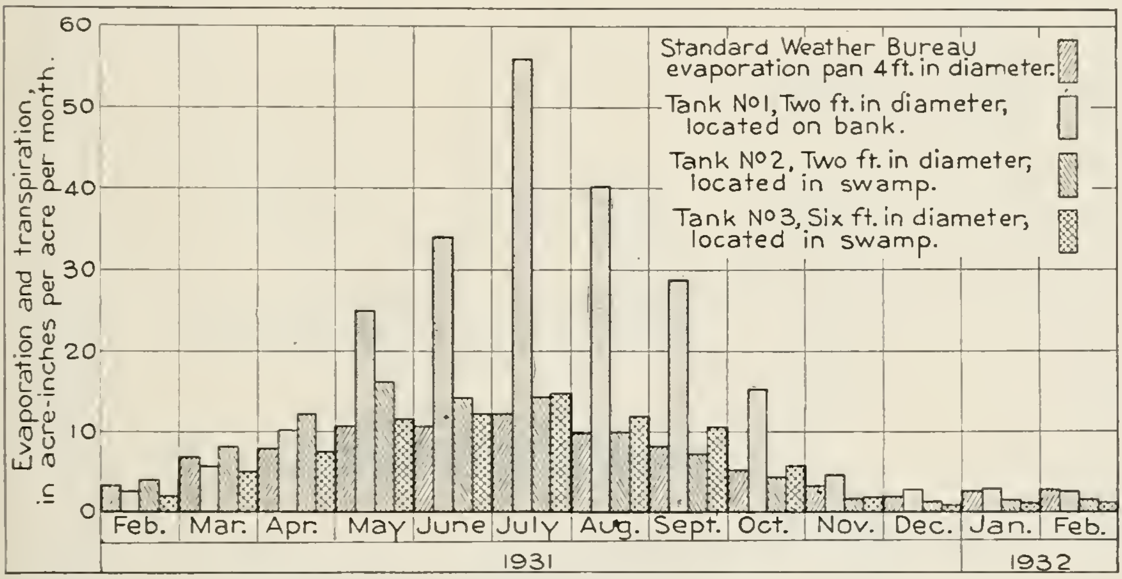
VIEW OF TANK NO. 1, TAKEN OCTOBER 31, 1931.

Plate XV-A is a general view of the station taken October 31, 1931, showing the location of the climatological apparatus, while Plate XV-B shows the location of Tanks Nos. 2 and 3, in the swamp, where they are surrounded by natural swamp growth. Plate XVI, taken on the same date, shows the tule growth in Tank No. 1.

CONSUMPTIVE USE OF WATER

Table 28 records, by months, for the period from February 1, 1931, to February 28, 1933; the evaporation from a standard Weather Bureau pan; the consumptive use of water from tule Tanks Nos. 1, 2, and 3; a percentage comparison of the consumptive use of water from the tule tanks expressed in per cent of the evaporation; the wind movement; the rainfall; and average daily maximum and minimum temperatures. A comparison of the losses, from February, 1931, to February, 1932, from the three tule tanks and from the evaporation pan is shown graphically in Plate XVII.

PLATE XVII



MONTHLY EVAPORATION AND USE OF WATER FROM TANKS NO. 1, NO. 2, AND NO. 3, FEBRUARY, 1931–FEBRUARY, 1932.

In April the tules in Tank No. 1, located on the bank, began to use water at a relatively high rate that increased rapidly until the highest use was reached in July, when it amounted to 4.55 times the evaporation, or 55.83 acre-inches per acre. After reaching a peak in July and August the use dropped until the plants were killed by frost in November, after which there was a continued loss by evaporation. There was practically no green growth in this tank until May, 1932, as indicated in Table 28, the use being shown to be much less than the evaporation from the Weather Bureau pan in March and April. After the tules started to grow in 1932 they used water rapidly until the highest use was reached in August, when it amounted to 78.99 acre-inches per acre, which was 6.77 times as great as the evaporation from the Weather Bureau pan.

The use of water from tule Tank No. 2, located in the swamp, was found to be considerably less than that from Tank No. 1 as the growing season advanced, although the tanks were of the same diameter. In

TABLE 28

MONTHLY SUMMARY SHOWING EVAPORATION, CONSUMPTIVE USE OF WATER FROM TULE TANKS, USE OF WATER EXPRESSED IN PER CENT OF EVAPORATION, WIND MOVEMENT, RAINFALL, AND TEMPERATURES AT VICTORVILLE STATION

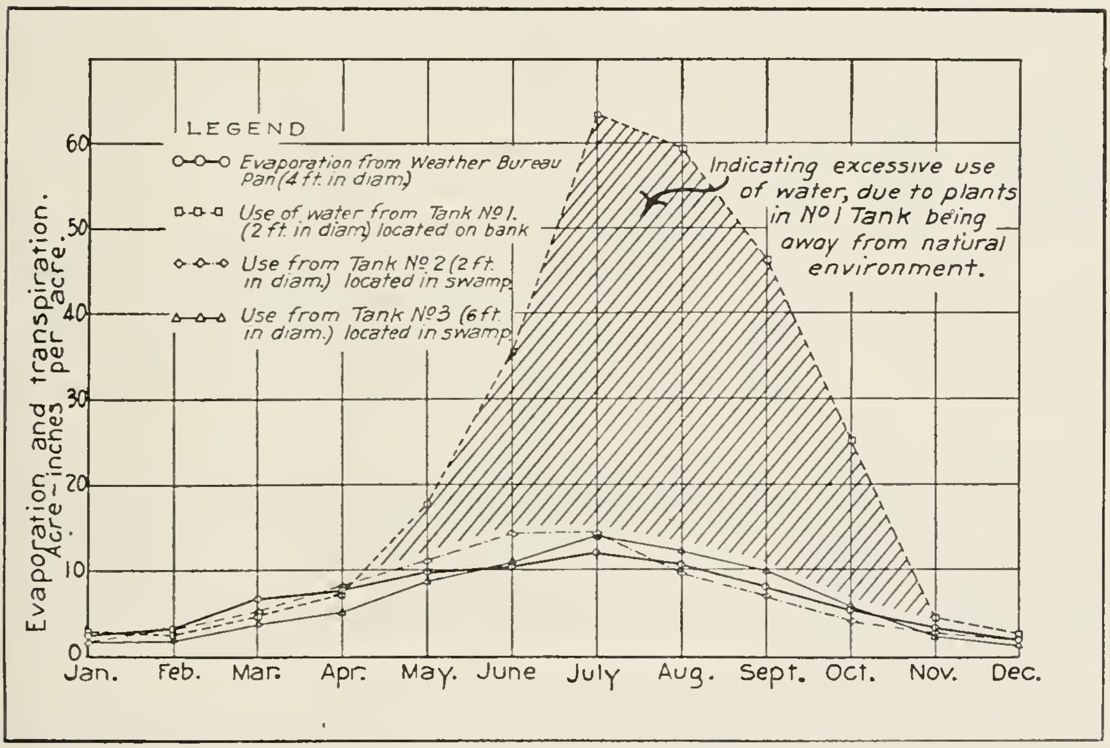
February 1, 1931, to February 28, 1933

Month	Evaporation from a standard Weather Bureau pan (4 feet in diameter), in inches	Use of water, in acre-inches per acre			Use of water expressed in per cent of the evaporation from a standard Weather Bureau pan			Wind movement, in miles	Rainfall, in inches	Temperature, in degrees Fahrenheit	
		Tule tank No. 1 (2 feet in diameter) located on bank	Tule tank No. 2 (2 feet in diameter) located in swamp	Tule tank No. 3 (6 feet in diameter) located in swamp	Tule tank No. 1 (2 feet in diameter) located on bank	Tule tank No. 2 (2 feet in diameter) located in swamp	Tule tank No. 3 (6 feet in diameter) located in swamp			Mean maximum	Mean minimum
1931											
February	3.28	2.49	3.99	1.89	76	122	58	1,231	1.77	----	----
March	6.83	5.63	8.06	4.97	82	118	73	1,713	.11	72	29
April	7.83	10.06	12.14	7.46	128	155	95	1,831	.80	77	38
May	10.63	25.00	16.03	11.62	235	151	109	1,649	.03	85	43
June	10.55	33.90	14.21	12.24	321	135	116	1,604	.03	86	47
July	12.26	55.83	14.37	14.65	455	117	119	1,187	----	101	57
August	9.68	40.10	9.87	11.98	414	102	124	1,001	1.01	96	56
September	8.10	28.66	7.17	10.56	354	89	130	1,198	.60	86	46
October	5.17	15.30	4.31	5.65	296	83	109	1,004	.47	77	39
November	3.14	4.61	1.65	1.85	147	53	59	1,123	1.02	60	27
December	1.92	2.75	1.35	.86	143	70	45	1,136	1.08	52	24
1932											
January	2.52	2.81	1.44	1.06	112	57	42	1,329	.85	52	21
February	2.79	[1]2.58	[1]1.56	[1]1.16	92	56	42	1,353	4.02	55	30
March	6.51	3.59	2.47	2.68	55	38	41	1,648	----	68	30
April	7.75	4.44	4.19	2.70	57	54	35	1,804	.01	71	32
May	9.20	[1]10.24	[1]6.19	[1]5.95	111	67	65	1,844	.78	77	40
June	10.22	37.04	(3)	9.37	362	----	92	1,189	.95	86	44
July	11.99	70.92	----	13.61	591	----	114	1,303	.08	93	48
August	11.67	78.99	----	12.65	677	----	108	1,228	----	93	47
September	8.34	64.10	----	9.51	769	----	114	890	.14	91	42
October	5.72	[1]35.25	(3)	[1]6.06	616	----	106	1,036	.59	76	35
November	3.89	(2)	4.45	3.00	----	114	77	671	----	71	26
December	2.08	----	2.88	2.03	----	138	98	1,105	.55	51	20
1933											
January	2.29	----	2.05	2.42	----	90	106	1,586	3.14	52	21
February	3.88	----	3.70	3.01	----	95	78	1,314	----	55	19

[1] Portion of month estimated because of floods.
[2] Tank taken out.
[3] Record uncertain, tank damaged by flood.

1931 the highest use from Tank No. 2 occurred in May, before the tank was entirely surrounded by swamp growth, and amounted to 16.03 acre-inches per acre, while the highest use for Tank No. 1 occurred in July, and amounted to 55.83 acre-inches per acre. The use in July from Tank No. 2 was 14.37 acre-inches per acre, which is approximately one-fourth of the use from Tank No. 1 for that month. This difference must be due to the relative exposures of the two tanks, since the density of stalks was not materially different. When the tules were set out in 1931 the plants in Tank No. 2 started to grow and use water earlier than the plants in Tank No. 1, because they were warmed by the rising water that flowed around the tanks in the swamp. A flood in May, 1932, damaged Tank No. 2 and the connected supply tank, so that the record from this tank is incomplete for 1932. The record for 1931, however, supplied the data necessary for the principal objective—demonstration of the effect of exposure on the use of water from 2-foot tanks. This is shown graphically in Plate XVII. A comparison on a mean monthly basis for the entire period of record is shown in Plate XVIII.

PLATE XVIII



MEAN MONTHLY EVAPORATION AND USE OF WATER FROM TANKS NO. 1, NO. 2, AND NO. 3.

A complete record was obtained from tule Tank No. 3 during both the 1931 and 1932 seasons. This tank was 6 feet in diameter and had a normal swamp exposure with a growth of tules completely surrounding the tank, so that there was a replication of natural conditions. The highest monthly use of water from this tank occurred during July in each year, amounting to 14.65 acre-inches per acre in July, 1931, and 13.61 acre-inches per acre in July, 1932. The mean annual use of water from this tank based on the 25-month period from February, 1931, to February, 1933, is 78.45 acre-inches per acre. This value was obtained by averaging the monthly values for each calendar month and then totaling these twelve monthly averages.

This value, 78.45 acre-inches per acre per year, represents the average annual loss of water during this period from tule swamps of the area with the water table at the ground surface or above. No reduction factor should be applied to this value, since the tank was set in a swamp and completely surrounded by a growth similar to that in the tank. The rim of the tank was completely hidden from the rays of the sun so there could be no rim effect, and the tank was bedded nearly 3 feet deep so that there could be no abnormal temperature variation or restriction of root activity.

Measured losses from the moist area on Temescal Creek compare favorably with the losses from the 6-foot tank at Victorville. The loss for the 30-day period from April 28 to May 27, 1929, for the swamp growth on Temescal Creek was 12.9 acre-inches per acre.* For the month of May, 1931, tule Tank No. 3 at Victorville used water at the rate of 11.62 acre-inches per acre per month, and the maximum rate measured in July, 1931, was 14.65 acre-inches per acre per month.

The cross-hatched area on Plate XVIII shows the relatively large loss of water from Tank No. 1 as compared with Tanks Nos. 2 and 3, where natural conditions were replicated. In this connection, it will be noted in Plate XV that the tule growth in the tanks in the swamp was 6 feet high, whereas the growth in Tank No. 1 on the bank (Plate XVI) averaged approximately 3 feet in height. These pictures were taken October 31, 1931. This indicates that the number of pounds of dry matter produced in the different tanks bears no rational relationship to the amount of water consumed when tules are grown in exposed tanks, such as tule Tank No. 1. That is, the loss of water from a natural swamp can not be computed from the relation of pounds of water used per pound of dry matter produced as determined from tules grown in isolated tanks. During July and August, 1931, Tank No. 1 used between three and four times as much water as either Tank No. 2 or Tank No. 3, yet the ultimate size of the plants produced in Tank No. 1 was only one-half the size of the plants in the swamp tanks. The results indicate that the controlling factor in the consumption of water is the exposure of the tanks and demonstrates, quite forcibly, that natural conditions must be replicated before data are of value in estimating field losses.

The diameter of a tank is a factor of importance when evaporation from a free water surface is being measured, as demonstrated by R. B. Sleight.** For the period from March 5 to November 13, 1916, Sleight found the evaporation from a 2-foot tank to be 117 per cent of that from a tank 6 feet in diameter.

However, with plants growing in a tank set in a similar growth of sufficient density so that radiation from the sun does not strike the edges of the tanks, the size of the tank should not materially affect the rate of loss per unit area from like densities of plant growth. Before May 15, 1931, the surrounding swamp growth had not shielded

* Bulletin No. 33, "Rainfall Penetration and Consumptive Use of Water in the Santa Ana River Valley and Coastal Plain," Division of Water Resources, California State Department of Public Works (Page 68).

** "Evaporation from the Surface of Water and River-bed Material," (Journal of Agricultural Research, Vol. X, No. 5, July, 1917.)

the tank rims fully and tule Tank No. 2 shows the higher rate of loss. Thereafter, differences in losses from the two tule tanks may be ascribed to a variation in the density of growth. By comparing the losses from tule Tanks Nos. 2 and 3, from June 1 to October 31, 1931, it is found that the loss is 49.93 acre-inches per acre from the 2-foot tank, and 55.08 acre-inches per acre from the 6-foot tank. For this period, the loss from the 2-foot tank is 91 per cent of the loss from the 6-foot tank, as compared to Sleight's ratio of 117 per cent for free water surfaces. The correlation of tank size is negative and difference in use must be due to some other factor such as density of growth.

Prior to the planting of tules in the tanks on January 29, 1931, all three tanks were maintained with free water surfaces. The evaporation in inches and rate of evaporation in inches per 30 days for the Weather Bureau pan and Tanks Nos. 1, 2, and 3, and also the evaporation from Tanks Nos. 1, 2, and 3, expressed as percentages of the evaporation from the Weather Bureau pan for the period, December 5, 1930, to January 29, 1931, are given in Table 29. During the period of these

TABLE 29

EVAPORATION FROM FREE WATER SURFACES IN THE WEATHER BUREAU PAN AND TANKS NOS. 1, 2, AND 3

December 5, 1930, to January 29, 1931

Pan or tank	Total evaporation in inches	Rate of evaporation in inches per 30 days	Per cent of evaporation from standard Weather Bureau pan
Standard Weather Bureau pan (4 feet in diameter)	4.20	2.29	100
Tank No. 1 (2 feet in diameter) located on bank near Weather Bureau pan	2.16	1.18	51
Tank No. 2 (2 feet in diameter) located in swamp	6.91	3.77	165
Tank No. 3 (6 feet in diameter) located in swamp	4.19	2.29	100

evaporation studies from free water surfaces, the mean daily maximum temperature was 65 degrees Fahrenheit, the mean daily minimum temperature was 11.5 degrees Fahrenheit, and the total wind movement was 1389 miles. The evaporation from the 6-foot tank (Tank No. 3), located in the swamp, was practically the same as that from the Weather Bureau pan (4 feet in diameter), the values being 4.19 and 4.20 inches, respectively, while the loss from the 2-foot tank (Tank No. 2), located in the swamp, was 165 per cent of that from the Weather Bureau pan. The 2-foot tank (Tank No. 1), located on the bank near the evaporation pan and set in the ground so that its rim was 1 inch above the surrounding ground surface, lost 51 per cent as much as the Weather Bureau pan.

This demonstrates the effect of exposure and location on the rates of loss from the different tanks. Tanks Nos. 2 and 3 were located in the swamp and the rising ground water from the swamp channel flowed around them continuously. The rising water in the swamp carried sufficient heat so that no ice formed on the water surface around the two tanks, even though a minimum air temperature of zero degrees Fahrenheit was recorded on December 23, 1930. The heat from this swamp water was transmitted to the water in the tanks most effectively in the case of the small tank 2 feet in diameter and to a less extent in the case of the 6-foot tank. The Weather Bureau pan, 4 feet in diameter and 10 inches deep, is set entirely above the ground, and receives heat from the sun on its sides as well as on the water surface, and it has also a maximum exposure to air movement. The 2-foot tank, located on the bank and sunk in the ground, could receive but very little heat energy from the dry cold ground surrounding it, but probably some of the heat received on its water surface was conducted down through the water and away into the soil. Accordingly, the evaporation from the 2-foot tank on the bank was least; and that from the 2-foot tank in the swamp was greatest, the latter being, in fact, 3.2 times as much as the former. The water in Tank No. 2 received enough heat energy from the swamp water to keep it relatively warm, while the water surface in Tank No. 1 remained relatively cold. The fact that the rate of evaporation is relatively high when the temperature of the water is greater than that of the air, has been pointed out by Rohwer.*

A comparison of the evaporation from Tanks Nos. 2 and 3 shows the loss from Tank No. 2 to be 1.65 times that from Tank No. 3. It is of interest to note that studies at the Salton Sea in 1910, using exposed tanks, showed a ratio of 1.48 to 1 for the loss from a 2-foot tank compared to that from a 6-foot tank.** In 1916, Sleight found the ratio of the loss from a 2-foot tank to that from a 6-foot tank to be 1.17 to 1 for tanks sunk in the ground. The higher ratio found at the Victorville station is undoubtedly due to the heating effect of the surrounding water as noted above.

As stated above, Table 29 indicates that the loss by evaporation from the free water surfaces in the cienega is relatively high during the winter. The reason for the high losses is that the rising water is relatively warmer than the air during the winter months.

In further demonstration of the extreme effect of exposure on rates of evaporation and transpiration from tanks, it should be noted that during December and January Tank No. 1 lost by evaporation less than one-third as much as Tank No. 2, but, in July, 1931, conditions were reversed and the consumptive use by evaporation and transpiration from the tules in Tank No. 1 was nearly four times as much as from Tank No. 2.

Mean monthly values for the entire period of record, for the evaporation and use of water from tule Tanks Nos. 1, 2 and 3, together with the climatological data, are given in Table 30. The mean annual evaporation from the Weather Bureau pan, as shown in Table 30, was 82.46 inches. The mean annual consumptive use of water from tule Tank No. 1, which had the same exposure on the bank as the evaporation pan, was 272.24 acre-inches per acre, while from tule Tanks Nos. 2 and 3, located in the swamp and characteristic of swamp conditions, there were used 84.45 acre-inches per acre and 78.45 acre-inches per acre, respectively. Plate XVIII shows the mean monthly evaporation and use of water from Tanks Nos. 1, 2 and 3.

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* "Evaporation from Free Water Surfaces," by Carl Rohwer, United States Department of Agriculture, Technical Bulletin, No. 271. (1931.)

** Studies on the Phenomena of Evaporation of Water Over Lakes and Reservoirs. Summary of the Results of the Salton Sea Campaign. By F. H. Bigelow. Monthly Weather Review, Vol. 38, No. 7. (1910.)

TABLE 30

SUMMARY BY MONTHS OF MEAN TEMPERATURES, WIND MOVEMENT, EVAPORATION, AND CONSUMPTIVE USE OF WATER FROM TULE TANKS NOS. 1, 2, AND 3, AND USE OF WATER FROM TULE TANK NO. 3, EXPRESSED IN PER CENT OF EVAPORATION AT VICTORVILLE STATION[1]

Month	Temperature, in degrees Fahrenheit		Wind movement, in miles	Evaporation from a standard Weather Bureau pan (4 feet in diameter) in inches	Use of water, in acre-inches, per acre			Use of water from tule tank No. 3, in per cent of evaporation from standard Weather Bureau pan
	Mean maximum	Mean minimum			Tule tank No. 1 (2 feet in diameter) located on bank	Tule tank No. 2 (2 feet in diameter) located in swamp	Tule tank No. 3 (6 feet in diameter) located in swamp	
January	52	21	1,458	2.40	2.81	1.74	1.74	72
February	55	24	1,299	3.32	2.54	3.08	2.02	61
March	70	30	1,680	6.67	4.61	5.26	3.82	57
April	74	35	1,818	7.79	7.25	8.16	5.08	65
May	81	42	1,746	9.92	17.62	11.11	8.78	89
June	86	46	1,396	10.38	35.47	14.21	10.80	104
July	97	52	1,245	12.12	63.38	14.37	14.13	117
August	94	52	1,114	10.68	59.54	9.87	12.32	115
September	88	44	1,044	8.22	46.38	7.17	10.04	122
October	76	37	1,020	5.44	25.28	4.31	5.86	108
November	66	26	897	3.52	4.61	3.05	2.42	69
December	52	22	1.120	2.00	2.75	2.12	1.44	72
Totals per year			15,837	82.46	272.24	84.45	78.45	[2]95

[1] This table is based on all data from February 1, 1931, to February 28, 1933.
[2] Per cent based on totals per year.

As tule Tank No. 3 replicated swamp conditions, the mean annual use of water from this tank was employed in determining a factor to be applied in calculating swamp use from an evaporation pan record. As the mean annual evaporation from the standard Weather Bureau pan was 82.46 inches and the mean annual use of water from tule Tank No. 3 was 78.45 acre-inches per acre, the use of water from the tule swamp area would be 95 per cent of the evaporation from the Weather Bureau pan.

The evaporation from a lake surface may be estimated as 0.7 of the measured loss from a standard Weather Bureau pan. The mean annual evaporation from a lake surface is, therefore, indicated to be 58 inches. The mean annual loss from tule Tank No. 3, which replicated natural conditions, was 78.45 inches. This indicates that the annual use by tules would be 20 inches more than the loss from a lake surface. This is probably a maximum differential and would be expected in a swamp area completely covered with tules growing in water.

It may be seen from Plate XI that a considerable portion of the moist area above the Narrows is covered with a scattered growth of cottonwoods interspersed with patches of open sandy areas. The dense tule growths are restricted principally to sections along the main channel of the river and in the swampy areas such as the one on which the station was located. The mean annual consumptive use for the entire moist area would undoubtedly be appreciably less than the value of 78 acre-inches per acre per year determined for the tule swamp areas.

If the period from May to October, inclusive, be considered, and a comparison made for that interval, it is found that the use of water by the tules was 61.93 inches, and the estimated evaporation from a lake surface, 40 inches. The difference is 22 inches, and for this period, the loss of water from a tule swamp area would be 155 per cent of the loss from a free water lake surface.

CHAPTER IV

INVESTIGATIONS IN COLDWATER CANYON

By Colin A. Taylor and Harry G. Nickle*

In many instances water supplies for irrigation, domestic, and industrial uses are diverted from the lower reaches of canyons and the water is allowed to flow through many miles of open channel bordered by growing vegetation. A large portion of the water used originates in the mountain watersheds and must pass through the canyons before it reaches the irrigated areas of the valleys. There is little information available as to the amount of water lost in such canyons through evaporation and transpiration from the native vegetation.

Losses from the moist land bordering the lower sections of Temescal Creek, four miles southeast of Corona, were investigated by the Division of Irrigation of the Bureau of Agricultural Engineering early in 1929. The growth was typical of the moist areas bordering the streams in the valleys, with willows and tules predominating. The results ** indicated that large losses must occur from similar growths along the Santa Ana River and that the supply of water diverted in the lower Santa Ana Canyon for irrigation in Orange County must be considerably diminished because of the loss of water in the moist areas adjacent to the river.

Since the losses from the areas supporting willows, tules, and kindred moist land growths were indicated to be of considerable magnitude, it was deemed advisable to extend the study to canyon reaches in which alder growths predominated, above the usual points of diversion from the streams. It was the purpose of this study to obtain data on the loss of water during the growing season by evaporation and transpiration from a typical small canyon and on the amount of additional water which might be derived were the water supply diverted at a higher point on the stream.

The experimental data for this study were obtained in Coldwater Canyon, located near Arrowhead Springs in the San Bernardino Mountains in the upper basin of the Santa Ana River, approximately 7 miles north of the city of San Bernardino. This canyon was chosen as being representative of many of the smaller canyons of southern California.

The data were collected during the growing seasons of 1931 and 1932. In 1931, two bedrock stations, hereinafter called ''controls,'' were installed in the canyon. The ''lower control'' was located about one mile above the mouth of the canyon, and the other, designated as the ''middle control,'' was located 2090 feet upstream from the lower

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* Prepared by C. A. Taylor, Assistant Irrigation Engineer, and Harry G. Nickle, Junior Hydraulic Engineer, Bureau of Agricultural Engineering, U. S. Department of Agriculture.

** "Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain," by Harry F. Blaney and C. A. Taylor, State of California, Department of Public Works Bulletin No. 33, Chapter IV, 1930.

PLATE XIX

AERIAL VIEW OF COLDWATER CANYON SHOWING LOCATION OF THE CONTROLS.

control. In 1932 the same controls were continued and, in addition, another bedrock control, designated as the "upper control," was installed 5875 feet upstream from the middle control, and a supplementary bedrock control was installed on the only branch entering the main canyon from the east between the middle and lower controls, at a point about 300 feet above its mouth. This branch canyon enters the main canyon 800 feet above the lower control.

The approximate elevations above sea level of the controls are 2300 feet for the lower control, 2500 feet for the middle control, and 3100 feet for the upper control.

A general view of Coldwater Canyon is shown in Plate XIX, the white marks indicating the location of the controls.

The canyon bottom vegetation between the controls is composed mostly of alders, bay (California laurel), sycamore, willow, and maple, with a few oak, mountain mahogany, cedar, spruce, and cottonwood trees. Also, there is considerable smaller growth of grapevine, blackberry, poison oak, ferns, etc. Table 31 shows the number and kinds

TABLE 31

CLASSIFICATION OF TREES BETWEEN MIDDLE AND LOWER CONTROLS IN COLDWATER CANYON

Diameter, in inches	Number of trees							
	Alder	Sycamore	Bay	Willow	Maple	Oak	Mountain mahogany	Total
Less than 2	33	3	4	7	2		2	51
2– 4	159	16	30	14	7	1		227
4– 6	144	10	2	2	4			162
6– 8	150	8	1	1	6			166
8–10	105	6			1			112
10–12	59	3		1	1			64
12–14	33	4			2	1		40
14–16	16	7						23
16–18	13	10						23
18–20	13	1				2		16
20–22	11	1						12
22–24	1	2						3
36–38						1		1
Totals	737	71	37	25	23	5	2	900
Per cent	81.9	7.9	4.1	2.8	2.5	0.6	0.2	100.0

of trees between the middle and lower controls, and Table 32 is a similar table of the trees between the upper and middle controls. These two tables show the difference in vegetation of the two sections of the canyon. In the lower section the alders constitute 81.9 per cent of the total number of trees, while in the upper section they constitute only 47.9 per cent of the total number. The lower percentage of alders in the upper section is accounted for principally by the increased number of bays which constitute but 4.1 per cent in the lower section, but make up 26.1 per cent of the total in the upper section. The lower section has a higher percentage of larger trees, while between the upper and middle controls the percentage of smaller trees is the greater and also the number of different kinds is greater. Views of the canyon bottom vegetation between the middle and lower controls are shown in Plate XX.

PLATE XX

A. ALDERS IN CANYON BOTTOM VIEWED FROM AN OVERHANGING CLIFF.

B. ALDERS IN CANYON BOTTOM ABOUT MIDWAY BETWEEN THE MIDDLE AND LOWER CONTROLS.

TABLE 32

CLASSIFICATION OF TREES BETWEEN UPPER AND MIDDLE CONTROLS IN COLDWATER CANYON

Diameter, in inches	Number of trees										
	Alder	Bay	Maple	Willow	Sycamore	Oak	Mountain mahogany	Cedar	Spruce	Cottonwood	Total
Less than 2	67	258	48	62	11	18	30	1			495
2- 4	222	371	81	82	60	32	8	5			861
4- 6	193	52	56	24	34	4		1			364
6 -8	242	11	26	8	24	2		1			314
8-10	184	5	10	3	15					1	218
10-12	175	3	5	1							184
12-14	84	1	5	1	9	1					101
14-16	48		1		7	3					59
16-18	26		1		2						29
18-20	15				3	1					19
20-22	13		1		3						17
22-24	12					1					13
26-28	3										3
28-30	2										2
30-32					1				2		3
34-36						1			1		2
36-38									1		1
38-40								1	2		3
Totals	1,286	701	234	181	169	63	38	9	6	1	2,688
Per cent	47.9	26 1	8.7	6.7	6.3	2.4	1.4	0.3	0 2	0.0	100.0

Above the upper control the growth in the main canyon bottom is principally alders, with some sycamores, willow, maple, bay, etc. The main canyon divides into two main branches, at a point 1920 feet above the upper control. Many of the smaller branch canyons above the forks have dense growths of ferns and underbrush.

Between the middle and lower controls there are only two branches entering the main canyon, one from the east on which the branch control was located, and one from the west which has an excellent bedrock exposure just as it enters the canyon. The west branch canyon contributed no water during the periods recorded in this report. There were no visible indications of water entering the canyon between the middle and lower controls during the period of record, except during the first part of the 1932 season as measured at the branch control.

There are several branch canyons entering the main canyon between the upper and middle controls. There were no visible indications of any water entering the canyon between these controls at any time during the 1932 season.

The material filling the main canyon bottom between the middle and lower controls ranges in width from 25 to 80 feet for the most part, and has an average width of 49 feet and an area of 2.36 acres. Between the upper and middle controls, the material filling the canyon bottom ranges in width from 15 to 80 feet for the most part, and has an average width of 44 feet and an area of 5.89 acres. On both sides the canyon walls are very precipitous.

The length of canyon in which surface water flowed was measured in October, 1931, after the flow had recovered to its maximum connected flow for the season. Above the forks, 1920 feet from the upper control, there were 13,170 linear feet of branch canyons in which surface water was flowing. This makes a total above the upper control of 15,090 linear feet of canyon, including all the branches, that had flowing water at the end of the 1931 growing season.

Above the lower control the area of the watershed is 3.4 square miles, of which area the east branch, on which the branch control is located, drains 0.9 square mile.

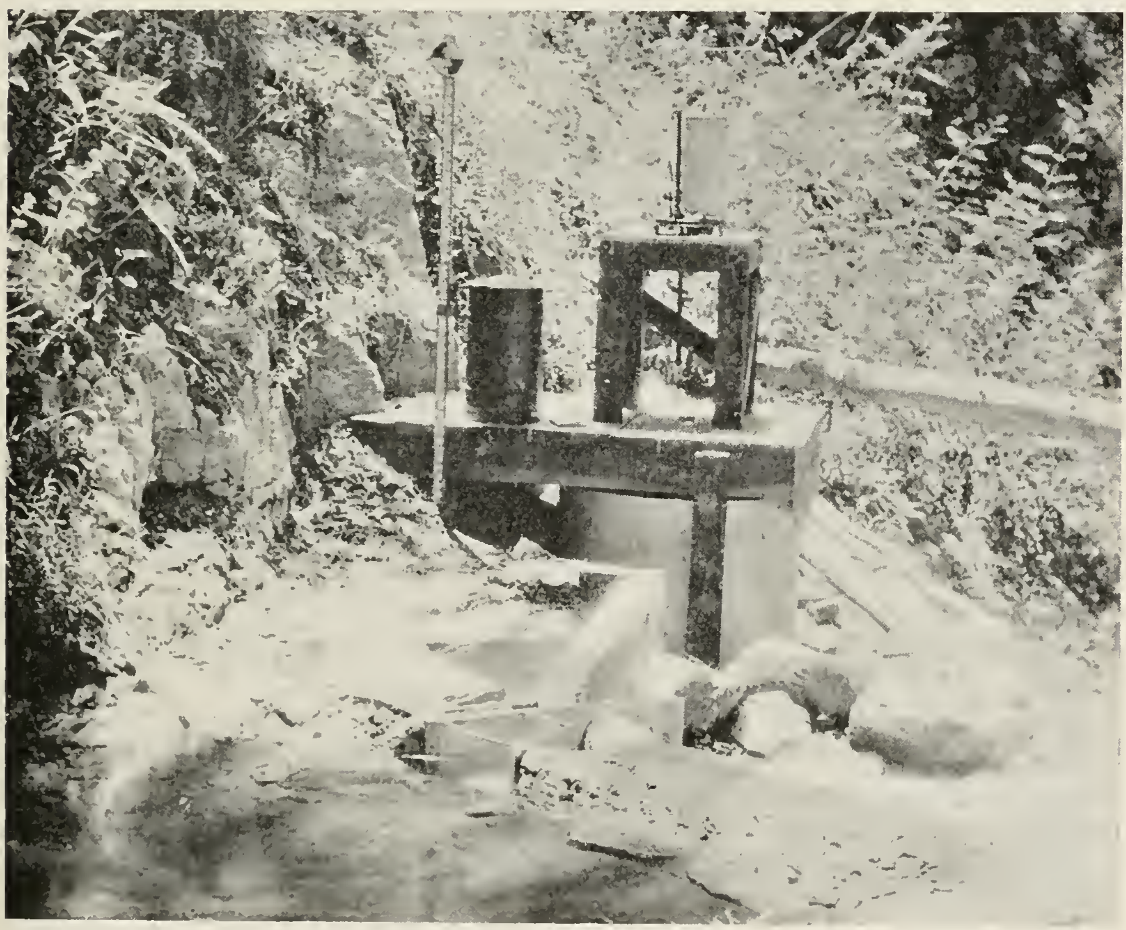
Records were obtained during the 1931 season at the middle and lower controls on the main canyon, from August 1 to October 17, and also during the 1932 season at the three controls on the main canyon, from June 24 to November 3. Water was also measured at the branch control from June 24 to July 9, 1932, no water passing this branch control at any other time during the periods of record.

EQUIPMENT

Controls

In 1931, the two bedrock controls were established in Coldwater Canyon at the locations previously described. At each of these controls, a low concrete dam was built on bedrock across the bed of the stream. The flow of water was passed through a 3-inch Parshall measuring flume placed in one end of each dam, and water stage recorders were installed to record the head on each flume. On September 17 of the same year a flow recorder for recording the discharge directly was installed at the lower control and was operated during the remainder of the season. The flow recorder is described in detail on page 96.

PLATE XXI



MIDDLE COLDWATER CONTROL SHOWING 3-INCH PARSHALL MEASURING FLUME AND FLOW RECORDER.

In 1932, flow recorders operated with 30-inch floats were installed at the two controls operated in 1931 and bedrock exposures were selected for the locations of the upper and branch controls. Low concrete dams were built on these sites and the flow passed through flumes in the dams, water stage recorders being set for recording the gage heights.

Plate XXI is a view of the middle control showing the 3-inch Parshall measuring flume and the flow recorder.

Flume for Winter Measurements

In order to measure small summer flows accurately and also to obtain a record of large winter flows, a combination flume, such as is shown in Plate XXII, was found desirable. This combination flume consists of two Parshall measuring flumes, one large and one small, so arranged that both large and small flows pass through the converging section of the large flume, but the small flows are by-passed from the dip in the large flume into a basin above the small flume and thence through this latter flume, while the greater part of the large flows continues on through the larger flume.

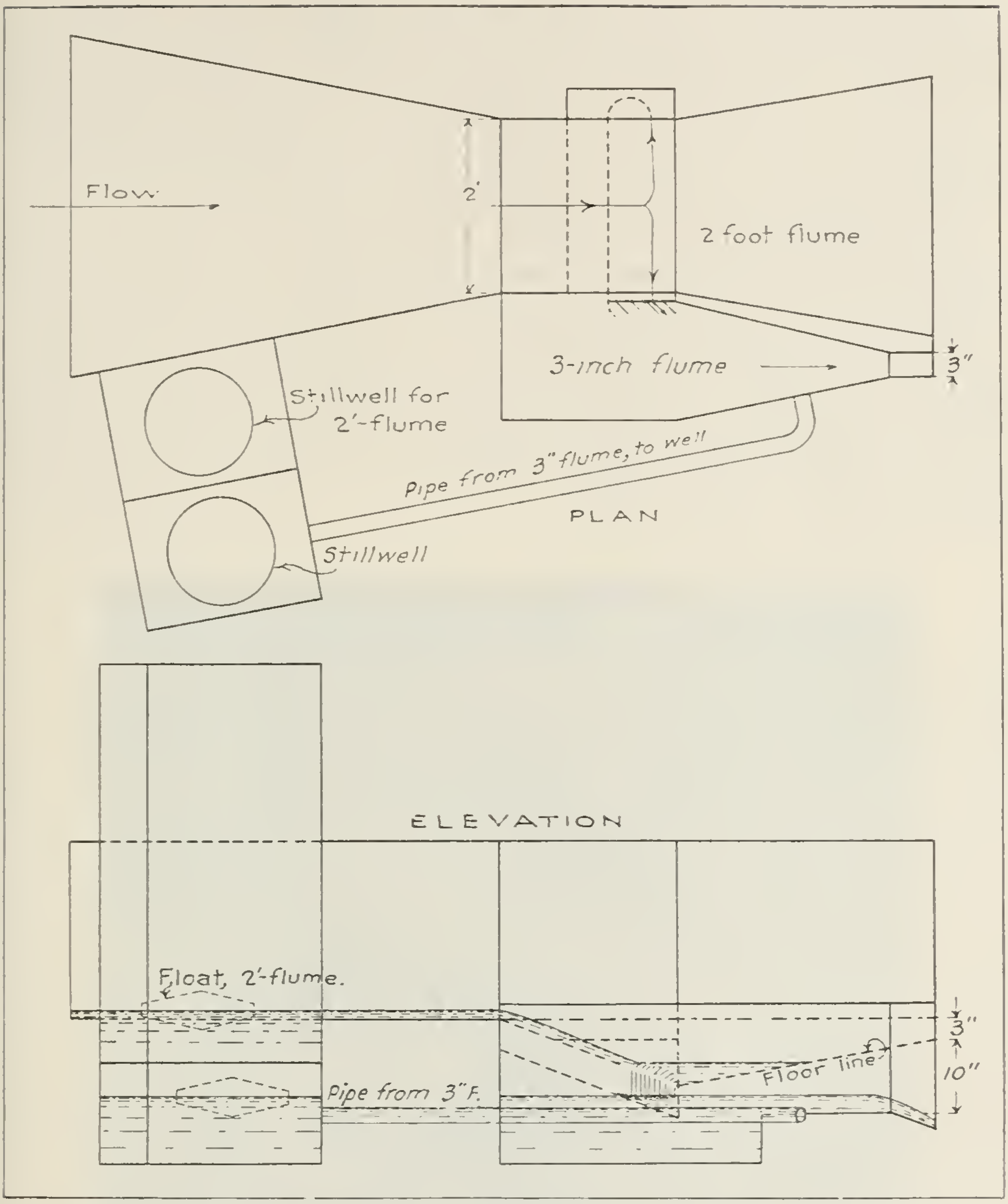
A record of the larger discharges is obtained by a recorder operated by a float in a still well connected to a larger flume, and a record of the smaller discharges is obtained by a flow recorder operated by a float in a still well connected to the smaller flume. Some overlap is provided so there is a small range during which a record may be obtained from both flumes. Two separate recorders may be used, or one duplex recorder is sufficient if it is desired to record gage heights only.

Plate XXII shows a combination of 3-inch and 2-foot Parshall measuring flumes, providing a range in discharge up to 23 second-feet. The sizes of both flumes may vary according to the accuracy and range desired. It should be recognized, however, that there are certain limitations on the accuracy of measurements over very wide variations in flows, and the selection of sizes should depend on whether the greatest accuracy is desired at very high, medium, or low stages.

The application of Parshall measuring flumes to measurements in mountain canyons involves problems not ordinarily met with in valley areas. The stream gradient is steep, often 10 per cent or more, and the water tends to cut a narrow channel and travel at a relatively high velocity and carry a large bed load as well as a considerable amount of suspended material.

A large flume placed, for example, directly in a stream channel where the grade is as high as 10 per cent will have a rating curve quite different from the standard calibration. It may pass as much as 30 per cent less water than that given for the lowest gage heights in the standard tables. The reason for this is that a small stream of water entering the center of a wide flume at high velocity tends to proceed through the center of the flume without changing its cross section greatly, leaving dead water along each side of the wide flume.. At high stages, the flume may pass more water than is indicated by the gage height in the standard tables, because of the high velocity of approach

PLATE XXII



COMBINATION FLUME FOR MEASUREMENT OF WATER AT BOTH HIGH AND LOW STAGES.

across the entire width of the flume. The large flumes should, therefore, be rated in place when the conditions are extreme, such as are indicated in the example cited.

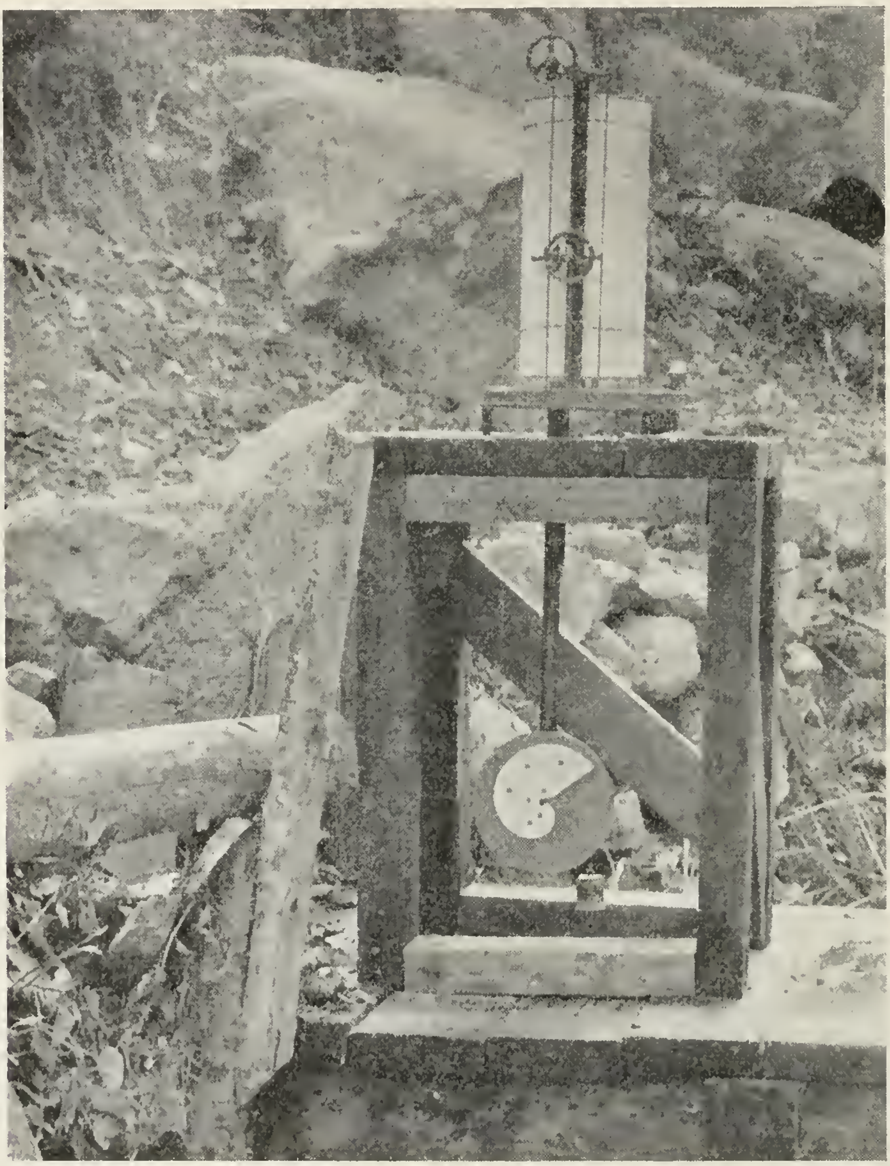
With clear water it is best to set the gaging station so that there is the least possible grade in the approach channel to the flume. Where heavy loads of detritus are being transported, deposition will occur in the entrance to the flume where the grade is flattened at the installation, and enough debris may lodge to affect the measurement. Usually, however, other conditions, such as bedrock exposure in the channel, will determine the location of the station, and it will be found more economical to rate the large flume for the given set of conditions after other factors have determined its location.

Flow Recorders

At first when ordinary water stage recorders were used it was necessary, in order to obtain sufficient accuracy, to take off hourly values from the water-stage recorder charts. The work of taking off these hourly values and from these values computing the loss each day was found to be a long and laborious process. In order to eliminate a large part of this routine work, thereby saving much time, it was decided to use flow recorder attachments on the recorders at the controls.

Accordingly, a flow recorder attachment was purchased and installed in Coldwater Canyon in conjunction with the water stage recorder at one of the controls in September, 1931. This flow recorder attachment consisted essentially of an adjustable spiral cam that mechanically solved the flow formula. The cam was geared to a float pulley wheel and the pencil cord was attached to the cam. The float turned the pulley wheel and, through the cam, moved the pencil to record the flow directly in units of discharge. A flow recorder installation is shown in Plate XXIII.

PLATE XXIII



FLOW RECORDER INSTALLATION AT LOWER COLDWATER CONTROL.

This first flow recorder attachment was installed to operate by a 12-inch float. After testing in the field, it was found that the pencil lag on the record chart was too great for the work being undertaken. This lag amounted to as much as 0.020 second-foot and as the fluctuations that were being measured amounted to 0.200 second-foot and less, the error was 10 per cent or more.

In order to secure greater sensitiveness, the gears were eliminated, the cam was balanced, and a 30-inch float was used. Nonadjustable cams were designed and made for use with 3-inch Parshall measuring flumes. With the improved flow recorder attachment, the pencil lag was reduced to 0.002 second-foot for flows above 0.50 second-foot, and for flows of less than 0.20 second-foot no lag could be detected.

By using these flow recorder charts, the loss per day may be obtained directly by superimposing two charts, one from each control, on top of a light-table, and planimetering the area between the two curves. This area represents the daily loss between controls and, when multiplied by the proper constant, can be converted into whatever units are desired.

Evaporimeter

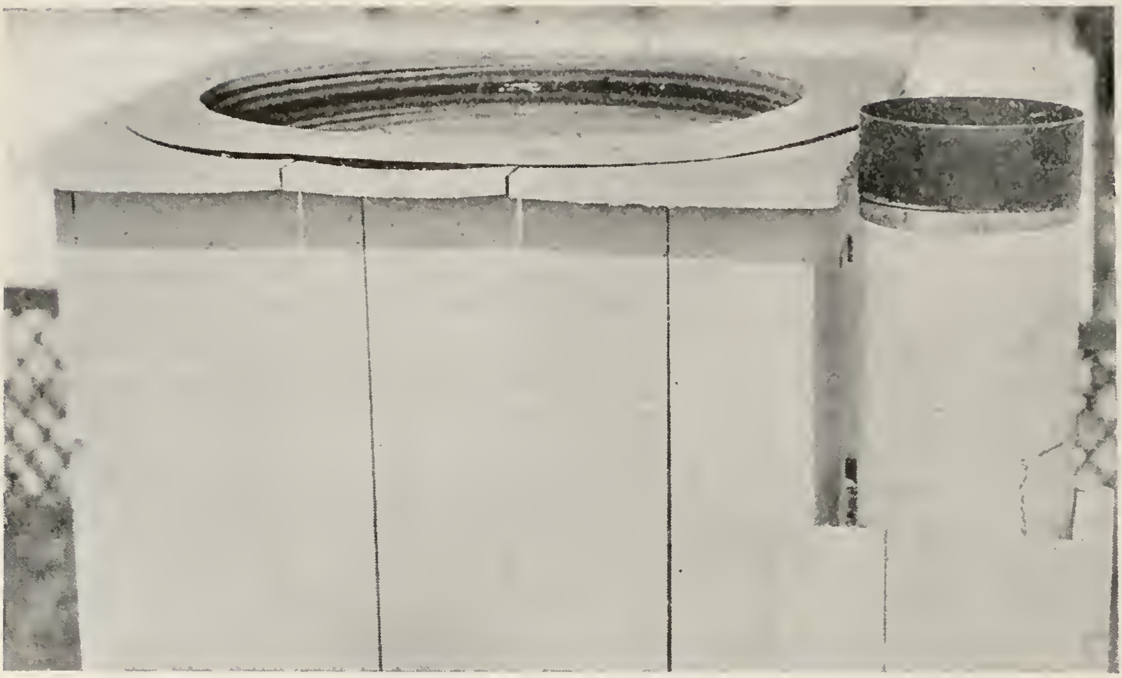
It became apparent, during the course of the investigation of the loss of water along stream channels by evaporation and transpiration, that the study would be materially aided if a continuous record could be obtained of the transpiration opportunity. Briggs and Shantz* showed that the evaporation from a shallow black pan correlated more closely with actual transpiration than that from any of the other devices which they tested. Loss of water from deep pans is affected by heat storage within the water. During the morning much of the heat received from the sun is used in raising the temperature of the water, and if the tank is 10 inches or more deep there is a lag of several hours in the curve of evaporation, behind the cycle of insolation. As the depth is decreased, the lag becomes less. The practical lower limit for the depth to be used appeared to be that depth which would be sufficient for one complete day's record on the hotter days. The 4-foot pan maintained at Ontario from 1928 to 1930 showed a peak rate of slightly less than 0.50 inch per day; therefore 0.60 inch was chosen as the most practical maximum depth for the water in the evaporimeter.

A Fergusson recording rain gage was used as the recording device. The evaporimeter pan was made 2 feet in diameter and 0.7 inch deep. This pan was attached to a cylinder that would fit inside the rain gage and take the place of the usual rain-gage bucket. The pan and recorder were then placed in a box 30 inches square by 27 inches high, to provide lateral heat insulation. The evaporimeter is shown in operation in Plate XXIV-A with a standard 8-inch rain gage to the right. The recording mechanism is shown in Plate XXIV-B. The chart scale is 9 to 1; that is, 9 inches on the chart is equivalent to 1 inch of evaporation. Record charts are shown in Plate XXV for typical days in August and October, 1931.

* Reprint from Journal of Agricultural Research, Vol. IX, No. 9, May, 1917. "Comparison of the Hourly Evaporation Rate of Atmometers and Free Water Surfaces with the Transpiration Rate of Medicago Sativa," by Lyman J. Briggs and H. L. Shantz.

7—4503

PLATE XXIV



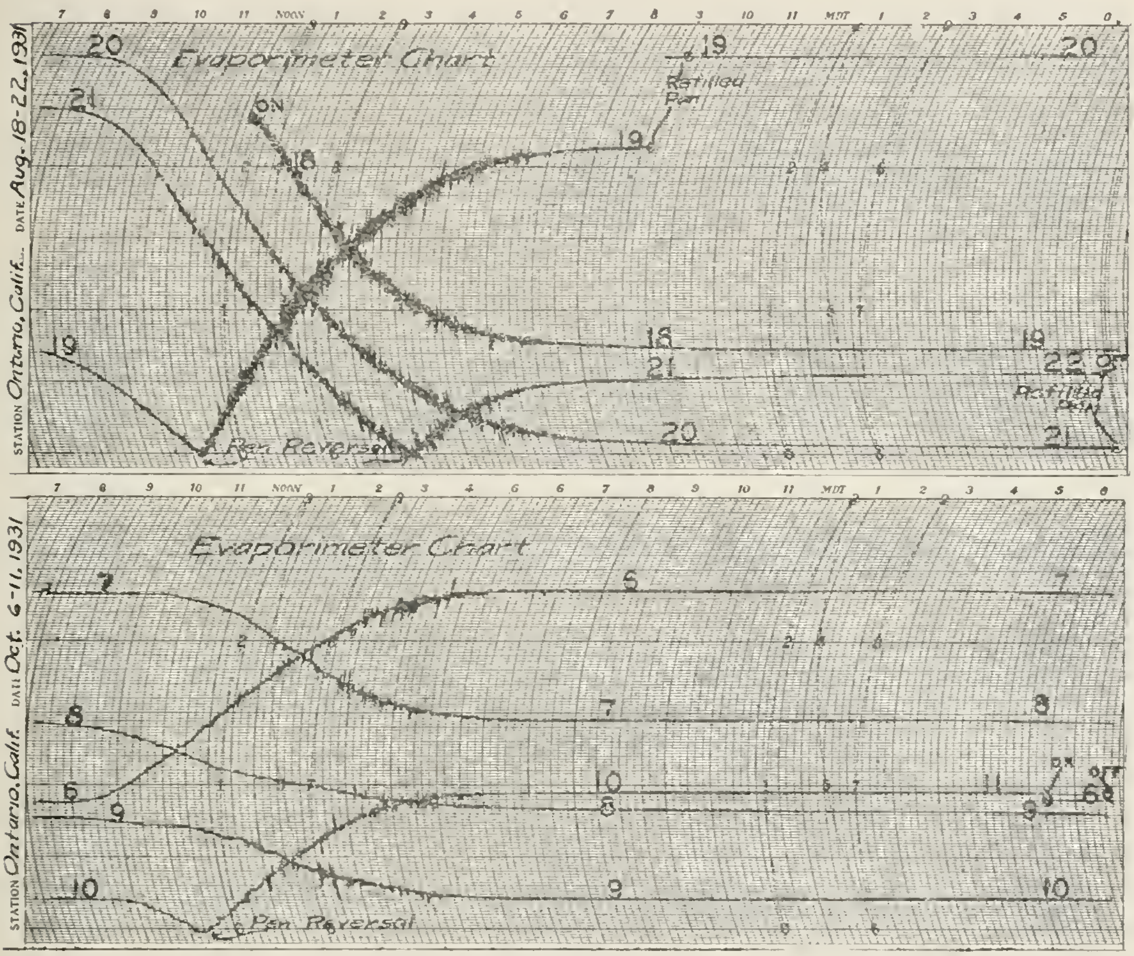
A. EVAPORIMETER WITH SHALLOW BLACK-PAN 24 INCHES IN DIAMETER.

B. EVAPORIMETER SHOWING WEIGHING MECHANISM AND RECORD CYLINDER.

Wind action affects the instrument, since the change in air pressure, as each gust passes, causes a vertical movement of the pan and produces a wavy line on the chart. In this way a continuous record is obtained of the time the wind blows and also a relative indication of its intensity.

During cold winter months the water in the shallow pan freezes solid, and an accurate record of the evaporation from an ice surface may be obtained since the mechanism is of the weighing type.

PLATE XXV



EVAPORIMETER CHARTS.

EVAPORATION AND TRANSPIRATION LOSSES ALONG THE STREAM CHANNEL

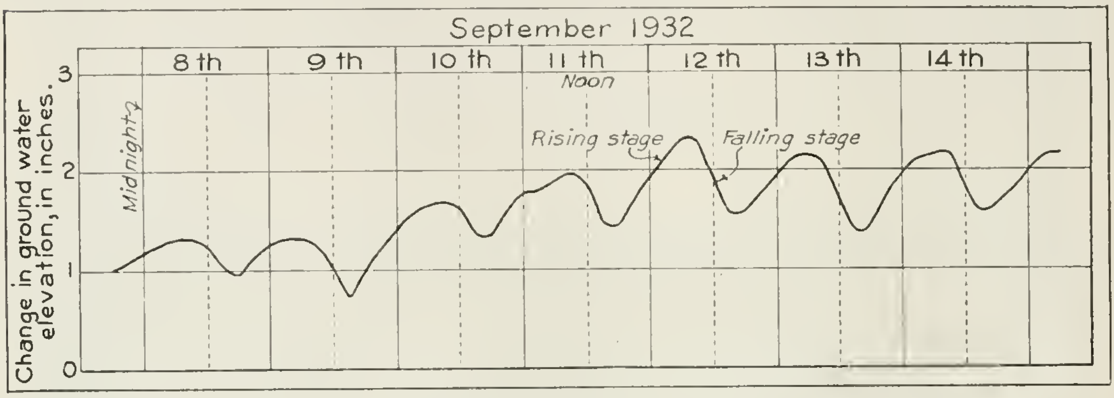
Loss from Stream Between Controls

The loss from a section of canyon was obtained by subtracting the volume of water leaving from the volume of water entering the section. Because of a possible storage differential in the section between the beginning and the end of any period, this method will result in small departures from the true differences in short periods, such as a 24-hour period, but in longer periods this difference will be negligible.

That this differential storage exists is shown by Plate XXVI, which presents a graph of the fluctuation in the water table September

7–15, 1932, in a ground-water pit located a short distance upstream from the lower control and about ten feet from the stream. From this graph it is seen that there would be a small storage differential each day between September 9 and 12, but that this differential is almost zero between September 8 and 9 and from September 12 to 15, and that the storage differential over the entire period would be only an extremely small portion of the use of water during the period. As between September 8 and 15, the storage differential is represented by 0.85 inch. Assuming the specific yield to be 8 per cent, this represents a depth of water of 0.068 inch which spread over 2.36 acres—the area between the middle and lower controls—gives a volume of 0.16 acre-inch. The total use between those controls for this period was 7.39 acre-inches. Hence the differential storage over the entire period is only 2.2 per cent of the total use of water for this period of one week, which is no doubt higher than usual as a hot wind was blowing during the early morning hours of September 8. For longer periods, such as a month, the percentage would be considerably less.

PLATE XXVI



FLUCTUATION IN THE WATER TABLE IN COLDWATER CANYON, SEPTEMBER 7–15, 1932.

To obtain the volumes of water passing each control not equipped with a flow recorder it was necessary, in order to attain sufficient accuracy, to take off hourly values from the water-stage recorder charts. Later, when the flow recorders were installed, the daily volumes of water passing each control could be planimetered directly from the flow recorder charts.

A section of the discharge curve at the middle control is shown in Plate XXVII. This plate shows the record of discharge at the middle control from August 9 to August 15, 1931. It includes four warm days, August 9, 10, 11, and 15; one day on which rain fell, August 12; and two cool, cloudy days, August 13 and 14.

The effect of evaporation is indicated by a comparison of the evaporation from an evaporation pan, placed in the middle of the stream so that water of the stream entirely surrounded the pan, and the loss between the middle and lower controls. During the period from September 8 to 14, inclusive, 1932, the average depth of evaporation from this pan was 0.0076 foot per day. Assuming an average width of stream surface of 3 feet the total volume which would be evaporated in the length of 2090 feet between the middle and lower controls, if the same rate were maintained, would be 0.013 acre-inch per day. Between these controls the average measured loss of water per day during this period was 1.06 acre-inches. Therefore the evaporation would be only 1.2 per cent of the total measured loss. These values are shown in Table 33 together with the daily comparisons during the period.

TABLE 33

COMPARISON OF ESTIMATED LOSS BY EVAPORATION FROM STREAM AND TOTAL LOSS BETWEEN MIDDLE AND LOWER CONTROLS IN COLDWATER CANYON

September 8-14, 1932

Date	Depth of evaporation from tank 2 feet in diameter surrounded by stream, in feet	Estimated evaporation from stream in acre-inches[1]	Loss between middle and lower controls, in acre-inches	Estimated evaporation loss expressed as a percentage of total loss
1932—				
September 8	0.015	0.026	1.44	1.8
September 9	.007	.012	1.19	1.0
September 10	.006	.010	.91	1.1
September 11	.007	.012	.86	1.4
September 12	.008	.014	1.01	1.4
September 13	.005	.009	.97	.9
September 14	.005	.009	1.01	.9
Averages	.0076	.013	1.06	1.2

[1] Evaporation computed for a stream surface 3 feet wide by 2,090 feet long at same rate as evaporation from 2-foot tank.

The true rate of evaporation from the stream would no doubt be less than the rate from the evaporation tank, as the average daily maximum temperature for the period was 2.4 degrees higher in the tank than in the stream. Air and water temperatures for this period are given in Table 34. It can be seen from Plate XX, which shows a typical section of the canyon, that the water surface of this stream is

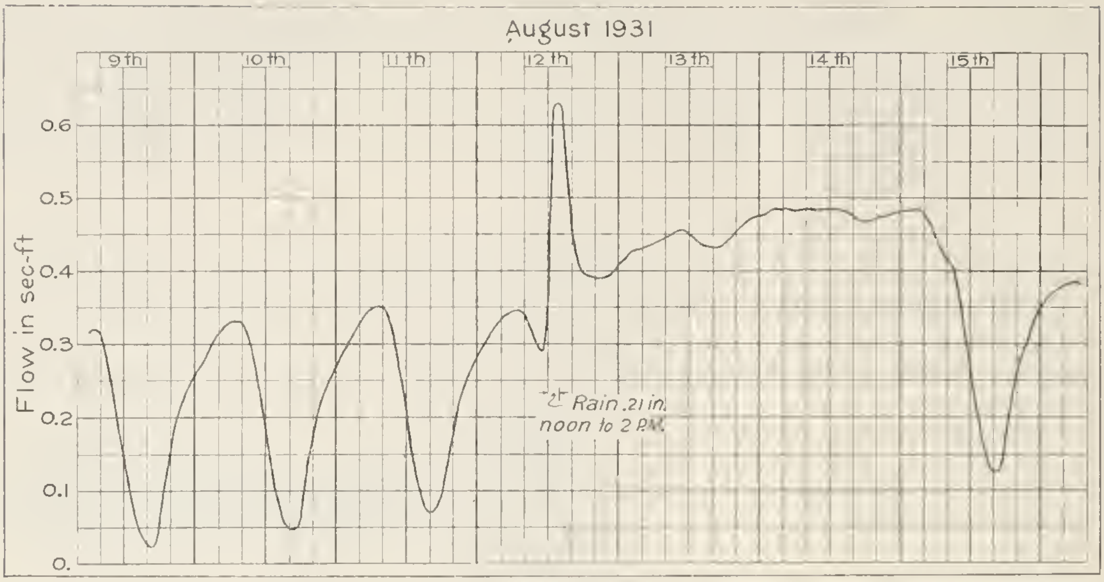
TABLE 34

DAILY MAXIMUM AND MINIMUM TEMPERATURES IN COLDWATER CANYON OF THE AIR, THE STREAM, AND THE WATER IN THE EVAPORATION PAN

September 8-14, 1932

Date	Temperature, in degrees Fahrenheit					
	Water in stream		Water in the evaporation pan		Air	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1932—						
September 8	68	62	71	62	100	87
September 9	68	64	72	64	93	81
September 10	67	60	69	61	86	60
September 11	66	58	68	60	85	58
September 12	66	58	67	59	87	60
September 13	66	58	68	58	85	63
September 14	65	60	68	59	83	59
Averages	66.6	60.0	69.0	60.4	88.4	66.9

PLATE XXVII



FLOW AT MIDDLE COLDWATER CANYON CONTROL, AUGUST 9–15, 1931.

almost completely shaded and the indicated evaporation rate can not be applied to open areas where the water surface is exposed to the sun.

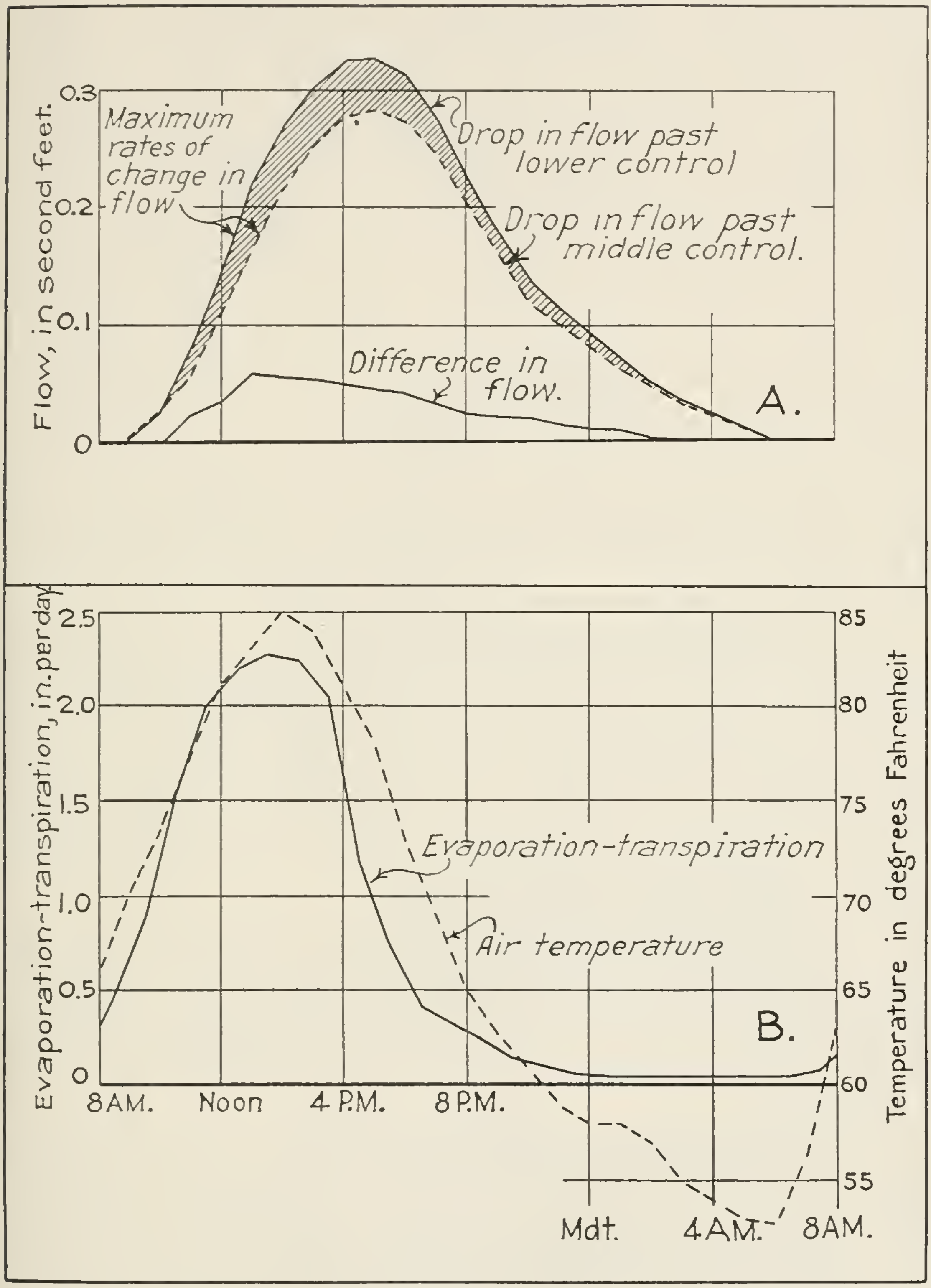
If transpiration is the main factor in causing the daily drop in a stream flow, the demand on the stream for water to take care of the transpiration needs of the vegetation growing in the canyon might be expected to follow a typical rate of transpiration curve. That it does tend to do this is shown by a comparison of a daily cycle of loss in discharge from Coldwater Canyon to the daily cycle of a typical rate of transpiration curve.

A graph of the drop in stream flow occurring at the upper and lower controls is shown in Plate XXVIII-A. Plate XXVIII-B shows a record of the loss of water by evaporation and transpiration on September 11–12, 1930, from a tank of mixed swamp vegetation, chiefly wire rush, tule, and willow at Ontario.

The Ontario tank record shows 94 per cent of the loss occurring between 8 a.m and 8 p.m. or between $2\frac{1}{2}$ hours after sunrise and 2 hours after sunset, and the peak rate of loss occurring between 1 and 2 p.m. Only 6 per cent of the loss occurs between 8 p.m. and 8 a.m., and the loss between midnight and sunrise is very low. The supply of heat energy available for vaporizing this water comes from the sun, and the insolation reaches a peak at noon and drops to zero at sunset; but there is some storage of heat in the ground and the overlying air, and therefore the cycle of transpiration lags behind the radiation cycle. Air temperature is an index of the heat energy available and, in Plate XXVIII-B, it is shown to have a good correlation with the rate of transpiration during the daylight hours. Both of the curves for the drop in stream flow have the same general shape as the rate of transpiration curve. The cross-hatched area between the two curves represents the loss of water suffered by the stream as it passed from the middle to the lower control.

The demand of transpiration first affects the water table underlying the soil in which the trees are rooted and, as the water table drops, water moves from the stream to replenish the draft. The maximum rate of drop in flow would be expected shortly after the time of maximum transpiration opportunity. The discharge curves shown in

PLATE XXVIII



A. DROP IN FLOW IN COLDWATER CANYON, AUGUST 11–12, 1931.

B. DAILY EVAPORATION-TRANSPIRATION CYCLE, ONTARIO WILLOW AND REED TANK, SEPTEMBER 11–12, 1930.

Plate XXVIII-A have the maximum rate of change in flow occurring shortly after noon; that is, there is a point of inflection on each discharge curve between 12 noon and 1 p.m. However, an elemental section of the stream passing the upper control at noon will not reach the lower control until approximately 3 p.m. It will lose water continuously as it passes down the channel to replenish the draft on the water table caused by transpiration. The maximum rate of loss should occur at approximately the same time at all points on the stream, but the effect of the time taken for each elemental section to move down the canyon is to displace the point of minimum flow to the right, as shown in the graph. For this reason, the loss in flow curve for the middle control, shown in Plate XXVIII-A, is moved to the right 45 minutes, the time taken for an elemental section of water to move from the middle to the lower control. The curve of difference in flows, which is a measure of the evaporation and transpiration between controls, rises rapidly to a peak shortly after noon and then, as the water table is recharged, it gradually falls and approaches zero before sunrise of the next day.

The position of the water table depends largely on the relation of the rate of use from the water table by the vegetation to the rate of recharge of the water table from the stream. The change in this relation is the chief reason for such fluctuations in the ground water as are shown on Plate XXVI, the water table reaching a maximum level in the morning and a minimum in the afternoon.

If the water table is completely recharged at the time of maximum stream flow early in the morning, and there is no transpiration or evaporation at that time, the total flow into the section must equal the total flow from the section. The total flow into the section is the total of the observed surface inflow and any underground inflow, as from hidden springs. The total flow from the section is the total observed surface outflow plus any underground seepage which leaves the section. If there is neither any underground inflow nor any underground seepage, it follows that in the stated case the observed inflow and the observed outflow must be equal.

As long as there is no inflow into a section between controls the water table is supplied only from the stream, and therefore the water table will never be higher than the water in the stream. From this it follows that the stream will never drain the water table and cannot gain in flow as it passes through a section where there is no underground inflow.

The daily maximum and minimum discharges at each of the controls for the days of record are given in Tables 35 and 36. An examination of these tables shows that during all the period of record in 1931 and during the periods in 1932 from June 25 to July 26 and from August 19 to November 3 the maximum daily discharge at the lower control never exceeded by any significant amount the combined discharges at the middle and branch controls. From this it follows that there could be no underground inflow between these controls during those periods, unless there was deep percolation as well.

It is possible that a combination of underground inflow and deep percolation might result in a daily difference of zero or thereabouts in maximum discharges at the controls, but the deep percolation, if it existed, would be approximately the same for different stages during

TABLE 35

DAILY MAXIMUM AND MINIMUM DISCHARGES AT MIDDLE AND LOWER CONTROLS IN COLDWATER CANYON

August 1 to October 17, 1931

Date, 1931	Maximum discharge, in second-feet		Minimum discharge, in second-feet		Date, 1931	Maximum discharge, in second-feet		Minimum discharge, in second-feet		Date, 1931	Maximum discharge, in second-feet		Minimum discharge, in second-feet	
	Middle control	Lower control	Middle control	Lower control		Middle control	Lower control	Middle control	Lower control		Middle control	Lower control	Middle control	Lower control
August 1	----	----	0.020	0.007	September 1	0.393	0.392	0.208	0.180	October 2	----	----	0.238	0.228
August 2	0.302	0.296	.011	.005	September 2	.389	.390	.206	.181	October 3	0.386	0.384	.218	.200
August 3	.299	.283	.123	.078	September 5	----	----	.196	.133	October 4	.375	.371	.211	.192
August 4	.346	.335	.015	.006	September 6	.388	.384	.159	.108	October 5	.372	.361	.212	.197
August 5	.331	.319	.040	.008	September 7	.377	.369	.149	.109	October 6	.376	.372	.244	.231
August 6	.333	.329	.015	.007	September 8	.378	.372	.189	.147	October 7	.403	.397	.342	.334
August 7	.319	.312	.012	.007	September 9	.380	.380	.181	.151	October 9	.462	.454	.437	.439
August 8	.309	.299	.009	.006	September 10	.381	.385	.209	.179	October 10	.467	.464	.366	.366
August 9	.320	.314	.023	.008	September 11	.368	.368	.150	.117	October 11	.448	.449	.319	.317
August 10	.332	.326	.047	.011	September 12	.355	.350	.135	.102	October 12	.417	.419	.260	.237
August 11	.351	.352	.070	.024	September 13	.343	.340	.122	.087	October 13	.389	.387	.233	.216
August 17	----	----	.020	.002	September 14	.359	.356	.266	.248	October 14	.382	.378	.237	.220
August 18	.335	.311	.014	.002	September 15	.404	.405	.251	.230	October 15	.373	.365	.242	.224
August 19	.320	.293	.012	.002	September 16	.380	.381	.166	.136	October 16	.373	.366	.233	.215
August 20	.297	.269	.010	.004	September 17	.361	.356	.159	.143	October 17	.384	.380	.271	.258
August 21	.303	.275	.010	.003	September 18	.349	.335	.146	.118					
August 22	.287	.256	.007	.003	September 19	.372	.359	.280	.266					
August 23	.268	.232	.006	.002	September 20	.356	.353	.163	.172					
August 24	.264	.229	.006	.003	September 25	.420	.420	.331	.334					
August 25	.255	.219	.005	.003	September 26	.384	.386	.210	.195					
August 26	.248	.210	.005	.003	September 27	.364	.363	.197	.181					
August 27	.257	.223	----	----	September 28	.351	.345	.171	.161					
August 29	.351	.352	.119	.085	September 29	.339	.344	.174	.165					
August 30	.371	.373	.106	.069	September 30	.313	.315	.148	.134					
August 31	.360	.360	.146	.099										

TABLE 36

DAILY MAXIMUM AND MINIMUM DISCHARGES AT EACH CONTROL IN COLDWATER CANYON

June 24, to November 3, 1932

Date	Maximum discharge in second-feet				Minimum discharge in second-feet			
	Upper control	Middle control	Lower control	Branch control	Upper control	Middle control	Lower control	Branch control
1932								
June 24	----------	----------	----------	----------	----------	0.394	0.335	0.010
June 25	----------	0.742	0.737	0.010	----------	.364	.316	.009
June 26	----------	.735	.726	.009	----------	.408	.360	.008
June 27	----------	.750	.733	.008	----------	.384	.331	.007
June 28	----------	.737	.719	.007	----------	.343	.283	.006
June 29	----------	.705	.681	.006	----------	.334	.262	.005
June 30	----------	.705	.680	.005	----------	.321	.255	.004
July 1	----------	.710	.689	.004	----------	.344	.285	.003
July 2	----------	.726	.713	.003	----------	.386	.336	.002
July 3	----------	.734	.724	.002	----------	.402	.356	.002
July 4	----------	.734	.727	.002	----------	.397	.353	.002
July 5	----------	.719	.710	.002	----------	.356	.308	.001
July 6	----------	.687	.673	.001	----------	.310	.256	.001
July 7	----------	.666	.648	.001	----------	.312	.252	.001
July 8	----------	.697	.677	.001	----------	.321	.260	.001
July 9	----------	.702	.680	.001	----------	.332	.272	.000
July 10	----------	.703	.682	No flow	----------	.337	.282	No flow
July 11	----------	.705	.687	No flow	----------	.337	.277	No flow
July 12	----------	.703	.683	No flow	----------	.402	.355	No flow
July 13	----------	.714	.699	No flow	----------	.368	.324	No flow
July 14	----------	.667	.653	No flow	----------	.290	.226	No flow
July 15	0.682	.655	.630	No flow	0.407	.259	.193	No flow
July 16	.682	.639	.614	No flow	.397	.245	.177	No flow
July 17	.651	.628	.600	No flaw	.395	.245	.176	No flow
July 18	.665	.648	.624	No flow	.434	.313	.255	No flow
July 19	.690	.660	.641	No flcw	.430	.314	.260	No flow
July 20	.653	.633	.612	No flow	.380	.240	.175	No flow
July 21	.641	.606	.578	No flow	.363	.211	.144	No flow
July 22	.626	.600	.571	No flow	.360	.196	.128	No flow
July 23	.615	.594	.562	No flow	.356	.193	.125	No flow
July 24	.621	.593	.557	No flow	.358	.198	.126	No flow
July 25	.615	.595	.559	No flow	.356	.188	.123	No flow
July 26	.615	.576	.557	No flow	.356	.199	.138	No flow
July 27	.626	.592	.575	No flow	.348	.197	.135	No flow
July 28	.607	.572	.557	No flow	.330	.172	.119	No flow
July 29	.616	.574	.561	No flow	.337	.171	.115	No flow
July 30	.615	.578	.568	No flow	.333	.173	.122	No flow
July 31	.612	.574	.554	No flow	.329	.166	.118	No flow
August 1	.608	.570	.549	No flow	.327	.171	.122	No flow
August 2	.603	.563	.559	No flow	.320	.160	.110	No flow
August 3	.586	.547	.540	No flow	.307	.142	.090	No flow
August 4	.577	.539	.536	No flow	.304	.135	.084	No flow
August 5	.578	.526	.528	No flow	.296	.123	.075	No flow
August 6	.572	.523	.519	No flow	.296	.128	.077	No flow
August 7	.568	.523	.522	No flow	.296	.140	.092	No flow
August 8	.570	.530	.528	No flow	.297	.139	.098	No flow
August 9	.576	.540	.543	No flow	.318	.172	.141	No flow
August 10	.603	.577	.591	No flow	.366	.240	.222	No flow
August 11	.618	.589	.601	No flow	.371	.237	.206	No flow
August 12	.615	.579	.586	No flow	.358	.226	.198	No flow
August 13	.603	.567	.573	No flow	.348	.221	.194	No flow
August 14	.596	.569	.580	No flow	.342	.218	.187	No flow
August 15	.591	.558	.567	No flow	.329	.194	.157	No flow
August 16	.589	.553	.556	No flow	.308	.156	.115	No flow
August 17	.559	.517	.513	No flow	.283	.121	.069	No flow
August 18	.539	.490	.479	No flow	.271	.099	.051	No flow
August 19	.528	.480	.452	No flow	.273	.107	.058	No flow
August 20	.528	.478	.453	No flow	.269	.104	.057	No flow
August 21	.527	.476	.449	No flow	.266	.102	.056	No flow
August 22	.516	.462	.433	No flow	.260	.088	.036	No flow
August 23	.507	.455	.426	No flow	.256	.081	.035	No flow
August 24	.503	.454	.424	No flow	.259	.080	.035	No flow
August 25	.503	.455	.426	No flow	.268	.080	.036	No flow
August 26	.514	.469	.440	No flow	.284	.136	.091	No flow
August 27	.551	.517	.495	No flow	.389	.284	.241	No flow
August 28	.593	.566	.553	No flow	.415	.316	.277	No flow
August 29	.605	.583	.569	No flow	.421	.324	.282	No flow
August 30	.626	.606	.593	No flow	.443	.358	.324	No flow
August 31	.579	.555	.548	No flow	----------	.193	.147	No flow

TABLE 36—Continued

DAILY MAXIMUM AND MINIMUM DISCHARGES AT EACH CONTROL IN COLDWATER CANYON

June 24, to November 3, 1932

Date	Maximum discharge in second-feet				Minimum discharge in second-feet			
	Upper control	Middle control	Lower control	Branch control	Upper control	Middle control	Lower control	Branch control
1932								
September 1	----------	.498	.476	No flow	----------	.130	.083	No flow
September 2	.522	.482	.462	No flow	.279	.121	.077	No flow
September 3	.523	.474	.451	No flow	.268	.110	.064	No flow
September 4	.506	.457	.431	No flow	.261	.089	.042	No flow
September 5	.490	.441	.412	No flow	.254	.076	.034	No flow
September 6	.480	.430	.417	No flow	.247	.073	.031	No flow
September 7	.451	.385	.364	No flow	.243	.069	.029	No flow
September 8	.446	.370	.320	No flow	.230	.052	.013	No flow
September 9	.438	.365	.322	No flow	.240	.074	.034	No flow
September 10	.458	.412	.384	No flow	.256	.113	.084	No flow
September 11	.470	.429	.411	No flow	----------	.097	.068	No flow
September 12	----------	.436	.408	No flow	----------	.098	.061	No flow
September 13	----------	.422	.394	No flow	----------	.093	.057	No flow
September 14	----------	.397	.373	No flow	----------	.103	.063	No flow
September 15	----------	.414	.386	No flow	.246	.086	.053	No flow
September 16	.468	.427	.413	No flow	.265	.098	.062	No flow
September 17	.453	.423	.409	No flow	.255	.110	.082	No flow
September 18	.477	.454	.440	No flow	.351	----------	.219	No flow
September 19	.544	----------	.526	No flow	.470	----------	.429	No flow
September 20	.555	----------	.542	No flow	.347	----------	.204	No flow
September 21	.520	----------	.492	No flow	.322	----------	.163	No flow
September 22	.509	----------	.459	No flow	.305	.164	.125	No flow
September 23	.500	.458	.437	No flow	.283	.131	.087	No flow
September 24	.485	.448	.428	No flow	.276	.118	.077	No flow
September 25	.481	.443	.424	No flow	.291	.142	.106	No flow
September 26	.503	.457	.439	No flow	.305	.181	.140	No flow
September 27	----------	.460	.444	No flow	----------	.166	.129	No flow
September 28	----------	.462	.458	No flow	----------	.244	.216	No flow
September 29	----------	.458	.451	No flow	----------	.183	.141	No flow
September 30	----------	.483	.467	No flow	----------	.263	.233	No flow
October 1	.510	.498	.486	No flow	.355	.244	.206	No flow
October 2	.526	.518	.509	No flow	.369	.295	.269	No flow
October 3	.523	.514	.502	No flow	.356	.265	.232	No flow
October 4	.510	.501	.486	No flow	.244	.135	.104	No flow
October 5	.416	.393	.363	No flow	.243	.111	.072	No flow
October 6	.452	.433	.405	No flow	.290	.174	.137	No flow
October 7	.527	.519	.502	No flow	.473	.465	.437	No flow
October 8	.570	.564	.548	No flow	.400	.346	.309	No flow
October 9	.646	.646	.631	No flow	.551	----------	----------	No flow
October 10	.624	.629	.618	No flow	.391	.291	.244	No flow
October 11	.535	.517	.493	No flow	.328	.208	.161	No flow
October 12	.509	.487	.460	No flow	.317	.216	.178	No flow
October 13	.504	.480	.462	No flow	.327	.237	.206	No flow
October 14	.490	.475	.453	No flow	.292	.195	.157	No flow
October 15	.457	.423	.385	No flow	.282	.160	.119	No flow
October 16	.463	.443	.418	No flow	.300	.197	.159	No flow
October 17	.514	.503	.487	No flow	.438	.405	.379	No flow
October 18	.530	.515	.499	No flow	.389	.311	.280	No flow
October 19	.505	.486	.467	No flow	.417	.346	.309	No flow
October 20	.514	.466	.447	No flow	.408	.330	.301	No flow
October 21	.506	.475	.462	No flow	.372	.292	.266	No flow
October 22	.523	.495	.487	No flow	.368	.286	.265	No flow
October 23	.524	.491	.488	No flow	.374	.295	.276	No flow
October 24	.510	.473	.465	No flow	.360	.251	.244	No flow
October 25	.466	.422	.414	No flow	.366	.284	.261	No flow
October 26	.466	.428	.414	No flow	.340	.267	.240	No flow
October 27	466	.428	.415	No flow	.335	.257	.227	No flow
October 28	.483	.459	.448	No flow	.354	.283	.255	No flow
October 29	.484	.465	.453	No flow	.372	.312	287	No flow
October 30	.494	.479	.470	No flow	.386	.334	.313	No flow
October 31	.493	.474	.460	No flow	.368	.298	.269	No flow
November 1	.488	.468	.458	No flow	.394	.345	.323	No flow
November 2	.522	.510	.504	No flow	.512	.505	.497	No flow
November 3	.553	.548	.548	No flow	----------	----------	----------	No flow

the periods of measurement, since the changes occurring in the head are very slight. Therefore, either the inflow and deep percolation would continue to be equal during the season, or else the inflow would fall off because of the drying of shallow springs. The former would not affect the results, and the latter would result in a constantly gaining difference in the discharges at the time of daily maximum flow which would not return to earlier values. An examination of Tables 35 and 36 shows that the latter case did not occur, and that no combination of deep percolation and inflow from shallow springs existed.

If deep percolation existed it would be the same approximately throughout the season, as has already been stated in the previous paragraph. It is not conceivable that it would change from day to day, since the temperature of the underflow does not vary appreciably. Hence, if percolation did exist, it would prohibit the values of daily differences in maximum discharges at the controls from ever reaching a zero value. This is not the case, as a zero value was reached several times in 1931, and in 1932 a value of 0.004 was reached on September 28, 0.003 on October 23, and zero on November 3. Hence, no deep percolation could exist by itself.

In case evaporation and transpiration are occurring at a time of daily maximum discharges, the flow from the section will be less than the flow into the section and the difference in maximum discharges will have a positive value. The same effect also will be caused by the water table's not being completely recharged from the stream by a time of daily maximum discharges. It takes time for this recharge to take place, and if the use by the vegetation has been high in the previous day the water table will not be completely recharged during the night. These two cases, either separately or together, account for the large number of days when there was a greater maximum discharge at the middle control than at the lower control, as shown in Tables 35 and 36. This difference in daily maximum discharges reached high values of 0.038 second-foot on August 26, 1931, after an excessively hot period, and 0.050 second-foot on September 8, 1932, after a hot night during which a hot wind was blowing down the canyon.

The growing seasons of 1931 and 1932 differed materially. During 1931 there were several summer rains accompanied by cloudy weather at about the time of the rains. These conditions caused the use by the vegetation to be less, on the average, this result being due not only to the cloudy weather's preventing as much sunshine from reaching the vegetation as would otherwise have occurred, but also to the fact that the rain itself reduced use from the water table by the vegetation. During 1932, no summer rains occurred and a greater amount of sunshine reached the vegetation, these conditions being more favorable to a large use from the water table, which in turn is fed by the stream.

An examination of Tables 35 and 36 shows that the values in these tables during the two seasons reflect the different conditions of the two seasons. In 1931 only a few days show any appreciably larger daily maximum discharges at the middle control than at the lower control, while in 1932 a great many of the days show daily maximum discharges which are appreciably larger at the middle control than at the lower control, because of the continued high use by the vegetation.

Also, the seasonal rainfall prior to the two growing seasons differed. The rainfall for the year prior to the 1931 season was 15.31 inches at San Bernardino and 28.98 inches at Alpine. For the year prior to the 1932 season it was 21.96 inches at San Bernardino and 55.83 inches at Alpine. The increase in rainfall varies from over 40 per cent during the second year at San Bernardino to over 90 per cent at Alpine. The Coldwater Canyon watershed lies between the two, but closer to Alpine and the average rainfall over the watershed was perhaps 70 per cent greater in the 1931–32 rainy season than it was in 1930–31.

As a result of the greater rainfall in the 1931–32 season, the stream flow was sustained at a much greater volume in 1932 than in 1931. The flow during the spring months was beyond the capacity of the flumes installed and it was not deemed advisable to make the large additional outlay necessary to measure the larger flows accurately. For this reason and also because of possible complications resulting from side inflow, records were not started in 1932 until June 24. Inflow from the east branch was measured from June 24 to July 9 at the branch control, which was on bedrock, but no more water passed the control after that date. A survey of the main canyon at that time showed no surface indications of springs between the middle and lower controls.

However, during the period from July 26 to August 19, 1932, there is evidence that there was some underground inflow between the middle and lower controls. That this was the case during a part of this period is shown by the greater daily maximum discharges at the lower control than at the middle control for some of the dates for the period, as shown in Table 36.

To evaluate this underground inflow during the period between July 26 and August 19, 1932, the differences in daily maximum discharges at the controls in question were compared with the maximum temperature recorded at San Bernardino on the preceding day, using all values during 1932 except the period in question. This showed that the amount of water charged to side inflow increased slowly and uniformly until about August 11, after which it dropped off quite rapidly. The daily loss between the middle and lower controls was corrected accordingly from July 26 to August 19. On nine days during this period, the side inflow was sufficient to make the daily maximum discharges slightly higher at the lower control than at the middle control. However, the measured flow at the lower control was never at any time as great as the flow at the upper control.

In 1931 the lowest daily maximum discharge at the lower control was 0.210 second-foot on August 26, and the absolute minimum flow was 0.002 second-foot during several days in August. In the following year the lowest daily maximum discharge at the same control was but 0.320 second-foot on September 8, and the absolute minimum flow was but 0.013 on the same date. On October 17, 1931, the last date on which measurements were taken in that season, the daily maximum discharge at the lower control was 0.380 second-foot with a daily minimum discharge of 0.258 second-foot, while on the same date a year later the daily maximum discharge had recovered to 0.487 second-foot with a daily minimum discharge of 0.379 second-foot.

In the preceding paragraphs the effect of the various factors affecting the measurement of the evaporation and transpiration from the canyon bottom on the section between the lower control and the middle and branch controls has been discussed. The same factors and conditions have a similar effect on the section between the middle control and the upper control.

An examination of Table 36 shows that the daily maximum discharge at the middle control never exceeded the daily maximum discharge at the upper control, except on October 10, when it was due to rain causing surface run-off between the controls. Hence there is no inflow unless there is also deep percolation. Deep percolation is eliminated as a possibility, except for the remote chance that the inflow and outflow would balance, by the occurrence of equal daily maximum discharges at the two controls on the cloudy morning of October 9.

The daily losses between the middle and branch controls and the lower control are given for 1931 in Table 37 and for 1932 in Table 38 and between the upper control and middle control for the 1932 season in Table 39.

TABLE 37

DAILY LOSS OF WATER FROM THE STREAM BETWEEN MIDDLE AND LOWER CONTROLS IN COLDWATER CANYON

August 1, to October 17, 1931

Date	Loss in acre-inches	Date	Loss in acre-inches	Date	Loss in acre-inches
1931		1931		1931	
Aug. 1	*0.55	Sept. 1	0.33	Oct. 2	0.22
Aug. 2	.76	Sept. 2	*.23	Oct. 3	.31
Aug. 3	.60	Sept. 6	.74	Oct. 4	.42
Aug. 4	.78	Sept. 7	.62	Oct. 5	.39
Aug. 5	.76	Sept. 8	.49	Oct. 6	.34
Aug. 6	.57	Spet. 9	.40	Oct. 7	*.19
Aug. 7	.65	Sept. 10	.37	Oct. 9	.01
Aug. 8	.73	Sept. 11	.55	Oct. 10	.08
Aug. 9	.66	Sept. 12	.57	Oct. 11	.02
Aug. 10	.56	Sept. 13	.63	Oct. 12	.15
Aug. 11	.49	Sept. 14	.22	Oct. 13	.31
Aug. 17	*.87	Sept. 15	.27	Oct. 14	.30
Aug. 18	.97	Sept. 16	.47	Oct. 15	.35
Aug. 19	.87	Sept. 17	.42	Oct. 16	.34
Aug. 20	.93	Sept. 18	.65	Oct. 17	*.17
Aug. 21	.88	Sept. 19	.25		
Aug. 22	.91	Sept. 26	.29		
Aug. 23	1.04	Sept. 27	.32		
Aug. 24	.99	Sept. 28	.25		
Aug. 25	.96	Sept. 29	.08		
Aug. 26	1.00	Sept. 30	*.20		
Aug. 29	.38				
Aug. 30	.47				
Aug. 31	.56				
Average per day (for complete days)	.75		.42		.25
Average per day per 1,000 feet of canyon	.36		.20		.12

*Portion of day only.

TABLE 38

DAILY LOSS OF WATER FROM THE STREAM BETWEEN MIDDLE AND BRANCH CONTROLS AND LOWER CONTROL IN COLDWATER CANYON

June 25, to November 2, 1932

Day of month	Loss in acre-inches					
	June	July	August	September	October	November
1	----	0.85	1.10	1.07	0.64	0.40
2	----	.75	1.11	.97	.48	.12
3	----	.66	1.15	.95	.60	----
4	----	.64	1.21	1.12	.70	----
5	----	.68	1.20	1.01	1.00	----
6	----	1.07	1.27	1.03	.76	----
7	----	.83	1.22	1.28	.51	----
8	----	1.02	1.19	1.44	.64	----
9	----	.96	.92	1.19	----	----
10	----	.92	.76	.91	.92	----
11	----	.96	.91	.86	.96	----
12	----	.83	1.01	1.01	.82	----
13	----	.61	.92	.97	.58	----
14	----	.94	.86	1.01	.85	----
15	----	1.05	.95	.95	1.01	----
16	----	1.09	1.08	.78	.76	----
17	----	1.15	1.31	.61	.44	----
18	----	.98	1.38	----	.58	----
19	----	.91	1.41	----	.69	----
20	----	1.05	1.29	----	.54	----
21	----	1.16	1.25	----	.45	----
22	----	1.17	1.28	.83	.33	----
23	----	1.33	1.15	.94	.29	----
24	----	1.32	1.18	.94	.31	----
25	0.70	1.26	1.15	.81	.44	----
26	.72	1.20	.99	.68	.54	----
27	.76	1.07	.71	.58	.58	----
28	.82	.91	.60	.42	.48	----
29	1.04	1.04	.58	.83	.42	----
30	.95	1.04	.50	.54	.43	----
31	----	1.07	.69	----	.52	----
Average per day	.83	.98	1.04	.91	.61	----
Average per day per 1,000 feet of canyon	.40	.47	.50	.44	.29	----

During the 54 days of full record in August, September, and October, 1931, that is, during the latter half of the growing season, the average loss from the stream between middle and lower controls per 1000 feet of canyon per day was 0.25 acre-inch.

For the 1932 season the record begins earlier, and during 124 days of record in June, July, August, September, and October the average loss from the stream between middle and lower controls per 1000 feet of canyon per day was 0.42 acre-inch.

The record for 1932 is more complete and it was not interrupted by rainy periods such as occurred in 1931. A graph of the use of water in acre-inches between the middle and lower controls in 1932 is shown on Plate XXIX. The measured daily use between controls is shown, and through these points a smooth average curve has been drawn. Ordinates to this smooth curve give the average daily use between the middle and lower controls in acre-inches during any part of the season, and the area between this curve and the baseline for any period of time represents to scale the total use during that period.

TABLE 39

DAILY LOSS OF WATER FROM THE STREAM BETWEEN THE UPPER AND MIDDLE CONTROLS IN COLDWATER CANYON

July 15, to November 2, 1932

Day of month	Loss in acre-inches				
	July	August	September	October	November
1		2.04		0.98	0.73
2		2.12	2.08	.60	.16
3		2.23	2.28	.75	
4		2.25	2.43	1.65	
5		2.53	2.50	1.91	
6		2.36	2.52	1.64	
7		2.23	2.73	.14	
8		2.13	2.81	.47	
9		2.09	2.54		
10		1.53	1.88	.89	
11		1.76		1.53	
12		1.79		1.38	
13		1.62		1.14	
14		1.66		1.36	
15	1.90	1.70		1.71	
16	1.80	2.11	1.99	1.64	
17	1.93	2.29	1.89	.95	
18	1.41	2.55		1.00	
19	1.00	2.32		1.22	
20	1.74	2.40		1.30	
21	1.96	2.43		1.36	
22	2.11	2.51	1.70	1.30	
23	1.96	2.67	1.97	1.31	
24	1.77	2.54	2.12	1.58	
25	2.05	2.67	1.96	1.38	
26	2.10	2.15		1.44	
27	1.96	1.47		1.30	
28	2.05	1.11		1.03	
29	2.24	1.38		.88	
30	2.18	.75		.77	
31	2.29			1.02	
Average per day	1.91	2.05	2.23	1.19	
Average per day per 1,000 feet of canyon	.33	.35	.38	.20	

The total use of water between the middle and lower controls for the six months, May to October, 1932, is indicated as 72 acre-inches per 1000 feet of canyon or 64 acre-inches per acre of canyon bottom.

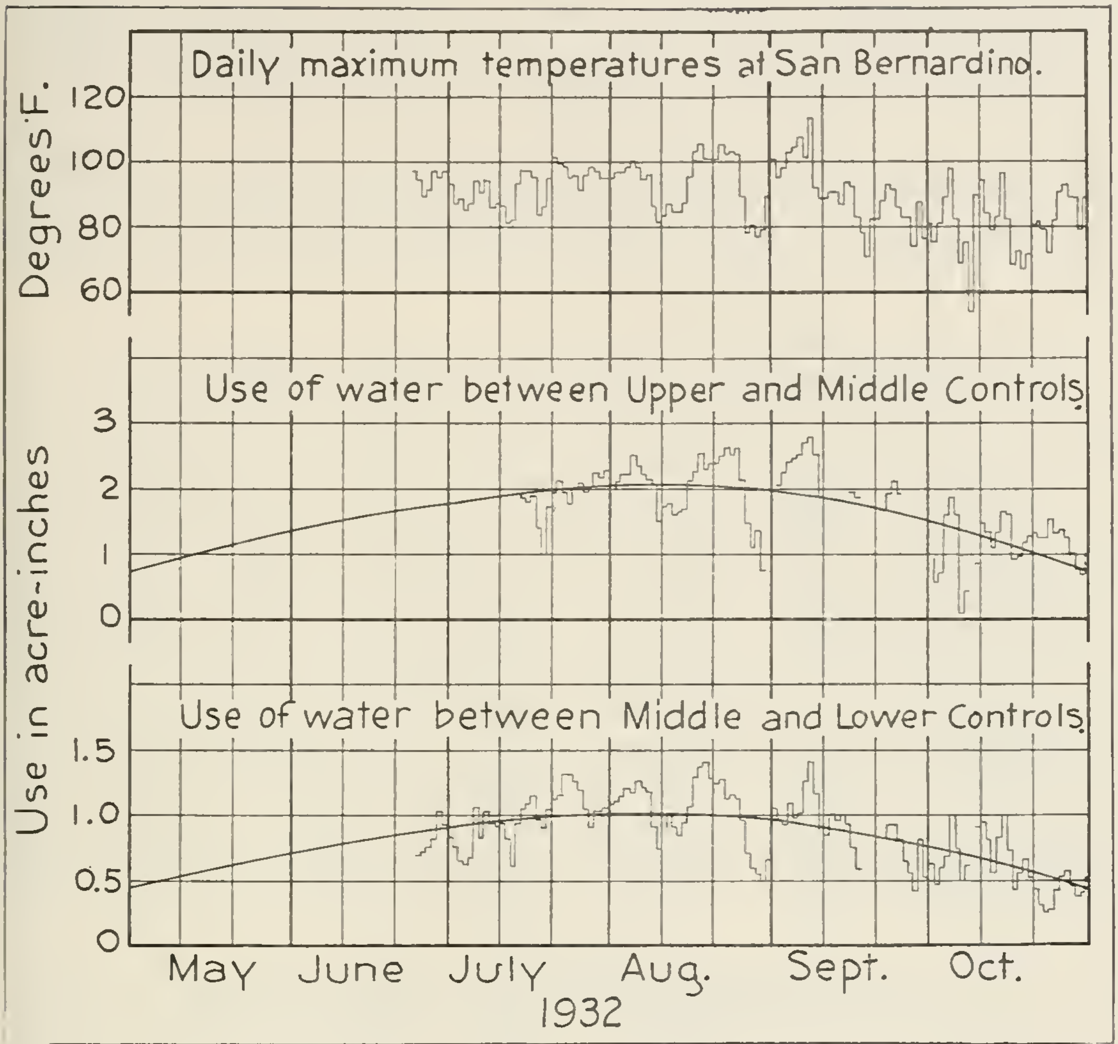
During 1931, the greatest daily loss from the stream between middle and lower controls was 0.50 acre-inch per 1000 feet of canyon on August 23, and during 1932 it was 0.69 acre-inch per 1000 feet of canyon on September 8. In the latter case the loss is equal to 0.61 acre-inch per acre, the maximum daily loss for both seasons.

During August, 1932, the average daily loss from the stream between middle and lower controls per 1000 feet of canyon per day was equivalent to 1.05 southern California miner's inches, continuous flow.

During the 92 days of record during July, August, September, and October of the 1932 season the average daily loss from the stream between the upper and middle controls was 1.77 acre-inches per day, or 0.30 acre-inch per day for each 1000 feet of canyon between the controls. As the area between these controls is 5.89 acres, the loss per day per acre was 0.30 acre-inch.

A graph of daily use of water for this section, similar to the graph for the lower section of the canyon, is also shown on Plate XXIX. The area below the average curve in this graph indicates the total use

PLATE XXIX



USE OF WATER BETWEEN CONTROLS IN COLDWATER CANYON AND DAILY MAXIMUM TEMPERATURES AT SAN BERNARDINO DURING 1932.

of water between the upper and middle controls for the months May to October, inclusive. This use is indicated to be 50 acre-inches per 1000 feet of canyon and, since the canyon bottom area averages one acre for each 1000 feet of canyon, the use of water in the canyon bottom is 50 acre-inches per acre.

During August, 1932, the average daily loss from the stream between the upper and middle controls per 1000 feet of canyon was equivalent to 0.74 southern California miner's inch, continuous flow.

From the graphs on Plate XXIX, a comparison by months can be made of the losses in the two sections of canyon. The average rate of use of water per 1000 feet of canyon between the middle and lower controls was 0.47 acre-inch per day during July, 0.49 acre-inch per day during August, 0.42 acre-inch per day during September, and 0.30 acre-inch per day during October in 1932. Between the upper and middle controls, the average rate of use of water per 1000 feet of canyon was 0.33 acre-inch per day during July, 0.35 acre-inch per day during August, 0.30 acre-inch per day during September, and 0.20 acre-inch per day during October.

The average rate of use of water per acre of canyon bottom fill between the middle and lower controls in 1932 was 0.42 acre-inch per day during July, 0.44 acre-inch per day during August, 0.37 acre-inch per day during September, and 0.26 acre-inch per day during October. Between the upper and middle controls, the average rate of use of water per acre of canyon bottom fill was 0.33 acre-inch per day during July, 0.35 acre-inch per day during August, 0.30 acre-inch per day during September, and 0.20 acre-inch per day during October. In the upper section, each 1000 feet of canyon has one acre of canyon bottom fill.

Loss from Stream Above the Highest Control

The highest control on the stream during the 1931 season was the control which later was called the middle control. During the 1932 season the upper control was the highest control on the stream.

The losses indicated by the daily cycle in the discharge curves at the middle control in the 1931 season and at the upper control in the 1932 season were evaluated in the following manner. The actual volume passing the control was subtracted from that volume which would have passed the control had a sustained flow occurred throughout the day equal to the average of the maximum flow on the day considered and the maximum of the next succeeding day. This value does not represent all of the loss by evaporation and transpiration occurring in the canyon bottoms above the control. It may, however, be considered as a fair approximation of the loss that might be reclaimed most readily by carrying the water down the main canyon in pipes. Table 40 shows the amount of water during the days of record in 1931 that

TABLE 40

DAILY LOSS OF WATER FROM THE STREAM INDICATED BY DIPS IN DISCHARGE CURVE AT MIDDLE CONTROL IN COLDWATER CANYON

August 1, to October 17, 1931

Date	Loss above middle control in acre-inches	Date	Loss above middle control in acre-inches	Date	Loss above middle control in acre-inches
1931		1931		1931	
Aug. 1	*2.02	Sept. 1	1.54	Oct. 2	1.70
Aug. 2	3.35	Sept. 2	*1.64	Oct. 3	1.68
Aug. 3	1.78	Sept. 5	*1.81	Oct. 4	1.81
Aug. 4	3.33	Sept. 6	2.34	Oct. 5	1.82
Aug. 5	2.89	Sept. 7	2.37	Oct. 6	1.42
Aug. 6	3.21	Sept. 8	1.93	Oct. 7	.66
Aug. 7	3.27	Sept. 9	2.05	Oct. 9	.27
Aug. 8	3.29	Sept. 10	1.64	Oct. 10	.98
Aug. 9	3.00	Sept. 11	2.24	Oct. 11	1.24
Aug. 10	2.88	Sept. 12	2.19	Oct. 12	1.52
Aug. 11	2.69	Sept. 13	2.44	Oct. 13	1.53
Aug. 17	*2.47	Sept. 14	1.01	Oct. 14	1.45
Aug. 18	3.25	Sept. 15	1.32	Oct. 15	1.30
Aug. 19	3.19	Sept. 16	2.06	Oct. 16	1.48
Aug. 20	2.98	Sept. 17	1.89	Oct. 17	*1.01
Aug. 21	3.25	Sept. 18	2.22		
Aug. 22	3.18	Sept. 19	.62		
Aug. 23	3.15	Sept. 26	1.72		
Aug. 24	3.04	Sept. 27	1.65		
Aug. 25	3.19	Sept. 28	1.74		
Aug. 26	2.98	Sept. 29	1.57		
Aug. 29	1.40	Sept. 30	*1.70		
Aug. 30	2.54				
Aug. 31	2.27				
Average per day (for full days)	2.91		1.82		1.35

*Portion of day only.

might be reclaimed above the middle control, if the water from the larger springs were carried in pipes and the stream bed kept dry. Table 41 similarly shows the amount of water during the days of record in 1932 that might be reclaimed above the upper control, if the

TABLE 41

DAILY LOSS OF WATER FROM THE STREAM INDICATED BY DIPS IN DISCHARGE CURVE AT UPPER CONTROL IN COLDWATER CANYON

July 15, to November 2, 1932

Day of month	Loss in acre-inches				
	July	August	September	October	November
1	----------	2.85	----------	1.57	1.03
2	----------	2.81	2.50	1.48	.13
3	----------	2.81	2.57	1.56	----------
4	----------	2.88	2.55	2.48	----------
5	----------	2.84	2.42	1.76	----------
6	----------	2.71	2.29	2.04	----------
7	----------	2.68	2.10	.32	----------
8	----------	2.74	2.34	1.50	----------
9	----------	2.62	2.12	.02	----------
10	----------	2.30	1.95	1.45	----------
11	----------	2.35	----------	2.05	----------
12	----------	2.40	----------	1.81	----------
13	----------	2.46	----------	1.70	----------
14	----------	2.44	----------	1.66	----------
15	2.84	2.59	----------	1.79	----------
16	2.79	2.69	1.93	1.86	----------
17	2.64	2.78	2.38	.74	----------
18	2.29	2.71	1.28	1.30	----------
19	2.32	2.55	.48	1.11	----------
20	2.72	2.62	1.85	1.11	----------
21	2.72	2.60	1.97	1.33	----------
22	2.62	2.65	2.10	1.46	----------
23	2.62	2.59	2.24	1.34	----------
24	2.62	2.50	2.20	1.50	----------
25	2.58	2.66	2.08	1.02	----------
26	2.69	2.39	----------	1.19	----------
27	2.86	1.42	----------	1.33	----------
28	2.92	1.54	----------	1.30	----------
29	2.88	1.74	----------	1.06	----------
30	2.83	1.25	----------	1.04	----------
31	2.80	----------	----------	1.20	----------
Average per day	2.69	2.47	2.07	1.39	----------

water from the larger springs were carried in pipes and the stream bed kept dry. There are, however, many small springs in branch canyons or on hillsides from which the water seeps slowly through a mantle of soil toward the main canyon. When there is little or no evaporation and transpiration, water from these small springs reaches the main canyon and contributes to the flow in the main channel, but on warm days the water from these small springs may not reach the main canyon at all, as it may be intercepted and used to meet the transpiration needs of the vegetation which has roots in the soil through or over which the water must pass. During periods of increased transpiration, more and more of these small springs are cut off from the main canyon and the maximum flow measured at a control on the main canyon becomes less each succeeding day. When the days are cloudy and cool, transpiration is decreased and the soil reservoirs that have intercepted these flows become filled and water from the smaller springs again reaches the main canyon. Then the maximum flow in the main canyon increases from day to day. This is a factor that operates to cause a seasonal drop in the discharge to a low point in August and a recovery during September and October before any rain of importance has occurred.

October 9, 10, 11, 1931, were cool cloudy days and the transpiration loss was very low and the maximum daily flow increased to 0.46 second-foot at the middle control. In contrast to this, August 24, 25, and 26, in the same year, were three days at the end of a long period of hot weather, and on the mornings of August 25, 26, and 27 the maximum flow was only 0.25 second-foot at the middle control. The difference between 0.46 second-foot and 0.25 second-foot, or 0.21 second-foot, represents a loss of water originating in these small springs, but this flow was entirely intercepted so that none of the water represented by this value of 0.21 second-foot reached the middle control at any time on August 24, 25, and 26. A flow of 0.21 second-foot is equivalent to 5.0 acre-inches per day. This is a loss that might be reclaimed if each spring were sought out and developed at its source. The draft on the connected flow measurable by the dip in the discharge curve at the middle control on August 24, 25, and 26 is given in Table 40 and averages 3.1 acre-inches per day. The loss between the middle and lower controls on those three days averaged 1.0 acre-inch per day. This makes a total of 9.1 acre-inches per day, for the average loss per day on August 24, 25, and 26 in 1931, and is chargeable to evaporation and transpiration between the springs, where the water first comes to the surface, and the lower control.

The source of the summer flow is within an area of 0.2 square mile between elevations of 3100 and 4250 feet in the stream bed. The drainage area back of the stream bed elevation of 3100 feet is 1.3 square miles and the elevation of the divide ranges from 5200 to 5800 feet. The seasonal precipitation recorded at Alpine at an elevation of 5750 feet was 53.66 inches in 1931–32, yet the first steady spring flow in Coldwater Canyon is below an elevation of 4250 feet.

The flow at the lower control was never as great as that measured at the upper control during the period of measurement from July 15 to November 3, 1932. The significance of this fact is that there was no effective yield of water as summer flow from the portion of the watershed tributary to the stream below the upper control, which portion is 62 per cent of the watershed area above the lower control. Since there was no gradual gain in flow as the stream passed through the 7965 feet of canyon between the upper and lower controls, it indicates that practically all the moisture from rainfall that might have been slowly moving downhill through the soil mantle over this lower portion of the watershed was intercepted by the vegetation before it reached the canyon bottom.

COMPARISON OF USE BETWEEN CONTROLS WITH METEOROLOGICAL DATA

During the 1932 season records were obtained from an air thermograph, maximum and minimum thermometers, and an atmometer located near the mouth of the canyon, and also from an atmometer located near the lower control in the canyon.

Monthly mean maximum and minimum temperatures are shown in Table 42 for the months of record in 1932 at the mouth of the canyon.

TABLE 42

MONTHLY MEAN MAXIMUM AND MINIMUM TEMPERATURES AT THE MOUTH OF COLDWATER CANYON, AT ALPINE, AND AT SAN BERNARDINO

June to October, 1931 and 1932

Month	Temperature in degrees Fahrenheit									
	Alpine, United States Weather Bureau, Squirrel Inn Station, elevation, 5,750 feet				San Bernardino, United States Weather Bureau Station, elevation 1,150 feet				Arrowhead Springs near mouth of Coldwater Canyon, elevation 2,000 feet	
	1931	1931	1932	1932	1931	1931	1932	1932	1932	1932
	Mean maximum	Mean minimum	Mean maximum	Mean minimum	Mean maximum	Mean minimum	Mean maximum	Mean minimum	Mean maximum	Mean minimum
June	71.5	46.5	74.5	42.3	90.5	55.4	86.0	48.4	--------	--------
July	85.1	62.6	80.6	51.1	103.2	65.0	92.9	52.0	--------	--------
August	79.2	60.8	81.1	53.6	100.0	63.0	93.7	51.9	94.5	61.4
September	74.8	47.6	83.4	53.7	92.3	54.1	91.2	48.7	92.9	60.5
October	71.9	39.4	66.9	41.5	83.3	50.0	82.0	43.7	79.9	56.8
Average June to October	76.5	51.4	77.3	48.4	93.9	57.5	89.2	48.9	--------	--------

TABLE 43

LOSS OF WATER FROM ATMOMETERS AT COLDWATER CANYON

July 18, to October 24, 1932

Period	Loss in cubic centimeters from atmometer "A" with full exposure located near mouth of canyon	Loss in cubic centimeters from atmometer "B" under trees in canyon bottom near lower control	Ratio B/A
July 18-Aug. 1	1,077	962	0.89
Aug. 1-Sept. 1	2,274	1,767	.78
Sept. 1-Oct. 1	1,898	1,588	.84
Oct. 1-Oct. 24	1,382	1,013	.73
July 18-Oct. 24	6,631	5,330	.80

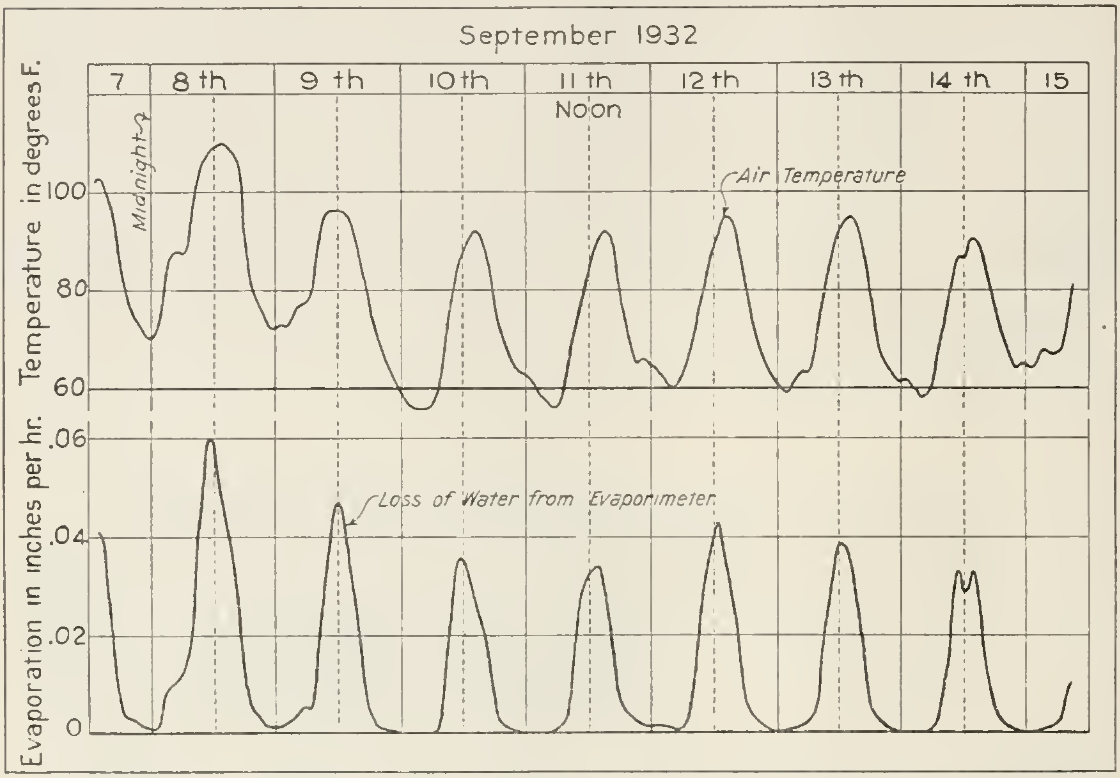
Values are also given in Table 42 of the monthly mean maximum and minimum temperatures at the Squirrel Inn and San Bernardino Weather Bureau stations for June to October, inclusive, during 1931 and 1932.

Table 43 gives the use from each of the atmometers during the periods between readings from July 18 to October 24, 1932.

For the period from September 7 to 15, 1932, a more intensive study was made of the meteorological data at Coldwater Canyon. An evaporimeter (described in detail on page 97). a hygro-thermograph, and a second atmometer were placed near the mouth of the canyon in addition to the maximum and minimum thermometers, rain gage, and atmometer already there. Two thermographs, one to record the air temperature and the other to record the temperature of the stream, and an additional atmometer were placed near the lower control in the canyon. There were also installed at the same location an evaporation pan sunk in the stream channel and completely surrounded by the stream, and a recorder on a ground water pit about 10 feet away from the stream.

Readings were taken at all installations throughout this period each day near sunrise, near sunset, and at various other times. Relative humidity was determined with a sling-psychrometer near the mouth of the canyon and at various locations in the canyon. The maximum and minimum discharges at the middle and the lower controls also were carefully checked each morning and evening.

PLATE XXX



COMPARISON OF LOSS OF WATER FROM EVAPORIMETER AND AIR TEMPERATURE NEAR MOUTH OF COLDWATER CANYON, SEPTEMBER 7–15, 1932.

Plate XXX shows the comparison, during the period, of the air temperature near the mouth of the canyon with the evaporation from the evaporimeter at the same location. Note that insolation is the primary causative factor controlling the loss from the evaporimeter, since it is very nearly in phase with the radiant energy cycle and reaches a maximum each day just about noon. The air temperature lags behind and does not reach a maximum generally until around 2 p.m.

The daily evaporation from the evaporimeter compared with the daily loss from the atmometers, both in the canyon and at the mouth of the canyon, is given in Table 44 together with the daily loss between the middle and the lower controls.

The record of the fluctuations during this period in the ground water pit has already been referred to and is shown on Plate XXVI. The evaporation from the evaporation pan also has been discussed and the daily values given in Table 33.

TABLE 44

COMPARISON OF LOSS OF WATER FROM ATMOMETERS, EVAPORIMETER, AND LOSS OF WATER BETWEEN MIDDLE AND LOWER CONTROLS

September 8-14, 1932

Date	Loss in cubic centimeters from atmometer near mouth of canyon	Loss in cubic centimeters from atmometer in canyon	Loss in inches from evaporimeter near mouth of canyon	Loss in acre-inches from stream between middle and lower controls	Per cent of average loss for the week		
					Atmometer near mouth of canyon	Evaporimeter near mouth of canyon	Loss from stream between middle and lower controls
1932							
September 8	129	....	0.50	1.44	190	160	136
September 9	70	68	.34	1.19	103	109	113
September 10	45	42	.25	.91	66	80	86
September 11	54	54	.28	.86	79	89	81
September 12	65	54	.30	1.01	96	96	96
September 13	61	45	.28	.97	90	89	92
September 14	52	44	.24	1.01	76	77	96
Average	68	....	.31	1.06	100	100	100

The daily maximum and minimum temperatures of the water, both in the stream and in the evaporation pan sunk in the stream, and the daily maximum and minimum air temperatures in the canyon are given in Table 34.

YIELD OF WATER FROM DRAINED SLOPES ON ARROWHEAD MOUNTAIN

During the last mile of its course, Coldwater Creek skirts the east slope of Arrowhead Mountain, which may be identified in Plate XIX by the natural outline of an arrowhead on the southwest face of the mountain. The cutting of the main canyon has proceeded more rapidly than that of the side canyons so that the side canyons drop off on a very steep grade as they enter the main channel. This has left excellent bedrock exposures at the lower ends of many of the side canyons and there was therefore an opportunity to observe the yield of water from the drained slope above these bedrock exposures.

Plate XXXI is a view of the east slope of Arrowhead Mountain taken from a point across Coldwater Canyon on the divide between that canyon and Strawberry Canyon. The elevation of the trail shown at the bottom of the view is approximately 2300 feet and of the mountain peak 3510 feet.

Seasonal rainfall records for 1931–32 to February 19 are given in Table 45. On February 19, 1932, each side canyon was explored for evidence of water flowing in its bed. No evidence of any yield of water was found in any of the canyons to the left of the point marked A in Plate XXXI. To the right of the point marked A, every channel had flowing water in it. It may be noted from Plate XXXI that there is a marked change in the density of the vegetation to the right of the line marked A-B. To the right of this line, the vegetation is less dense and there are more rock outcrops than to the left of the line. The elevation of the point marked B is approximately

TABLE 45

PRECIPITATION 1931-32 SEASON

Station	Distance from Arrowhead Mt.	Elevation above sea level	Total rain July 1, 1931, to Feb. 19, 1932
	Miles	Feet	Inches
San Bernardino (U. S. Weather Bureau)	6.5	1,150	20.87
Newmark Reservoir (San Bernardino Water Dept.)	3.5	1,400	24.30
Devil Canyon Gate (San Bernardino Water Dept.)	4.5	1,850	28.47
Devil Canyon Nursery (U. S. Forest Service)	4.5	2,700	32.76
Alpine (U. S. Weather Bureau Squirrel Inn Station)	3.0	5,750	53.66
Arrowhead Springs Hotel	0.5	2,000	[1]24.39

[1] No record prior to October 18, 1931.

3000 feet. Probably more rainfall was received at the higher elevations and water percolating downward from the higher areas found its way into the channels in which the flow was observed. There was no further rain of importance after February 19 and three weeks later all of the channels had dried up and there was no more flow in them during the season of 1931–32.

It therefore appears that the soil mantle on the slopes to the left of the line A-B had sufficient capacity to intercept and hold all of the rain that fell during the 1931–32 season. This amounted to at least 24.39 inches as recorded at Arrowhead Springs Hotel, and in the 19-day period from February 1 to February 19, 11.55 inches fell. It may appear rather astonishing that this large amount of rain coming within a period of 19 days at the end of the 1931–32 rainy season, was held without storm run-off by the soil mantle to the left of the line

PLATE XXXI

EAST SLOPE OF ARROWHEAD MOUNTAIN DRAINING INTO COLDWATER CANYON.

A-B. However, the underlying rock is granite and it has apparently been weathered to considerable depth. The rock was found to be weathered and seamed to depths of 30 feet and more in the road cuts along the new Arrowhead high-gear road opposite the entrance to Arrowhead Springs one mile west of the area. Roots of chamise were found in seams along the faces of the road cuts as deep as 29 feet below the top of the cut.

The capacity of the soil mantle to hold moisture on the slope of a mountain depends, among other things, on the soil depth. If the average thickness of the soil mantle on a 45-degree slope were 2 feet, the equivalent depth for the same volume of soil on a horizontal plane would be 2.8 feet. Rainfall is measured by the amount falling on a horizontal plane and if equivalent depth of the soil mantle on the same plane be considered, it is apparent that the capacity for the storage of water from rainfall as soil moisture on a slope is relatively large. Water from rainfall in its movement downhill after penetrating to bedrock may be intercepted and held in the pockets of deeper soil that lie in the depressions through which the water moves in its progress towards lower elevations. In the canyon bottom, though the rate of loss is high, the area of the canyon bottom fill is but a small portion of the watershed and the actual loss by evaporation and transpiration from the canyon bottom vegetation is less than 2 per cent of the seasonal precipitation falling on the watershed. The larger portion of the precipitation must be accounted for on the drained slopes.

Most of the steady spring flow that feeds Coldwater Creek comes from the higher reaches of the canyon above an elevation of 3500 feet where the seasonal precipitation is high. The source of all of the steady summer flow was found to come from within an area of 0.2 square mile between elevations of 3100 and 4250 feet in the stream bed. The area contributing to the surface drainage back of the stream bed elevation of 3100 feet is 1.3 square miles and the elevation of the divide ranges from 5200 to 5800 feet. The first steady stream flow in Coldwater Canyon is found at an elevation of 4250 feet, yet a precipitation of 53.66 inches was recorded at Alpine during the 1931–32 season. Alpine is at an elevation of 5750 feet. There is a considerable area over the divide that lies above an elevation of 4250 feet from which the surface drainage waters flow northward. The close proximity of the larger springs to this area of high elevation that receives a relatively large amount of precipitation suggests that a considerable amount of deep seepage must be occurring over this upland area. The results of this investigation point to deep seepage from these upland areas above an elevation of about 3500 feet as the source of most of the summer flow. A more complete study should be made of this problem by tracing the source of all of the summer flow coming from all of the drainage systems radiating from Strawberry Peak.

CHAPTER V

EVAPORATION FROM FREE WATER SURFACES*

In any study of water supply a knowledge of unavoidable losses occurring in transmission and storage is important, and in this connection evaporation from free water surfaces is of primary importance. The rate and amount of evaporation are dependent upon climatological factors and vary with each locality in conformity with atmospheric conditions. Evaporation losses from reservoirs used for storage of water materially reduce the quantities available for domestic, industrial and agricultural uses. Although much of such losses can not be prevented, a knowledge of their magnitude and of the factors which influence evaporation is desirable for use in devising means of reducing them to a minimum, in estimating the available supply, and in determining the economic feasibility of a project, taking into consideration the evaporation losses from proposed reservoirs. For these reasons the Division of Irrigation of the Bureau of Agricultural Engineering has been making evaporation studies** in the West for many years.

Evaporation data are also valuable in estimating consumptive use of water by native vegetation growing in moist areas. Since 1928 the Bureau of Agricultural Engineering has been keeping evaporation records at several stations in cooperation with the State Division of Water Resources and other agencies also have been making such observations. Not all of these agencies use the same type of evaporation pan, and results from the different types are not always comparable. For this reason, a cooperative key station was established at Baldwin Park in 1932 for the purpose of correlating the data that are being collected by the various organizations and for determining factors that may be used to reduce the observations on various types of evaporation pans to a comparable basis. Heretofore, very few data on evaporation in southern California have been published and it is the purpose of this chapter to bring together such records and make them available for general use.

BALDWIN PARK KEY STATION

The Los Angeles County Flood Control District, the San Gabriel Valley Protective Association, the Pasadena Water Department, the California State Division of Water Resources, and the United States Geological Survey are cooperating with the Bureau of Agricultural Engineering, in conducting this investigation. Three types of evaporation pans have been installed at the station:

1. Standard Weather Bureau type of pan, 4 feet in diameter by 10 inches deep, set upon a wooden platform above ground.

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* Prepared by Harry F. Blaney, Irrigation Engineer, Bureau of Agricultural Engineering, United States Department of Agriculture.

** "Evaporation from the Surfaces of Water and River-bed Materials," by R. B. Sleight (Journal of Agricultural Research, Vol. X, No. 5, July 30, 1917) and "Evaporation from Free Water Surfaces," by Carl Rohwer, U. S. Department of Agriculture Technical Bulletin No. 271.

2. U. S. Bureau of Agricultural Engineering type, 6 feet in diameter by 3 feet deep, set 2.75 feet in the ground.
3. Los Angeles County Flood Control District type, 2 feet in diameter by 3 feet deep, set 2.75 feet in the ground.

The standard Weather Bureau pan is the one most commonly used throughout the west and the one from which the majority of records are available. In southern California the Bureau of Agricultural Engineering has used this type of pan at each of its experiment stations. The 6-foot tank set in the ground is used in various localities on the valley floor, while the 2-foot tank is used in the mountain watersheds. Other equipment at the Baldwin Park station consists of a Livingston spherical atmometer, maximum and minimum thermometers, a thermograph for recording temperatures, a barograph for barometric pressure, an anemometer for wind movement, and both automatic and standard rain gages.

Monthly evaporation records obtained from the three types of pans at the Baldwin Park station are given in Table 46.

TABLE 46

MONTHLY EVAPORATION RECORDS AT COOPERATIVE KEY STATION AT BALDWIN PARK, CALIFORNIA, 1932-1933

Month	Depth in inches					
	Standard Weather Bureau pan		Bureau of Agricultural Engineering pan		Los Angeles County Flood Control District pan	
	1932	1933	1932	1933	1932	1933
January		2.47		1.89		2.213
February		3.49		2.38		3.145
March		4.79		3.61		4.880
April		5.28		4.16		5.825
May		6.89		6.43		7.750
June		8.15		6.89		9.085
July	8.30	9.49	7.47	7.75	9.310	10.040
August	8.02		7.26		9.395	
September	5.64		4.81		6.565	
October	5.00		4.43		5.630	
November	4.23		4.06		4.805	
December	2.07		2.22		2.367	

Description of pans:

Standard Weather Bureau pan—48 inches in diameter by 10 inches deep.

Bureau of Agricultural Engineering pan—6 feet in diameter by 3 feet deep, set 2.75 feet in the ground.

Los Angeles County Flood Control District pan—2 feet in diameter by 3 feet deep, set 2.75 feet in the ground. Gage held in center of pan by metal cross bar below water surface.

Elevation of station: Approximately 400 feet.

Remarks: This station is operated cooperatively by the following agencies: Bureau of Agricultural Engineering, U. S. Department of Agriculture; Geological Survey, U. S. Department of the Interior; Los Angeles County Flood Control District; Pasadena Water Department; San Gabriel Valley Protective Association; Division of Water Resources, Department of Public Works, State of California.

It is expected that this investigation will be continued for several years, until sufficient data are available for correlating the evaporation records that are being collected by the various agencies. The value of many of these records will be greatly enhanced if the proper coefficients can be determined to reduce the measured losses to the equivalent evaporation from a lake surface. It is hoped that eventually every type of pan in common use will be installed at Baldwin Park key station, and that the proper conversion coefficients will be determined.

No definite conclusions should be drawn at this time from the results of the first year's work. However, the data presented in Table 46 indicate that the evaporation loss from the Los Angeles County Flood Control pan is greater than that from the standard Weather Bureau pan at Baldwin Park during 1932. The cause of this result is not apparent at this time as Sleight * found that the loss from a standard Weather Bureau pan was greater than that from his 2-foot pan, but it is possible that the discrepancy is due to differences in construction and especially to the use of a cross bar in the Los Angeles pan that was not used in the Sleight type. This cross bar was introduced to make possible measurements of depth in the center of the pan.

MISCELLANEOUS EVAPORATION RECORDS

Evaporation stations maintained by the Bureau of Agricultural Engineering at locations other than Baldwin Park have been previously described in Chapters II and III.

In addition to observations of evaporation from standard Weather Bureau pans at the Santa Ana and San Bernardino stations, records were obtained from circular tanks 23 inches in diameter by 32 inches deep, set 30 inches in the ground. Measurements were made with a hook gage in a still well to prevent inaccuracies due to surface movement. The normal rate of evaporation from the sunken tank was more uniform than that from the Weather Bureau pan as the water in the tank maintained a more even temperature. The total evaporation, however, was less than that from the pan. Experiments by Sleight* at Denver indicate that evaporation from a similar tank 24 inches in diameter by 3 feet deep, set 2.75 feet in the ground was 86.2 per cent of that from an adjacent standard Weather Bureau pan for the period April to November 1916. This agrees closely with the average ratio of 88.8 per cent derived at Santa Ana and 86.6 per cent at San Bernardino for the three-year period ending April 30, 1932. The difference in depths of the tank at Denver and those in California is probably of no importance, but the difference of one inch in diameter may have had a slight effect on the evaporation.

Evaporation data collected by the Bureau of Agricultural Engineering at Santa Ana, San Bernardino, Prado, Ontario, and Victorville stations are summarized in Tables 47 to 51, inclusive.

A canvass was made for other evaporation records and these are published herewith as Tables 52 to 69, inclusive, through the courtesy of agencies collecting them.

* "Evaporation from the Surfaces of Water and River-bed Materials," by R. B. Sleight, Journal of Agricultural Research, Vol. X, No. 5, July 30, 1917.

TABLE 47

MONTHLY EVAPORATION RECORDS AT SANTA ANA, CALIFORNIA, 1929-1932

Observed by the Bureau of Agricultural Engineering, United States Department of Agriculture

Month	Depth in inches									
	Standard Weather Bureau pan				Standard Weather Bureau pan containing 5 per cent NaCl		Circular sunken tank			
	1929	1930	1931	1932	1931	1932	1929	1930	1931	1932
January		2.280	2.890	2.376		2.064		1.860	2.194	1.788
February		2.872	2.736	2.730		1.902		2.436	2.472	1.602
March		4.476	5.778	4.980		4.536		3.384	5.454	3.504
April		6.048	6.016	5.858		5.126		4.968	5.212	4.442
May	8.394	6.792	6.886		6.331		[1]5.574	5.988	5.746	
June	8.234	6.948	8.050		7.318		7.910	6.440	6.850	
July	8.892	8.544	8.904		8.148		8.196	7.824	8.100	
August	8.904	7.392	7.462		7.018		8.328	6.744	7.102	
September	5.654	5.828	6.206		5.834		5.762	5.588	5.942	
October	6.060	5.500	4.698		4.542		5.640	5.032	4.266	
November	5.256	4.262	3.094		2.698		4.884	3.816	2.734	
December	3.444	3.312	1.988		1.484		3.060	3.144	1.448	
Totals		64.254	64.708					57.224	57.520	

Description of pans:

Standard Weather Bureau pan—48 inches in diameter by 10 inches deep. Circular sunken tank—23 inches in diameter by 32 inches deep, set 30 inches in the ground.

Elevation of station, approximately 75 feet.

[1] Record began May 8, 1929. In cooperation with the Division of Water Resources, Department of Public Works, State of California.

TABLE 48

MONTHLY EVAPORATION RECORDS AT SAN BERNARDINO, CALIFORNIA, 1929-1932

Observed by the Bureau of Agricultural Engineering, United States Department of Agriculture

Month	Depth in inches							
	Standard Weather Bureau pan				Circular sunken tank			
	1929	1930	1931	1932	1929	1930	1931	1932
January	----------	2.316	3.100	3.126	----------	2.220	2.789	3.008
February	----------	3.456	3.058	3.134	----------	2.676	2.253	2.892
March	----------	5.016	5.766	5.240	----------	3.912	4.953	4.232
April	----------	5.376	4.892	6.276	----------	5.400	4.064	5.100
May	7.780	5.496	6.794	----------	6.090	4.572	4.850	----------
June	8.892	6.588	7.384	----------	7.596	5.976	5.734	----------
July	9.780	8.076	8.918	----------	8.892	6.804	6.727	----------
August	8.808	7.536	8.062	----------	7.740	5.844	6.886	----------
September	5.690	5.472	5.808	----------	5.426	5.124	5.448	----------
October	5.580	5.208	4.812	----------	5.436	4.860	4.596	----------
November	4.980	3.768	3.482	----------	4.704	3.506	2.674	----------
December	3.816	2.634	2.098	----------	3.480	2.651	2.786	----------
Totals	----------	60.942	64.174	----------	----------	53.545	53.760	----------

Description of pans:

Standard Weather Bureau pan—48 inches in diameter by 10 inches deep. Circular sunken tank—23 inches in diameter by 32 inches deep, set 30 inches in the ground.

Elevation of station—1,050 feet (approximately).

Remarks: In cooperation with the Division of Water Resources, Department of Public Works, State of California and city of San Bernardino.

TABLE 49

MONTHLY EVAPORATION RECORDS AT PRADO, CALIFORNIA, 1930-1933

Observed by the Bureau of Agricultural Engineering, United States Department of Agriculture

Month	Depth in inches			
	1930	1931	1932	1933
January	-------------	4.028	4.208	3.129
February	-------------	2.432	-------------	4.391
March	-------------	5.748	5.172	5.261
April	-------------	6.077	6.028	5.426
May	-------------	7.762	8.180	7.514
June	-------------	9.124	9.137	9.016
July	11.003	11.518	9.985	-------------
August	9.852	9.855	10.470	-------------
September	-------------	7.627	7.051	-------------
October	-------------	5.391	5.999	-------------
November	5.018	3.558	5.389	-------------
December	3.804	2.501	2.746	-------------
Total	-------------	75.621	-------------	-------------

Type of pan—Standard Weather Bureau pan.
Description of pan—48 inches in diameter by 10 inches deep.
Elevation of station—480 feet (approximately).
Remarks: In cooperation with the Geological Survey, U. S. Department of the Interior; and the Division of Water Resources, Department of Public Works, State of California.

TABLE 50

MONTHLY EVAPORATION RECORDS AT ONTARIO, CALIFORNIA, 1928-1931

Observed by the Bureau of Agricultural Engineering, United States Department of Agriculture

Month	Depth in inches			
	1928	1929	1930	1931
January	-------------	1.87	1.51	2.17
February	-------------	1.85	2.57	2.19
March	3.39	3.53	3.54	5.02
April	6.28	3.83	5.19	5.23
May	6.04	7.31	5.25	6.11
June	7.37	8.59	6.76	6.70
July	9.74	10.17	8.43	-------------
August	9.28	10.55	7.65	-------------
September	8.25	6.39	4.98	-------------
October	4.44	6.21	3.48	-------------
November	3.46	4.96	2.95	-------------
December	1.96	3.32	1.74	-------------
Totals	-------------	68.58	54.05	-------------

Type of pan—Standard Weather Bureau pan. Description of pan—48 inches in diameter by 10 inches deep.
Elevation of station—Approximately 1,000 feet.
Remarks: The record for 1930 and 1931 represents evaporation within the city limits where buildings are reasonably close together, limiting both wind movement and hours of sunshine at the pan. It does not represent conditions in open agricultural districts as does the record for 1928 and 1929. In cooperation with Division of Water Resources, Department of Public Works, State of California.

TABLE 51

MONTHLY EVAPORATION RECORDS AT VICTORVILLE, CALIFORNIA, 1931-1933

Observed by the Bureau of Agricultural Engineering, United States Department of Agriculture

Month	Depth in inches		
	1931	1932	1933
January	------------	2.52	2.29
February	3.28	2.79	3.88
March	6.83	6.51	------------
April	7.83	7.75	------------
May	10.63	9.20	------------
June	10.55	10.22	------------
July	12.26	11.99	------------
August	9.68	11.67	------------
September	8.10	8.34	------------
October	5.17	5.72	------------
November	3.14	3.89	------------
December	1.92	2.08	------------
Total	------------	82.68	------------

Type of pan—Standard Weather Bureau pan. Description—48 inches in diameter by 10 inches deep.
Elevation of station—2,700 feet (approximately).
Remarks: In cooperation with the Geological Survey, U. S. Department of the Interior; and the Division of Water Resources, Department of Public Works, State of California.

TABLE 52

MONTHLY EVAPORATION RECORDS NEAR POMONA, CALIFORNIA, 1903-1905

Observed by the Office of Experiment Stations, United States Department of Agriculture

Month	Depth in inches		
	1903	1904	1905
January	------------	2.78	1.93
February	------------	2.57	1.65
March	------------	3.69	3.73
April	------------	5.00	4.08
May	------------	6.50	5.98
June	------------	8.20	7.73
July	9.07	9.34	8.93
August	9.37	9.37	9.02
September	6.29	7.23	7.45
October	6.63	5.37	5.28
November	4 25	4 05	------------
December	2.51	2.94	------------
Total	------------	67.04	------------

Description of tank—Rectangular tank 22 by 36 inches by 30 inches deep, set 29 inches in the ground.
Elevation of station—Approximately 870 feet.
Reference: Office of Experiment Stations, U. S. Department of Agriculture, Bulletin 177.
Remarks: In cooperation with the State of California.

TABLE 53

MONTHLY EVAPORATION RECORDS AT CHULA VISTA, CALIFORNIA. 1918-1933

Observed by the Weather Bureau, United States Department of Agriculture.

Year	Depth in inches												
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1918									6.066	4.846	3.795	2.799	
1919	4.144	3.363	4.781	5.474	6.133	7.885	7.619	6.863	5.915	5.226	3.999	2.982	64.384
1920	2.639	2.918	4.919	6.184	6.354	7.385	7.356	7.413	6.162	4.970	3.533	3.051	62.884
1921	2.694	3.166	5.028	6.655	5.516	6.117	7.265	6.589	6.171	4.303	3.483	2.988	59.975
1922	2.879	3.290	4.771	5.372	6.215	6.397	6.870	6.936	5.932	4.966	3.468	2.177	59.273
1923	2.586	2.957	5.136	5.034	7.268	6.939	6.888	6.835	5.288	4.818	4.104	3.744	61.597
1924	3.017	3.867	4.824	5.418	6.366	6.879	7.483	6.711	5.604	4.458	3.721	2.480	60.828
1925	2.723	2.726	4.641	4.807	5.949	6.530	7.903	7.188	5.661	3.684	4.237	3.027	59.076
1926	3.287	3.612	5.450	5.103	6.694	6.442	7.258	7.183	5.754	4.862	4.058	2.305	62.008
1927	2.097	2.372	4.141	4.880	6.124	5.916	7.135	6.799	5.777	4.172	2.966	2.509	54.888
1928	2.812	3.333	4.751	6.011	5.672	6.334	7.434	6.693	5.426	4.489	3.802	2.997	59.754
1929	2.676	3.300	4.762	6.063	7.492	7.160	7.912	7.225	5.483	5.100	4.039	2.944	64.156
1930	2.975	3.515	4.970	6.095	6.748	6.636	7.818	7.477	6.454	5.417	4.582	3.252	65.939
1931	2.932	3.643	5.757	6.011	7.348	8.275	8.228	7.340	6.673	5.375	3.480	2.731	67.793
1932	2.856	3.045	5.063	6.452	7.026	7.188	7.171	6.966	5.276	4.405	4.055	2.758	62.261
1933	2.721	3.572	5.161										

Type of pan—Standard Weather Bureau pan. Description, 48 inches diameter, 10 inches deep.
Elevation of station—9 feet.
Reference—U. S. Department of Agriculture, Weather Bureau. Climatic Summary of the United States, Section 18, Southern California and Owens Valley.

TABLE 54

MONTHLY WIND MOVEMENT AT CHULA VISTA, CALIFORNIA. 1918-1930

Observed by the Weather Bureau, United States Department of Agriculture

Year	Wind movement in miles												
	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1918	----	----	----	----	----	----	----	----	2,913	2,682	2,723	2,544	----
1919	2,435	3,082	3,307	3,280	3,781	3,445	3,336	3,208	2,988	2,643	2,657	2,108	36,270
1920	2,175	2,293	3,683	3,781	3,805	3,516	3,484	3,368	3,011	2,970	2,245	2,585	36,916
1921	2,392	2,530	3,223	3,863	3,608	3,191	3,175	3,172	2,866	2,467	2,084	2,360	34,931
1922	2,915	2,510	3,128	3,553	3,460	2,982	2,983	2,808	2,577	2,491	2,147	2,040	33,594
1923	2,097	2,164	2,782	3,353	3,683	3,558	3,340	3,106	3,000	2,575	2,090	2,871	34,619
1924	2,081	2,007	3,762	3,153	3,196	3,174	3,674	3,159	2,702	2,479	1,980	2,353	33,720
1925	1,993	2,144	2,759	3,037	3,302	3,317	3,113	3,147	2,676	2,100	2,380	1,878	31,846
1926	2,252	2,213	2,658	2,899	3,033	2,442	2,621	2,835	2,496	2,196	1,820	2,163	29,628
1927	1,609	2,123	2,480	2,550	3,231	3,037	3,058	2,794	2,739	2,196	1,746	2,026	29,589
1928	1,740	2,216	2,767	2,930	3,006	3,029	2,847	2,811	2,350	2,335	2,038	1,843	29,912
1929	2,162	2,434	3,122	3,424	3,144	3,101	3,109	2,811	2,415	2,122	1,531	1,813	31,188
1930	2,607	2,200	2,874	3,062	3,654	3,095	2,820	2,580	2,593	2,119	2,216	1,602	31,422

Anemometer 7 inches from pan and 6 inches above.
Elevation of station—9 feet.
Reference: U. S. Department of Agriculture, Weather Bureau. Climatic Summary of the United States, Section 18, Southern California and Owens Valley.

TABLE 55

MONTHLY EVAPORATION RECORDS AT RIVERSIDE, CALIFORNIA, 1924-1933

Observed by the Citrus Experiment Station, University of California

Month	Depth in inches									
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933
January		3.558	4.422	1.199	2.538	2.406	1.755	2.849		2.366
February		2.626	3.808	.935	4.503	2.384	2.206	4.887		3.573
March		4.990	4.851	4.127	3.903	4.122	3.891	5.691	5.221	4.815
April		5.282	4.570	3.999	6.731	4.593	5.437	5.850	5.883	
May		6.523	7.856	7.610	5.763	6.905	5.845	6.990	6.118	
June		8.402	7.437	7.596	7.590	8.611	7.684	7.534	6.103	
July		10.558	9.045	9.975	9.523	10.093	9.504	9.781	8.935	
August		9.518	9.317	10.302	9.441	9.970	8.523	8.321	8.679	
September		7.152	7.003	7.227	7.739	5.405	6.176	6.086	5.771	
October		3.470	5.899	5.620	4.705	5.526	4.983	4.279	3.954	
November	4.400	5.041	2.561	3.768	3.215	5.492	4.167	2.666	3.975	
December	3.362	2.937	1.888	1.975	2.827	3.598	2.936	1.821	2.122	
Totals		70.057	68.657	64.333	68.478	69.105	63.107	66.755		

Type of pan—Standard Weather Bureau pan. Description of pan—48 inches in diameter by 10 inches deep, set upon an open wooden platform.
Elevation of station—1,100 feet (approximately).
Records furnished by Dr. L. D. Batchelor, Director.

TABLE 56

MONTHLY EVAPORATION RECORDS AT SOUTH HAIWEE RESERVOIR, CALIFORNIA, 1924-1932

Observed by Bureau of Water Works and Supply, City of Los Angeles

Month	Depth in inches								
	1924	1925	1926	1927	1928	1929	1930	1931	1932
January	*1.68	1.75	1.91	*1.75	*1.00	*1.75	*1.00	*1.75	*1.00
February	3.22	2.27	1.97	*3.10	*1.18	1.94	*2.31	*2.15	*1.52
March	*5.32	3.19	3.73	5.76	3.39	3.71	3.13	2.23	5.10
April	5.33	6.49	4.84	4.30	5.26	4.22	3.67	3.13	6.95
May	9.04	6.46	6.89	6.80	5.02	6.10	5.87	3.90	7.00
June	9.30	9.15	8.00	7.00	7.36	5.80	5.94	7.14	8.05
July	10.85	9.28	8.90	7.85	8.35	8.15	8.00	8.00	12.80
August	9.98	7.07	6.80	7.70	6.00	7.11	7.80	6.94	11.63
September	7.10	6.35	5.50	6.72	6.25	6.61	6.70	6.10	8.45
October	*3.31	3.53	3.92	3.80	3.15	4.70	3.17	3.56	3.95
November	*2.28	2.45	3.80	1.64	2.00	2.50	2.48	*2.57	2.24
December	*1.68	1.24	*2.54	*1.35	*1.65	1.81	*1.13	*1.00	1.76
Totals	69.09	59.23	58.80	57.77	50.61	54.40	51.20	48.47	70.45

Type of pan—Colorado land pan. Description of pan—3 by 3 by 1½ feet deep, set in the ground.
Elevation of station—3,800 feet.
Record furnished by H. A. Van Norman, Chief Engineer and General Manager.
Remarks: *Portion of record estimated.

TABLE 57

MONTHLY EVAPORATION RECORDS AT FAIRMONT RESERVOIR, CALIFORNIA, 1923-1932

Observed by Bureau of Water Works and Supply, City of Los Angeles

Month	Depth in inches									
	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932
January	--------	*2.88	3.46	3.02	3.02	2.14	2.94	2.81	2.74	2.39
February	--------	*3.57	4.11	3.02	3.82	3.58	3.24	4.10	3.13	2.67
March	--------	5.75	6.92	4.97	4.89	5.09	5.22	4.59	6.85	5.98
April	--------	7.31	7.14	4.53	7.52	7.61	6.48	8.06	7.56	7.66
May	--------	14.15	9.14	10.58	11.31	10.51	12.25	8.79	12.12	9.42
June	--------	15.75	12.16	16.26	12.74	13.64	11.67	14.24	12.76	14.36
July	--------	16.67	*17.48	18.51	16.89	16.27	18.08	17.69	18.26	17.62
August	--------	17.91	*15.92	16.47	15.34	16.44	16.08	14.92	14.27	16.00
September	--------	14.35	*11.02	12.12	9.64	11.83	10.13	9.47	9.63	12.15
October	--------	7.70	*7.42	8.43	8.14	7.33	7.84	6.10	6.41	7.63
November	5.38	4.42	4.20	5.75	3.99	4.12	5.51	4.54	3.42	5.70
December	3.34	*2.91	2.85	2.09	1.73	2.50	4.44	1.81	2.26	2.24
Totals	--------	113.37	101.82	105.75	99.03	101.06	103.88	97.12	99.41	103.82

Type of pan—Colorado land pan. Description of pan—3 by 3 by 1½ feet deep, set in the ground.
Elevation of station—3,050 feet.
Record furnished by H. A. Van Norman, Chief Engineer and General Manager.
Remarks: *Portion of record estimated.

TABLE 58

MONTHLY EVAPORATION RECORDS AT SILVER LAKE RESERVOIR, CALIFORNIA, 1930-1933

Observed by Bureau of Water Works and Supply, City of Los Angeles

Month	Depth in inches			
	1930	1931	1932	1933
January			3.43	
February		4.80		2.65
March		4.74	4.30	3.72
April		6.28	5.63	
May		5 68	5.50	
June		7.01	6.27	
July		8.22	7.19	
August	7.58	7.32	7.52	
September	6.21	6.10	5.16	
October	5.75	4.89	4.62	
November	4.13	3.89	3.49	
December	2.93		2.28	

Type of pan—Floating pan. Description of pan—30 inches square by 18 inches deep.
Elevation of station—Approximately 440 feet.
Records furnished by H. A. Van Norman, Chief Engineer and General Manager.

TABLE 59

MONTHLY EVAPORATION RECORDS AT LOWER FERNANDO RESERVOIR, CALIFORNIA, 1930-1933

Observed by Bureau of Water Works and Supply, City of Los Angeles

Month	Depth in inches					
	Standard Weather Bureau pan				Floating pan	
	1930	1931	1932	1933	1930	1931
January		9.06	8.23			
February		7.54		8.20		
March		11.62	8.48	8.09		
April		8.72	9.37			
May		7.51	4.49			5.06
June		9 45	6.30			6.93
July		11.71	9.72			8.94
August		9.76	10.32			8.32
September		9.33	8.13			8.13
October	10.97	8.07	8.64		8.25	6.37
November	12.94	6.23	13 02		7.97	4.65
December	10.69		6.02		6.43	

Description of pans:
Standard Weather Bureau pan—48 inches in diameter by 10 inches deep. Floating pan—30 inches square by 18 inches deep.
Elevation of station—Approximately 1,140 feet.
Records furnished by H. A. Van Norman, Chief Engineer and General Manager.

TABLE 60

MONTHLY EVAPORATION RECORDS AT CHATSWORTH RESERVOIR, CALIFORNIA, 1931-1933

Observed by Bureau of Water Works and Supply, City of Los Angeles

Month	Depth in inches		
	1931	1932	1933
January	------	4.095	4.688
February	------	3.302	5.425
March	------	5.890	6.605
April	------	7.235	5.705
May	------	7.615	------
June	------	8.410	------
July	------	10.100	------
August	10.106	10.350	------
September	8.260	7.355	------
October	7.475	7.655	------
November	5.245	7.600	------
December	3.686	4.310	------
Total	------	83.917	------

Type of tank—Los Angeles County Flood Control District.
Description of tank: 2 feet in diameter by 3 feet deep; set 2.75 feet in the ground.
Elevation of station—Approximately 900 feet.
Records furnished by H. A. Van Norman, Chief Engineer and General Manager.

TABLE 61

MONTHLY EVAPORATION RECORDS AT ENCINO RESERVOIR, CALIFORNIA, 1930-1933

Observed by Bureau of Water Works and Supply, City of Los Angeles

Month	Depth in inches							
	Standard Weather Bureau pan		Floating pan				Los Angeles County Flood Control District tank	
	1932	1933	1930	1931	1932	1933	1932	1933
January	------	------	------	4.36	4.19	------	------	------
February	------	5.00	------	6.19	------	3.59	------	5.22
March	------	6.85	------	5.66	5.14	4.93	------	7.38
April	------	------	------	4.90	6.64	------	------	------
May	------	------	------	6.07	6.16	------	8.48	------
June	------	------	------	7.84	7.65	------	9.56	------
July	9.98	------	------	9.60	8.39	------	10.16	------
August	11.14	------	9.19	8.91	10.04	------	13.00	------
September	7.21	------	7.14	7.84	7.10	------	8.14	------
October	6.56	------	6.47	5.95	6.25	------	7.58	------
November	7.15	------	4.56	4.79	5.41	------	7.49	------
December	3.32	------	3.95	------	3.39	------	3.70	------

Description of pans:
Standard Weather Bureau pan—48 inches in diameter by 10 inches deep.
Floating pan—30 inches square by 18 inches deep.
Los Angeles County Flood Control District tank—2 feet in diameter by 3 feet deep; set 2.75 feet in the ground.
Elevation of station—Approximately 1,020 feet.
Records furnished by H. A. Van Norman, Chief Engineer and General Manager.

TABLE 62

MONTHLY EVAPORATION RECORDS AT AZUSA, MONROVIA, WHITTIER, TELEGRAPH ROAD AND COLLINS ROAD, AND LONG BEACH, CALIFORNIA, 1929-1931

Observed by the San Gabriel Valley Protective Association

Month	Depth in inches														
	Azusa			Monrovia			Whittier			Telegraph Road and Collins Road			Long Beach		
	1929	1930	1931	1929	1930	1931	1929	1930	1931	1929	1930	1931	1929	1930	1931
January	----------	1.84	2.18	----------	1.39	1.34	----------	1.28	1.73	----------	1.14	1.14	----------	1.08	1.68
February	----------	2.44	2.20	----------	1.93	2.11	----------	2.02	2.34	----------	1.64	1.76	----------	1.87	2.02
March	----------	3.40	4.91	----------	2.95	3.71	----------	2.84	3.96	----------	2.70	3.79	----------	2.44	4.63
April	----------	4.07	4.90	----------	3.86	4.09	----------	3.64	4.20	----------	4.06	3.90	----------	4.00	5.16
May	----------	4.32	5.69	----------	4.09	4.58	----------	3.94	4.54	----------	4.49	4.52	----------	5.11	5.48
June	----------	5.29	6.26	----------	5.09	5.81	----------	4.92	5.75	----------	4.99	5.33	----------	5.51	6.79
July	----------	7.50	8.28	----------	7.02	6.71	----------	6.97	6.72	----------	6.58	6.46	----------	7.30	7.79
August	----------	6.38	7.16	----------	6.11	5.98	----------	5.77	5.83	----------	5.78	5.65	----------	6.80	6.74
September	----------	4.75	6.28	----------	4.56	4.94	----------	4.21	4.72	----------	4.15	4.72	----------	5.54	5.89
October	----------	4.70	4.66	----------	3.55	3.23	----------	3.36	3.50	----------	3.45	3.11	----------	4.93	4.58
November	----------	4.22	3.22	2.78	2.60	1.92	3.13	2.87	2.09	2.53	2.47	1.92	----------	3.61	2.98
December	3.32	3.28	1.84	1.93	1.64	.83	2.30	1.96	1.02	1.82	1.57	.78	2.15	2.40	1.08
Totals	----------	52.19	57.58	----------	44.79	45.25	----------	43.78	46.40	----------	43.02	43.08	----------	50.59	54.80

Type of tank—Bureau of Agricultural Engineering, U. S. Department of Agriculture.
Description of tank—Six feet in diameter by 3 feet deep; set 2.75 feet in the ground.
Approximate elevation of stations—Azusa, 675 feet; Monrovia, 368 feet; Whittier, 203 feet; Telegraph and Collins Roads, 145 feet, and Long Beach, 30 feet.
Records furnished by Willis S. Jones, Chief Engineer.

TABLE 63

MONTHLY EVAPORATION RECORDS AT PINE CANYON STATION, SAN GABRIEL RIVER, 1930-1933

Observed by the Pasadena Water Department

Month	Depth in inches							
	Standard Weather Bureau pan				Bureau of Agricultural Engineering tank			
	1930	1931	1932	1933	1930	1931	1932	1933
January	----------	2.844	1.956	3.120	----------	2.232	1.536	2.388
February	----------	2.892	2.724	3.684	----------	2.400	1.788	3.012
March	----------	6.420	5.220	5 604	----------	4.992	3.888	4.212
April	----------	5.832	6.324	5.340	----------	4.488	5.040	3.744
May	----------	7.140	6.492	----------	----------	5 460	5.256	----------
June	----------	7.788	7.176	----------	----------	6.384	6.216	----------
July	----------	10 368	9.756	----------	----------	8.796	7.644	----------
August	----------	9.264	9.216	----------	----------	7.692	7.512	----------
September	----------	7.596	7.752	----------	----------	6.300	6.168	----------
October	6.036	5.436	6.312	----------	4.896	4.356	5.016	----------
November	5.220	3.624	5 556	----------	4.152	2.796	4.212	----------
December	3.156	1.764	2.676	----------	2.760	1.416	2.028	----------
Totals	----------	70 968	71.160	----------	----------	57.312	56 304	----------

Description of pan and tank:
Standard Weather Bureau pan—48 inches in diameter by 10 inches deep.
Bureau of Agricultural Engineering tank—6 feet in diameter by 3 feet deep; set 2.75 feet in the ground.
Elevation of station—950 feet, U. S. G. S.
Record furnished by C. W. Sopp.

TABLE 64

MONTHLY EVAPORATION RECORDS AT LITTLE CIENAGA, CALIFORNIA, 1929-1933

Observed by Los Angeles County Flood Control District

Month	Depth in inches				
	1929	1930	1931	1932	1933
January	----------	1.12	2.78	0.971	1.150
February	----------	----------	.62	0.945	1.691
March	----------	1.23	2.53	3.816	3.120
April	----------	1.67	----------	4.130	----------
May	----------	----------	3.87	4.930	----------
June	----------	2.62	3.62	5.110	----------
July	5.51	3.90	4.12	6.838	----------
August	4.98	4.85	----------	6.540	----------
September	3.40	3.95	3.96	6.475	----------
October	2.78	3.10	3.245	4.095	----------
November	2.52	2.80	2.073	3.445	----------
December	1.71	1.54	.901	1.045	----------
Total	----------	----------	----------	48.340	----------

Type of tank—Los Angeles County Flood Control.
Description of tank—2 feet in diameter by 3 feet deep; set 2.75 feet in the ground.
Elevation of station—4,650 feet.
Record furnished by E. C. Eaton, Chief Engineer.
Remarks: Located 1 mile north of Colbrook Camp.

TABLE 65

MONTHLY EVAPORATION RECORDS AT BIG DALTON DAM, CALIFORNIA, 1930-1933

Observed by Los Angeles County Flood Control District

Month	Depth in inches			
	1930	1931	1932	1933
January	-------------	4.66	3.210	4.250
February	-------------	3.86	2.710	4.350
March	-------------	8.86	6.020	6.470
April	-------------	7.74	7.195	-------------
May	-------------	8.02	7.150	-------------
June	10.44	9.80	8.410	-------------
July	9.61	12.76	11.025	-------------
August	14.45	11.97	11.835	-------------
September	9.14	11.16	8.855	-------------
October	10.22	7.32	6.785	-------------
November	9.17	5.085	7.885	-------------
December	5.84	3.025	3.100	-------------
Totals	-------------	94.260	84.180	-------------

Type of tank—Los Angeles County Flood Control. Description of tank—2 feet in diameter by 3 feet deep, set 2.75 feet in the ground.

Elevation of station—1,500 feet.

Records furnished by E. C. Eaton, Chief Engineer.

TABLE 66

MONTHLY EVAPORATION RECORDS AT PUDDINGSTONE RESERVOIR, CALIFORNIA, 1929-1933

Observed by Los Angeles County Flood Control District

Month	Depth in inches				
	1929	1930	1931	1932	1933
January	-------------	*2.29	*3.25	*2.24	3.30
February	-------------	*2.76	*1.67	*1.61	3.88
March	-------------	*3.60	5.78	4.20	5.32
April	-------------	4.52	*5.27	5.47	5.18
May	-------------	*4.64	5.86	5.50	-------------
June	-------------	6.73	7.29	6.65	-------------
July	-------------	11.65	10.17	9.42	-------------
August	-------------	10.52	9.16	9.30	-------------
September	6.99	7.37	8.66	6.70	-------------
October	7.90	7.43	6.04	6.53	-------------
November	7.73	*3.30	*3.74	6.76	-------------
December	5.32	5.24	*2.33	3.38	-------------

Type of tank—Los Angeles County Flood Control. Description of tank—2 feet in diameter by 3 feet deep, set 2.75 feet in the ground.

Elevation of station—1,030 feet.

Record furnished by E. C. Eaton, Chief Engineer.

Remarks: *Incomplete for days of rain.

TABLE 67

MONTHLY EVAPORATION RECORDS AT PACOIMA DAM, CALIFORNIA, 1930-1933

Observed by Los Angeles County Flood Control District

Month	Depth in inches			
	1930	1931	1932	1933
January	------------	2.72	2.330	3.415
February	------------	2.98	1.915	4.320
March	------------	7.61	5.435	5.640
April	------------	6.50	6.565	4.940
May	4.85	5.18	5.280	------------
June	9.80	6.85	7.815	------------
July	9.06	9.54	9.285	------------
August	9.29	8.58	9.045	------------
September	9.06	8.64	7.830	------------
October	6.07	7.28	7.290	------------
November	7.10	5.93	7.810	------------
December	4.46	2.51	3.355	------------
Totals	------------	74.32	73.955	------------

Type of tank—Los Angeles County Flood Control. Description of tank—2 feet in diameter by 3 feet deep, set 2.75 feet in the ground.
Elevation of station—1,900 feet.
Records furnished by E. C. Eaton, Chief Engineer.
Remarks: Located at mouth of the canyon.

TABLE 68

MONTHLY EVAPORATION RECORDS NEAR ACTON (MELLON), CALIFORNIA, 1931-1933

Observed by Los Angeles County Flood Control District

Month	Depth in inches		
	1931	1932	1933
January	------------	2.636	3.045
February	------------	1.945	4.415
March	------------	5.885	6.260
April	------------	6.925	6.860
May	------------	7.795	------------
June	------------	10.180	------------
July	------------	13.375	------------
August	11.38	13.980	------------
September	9.40	10.935	------------
October	6.81	7.940	------------
November	4.325	6.490	------------
December	2.185	3.130	------------
Total	------------	91.216	------------

Type of tank—Los Angeles County Flood Control. Description of tank—2 feet in diameter by 3 feet deep, set 2.75 feet in the ground.
Elevation of station—3,100 feet.
Records furnished by E. C. Eaton, Chief Engineer.
Remarks: Located at North Branch of Escondido Canyon.

TABLE 69

MONTHLY EVAPORATION RECORDS AT EL SEGUNDO, CALIFORNIA, 1931-1933

Observed by Los Angeles County Flood Control District

Month	Depth in inches		
	1931	1932	1933
January	------------	3.210	2.875
February	------------	2.845	3.895
March	------------	5.415	5.145
April	------------	6.945	6.085
May	------------	7.525	------------
June	------------	7.450	------------
July	------------	7.650	------------
August	------------	7.435	------------
September	6.940	5.445	------------
October	5.670	5.005	------------
November	4.434	4.395	------------
December	2.960	3.529	------------
Total	------------	66.849	------------

Type of tank—Los Angeles County Flood Control. Description of tank—2 feet in diameter by 3 feet deep, set 2.7 feet in the ground.

Elevation of station—135 feet.

Records furnished by E. C. Eaton, Chief Engineer.

Remarks: Location at Standard Oil Company.

PART II

GROUND WATER SUPPLY AND NATURAL LOSSES IN THE VALLEY OF SANTA ANA RIVER BETWEEN THE RIVERSIDE NARROWS AND THE ORANGE COUNTY LINE

By Harold C. Troxell

A record of noneconomic loss of water along Santa Ana River from Riverside Narrows to the Orange County line together with an estimate of inflow from ground water above Lower Santa Ana Canyon.

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LETTER OF TRANSMITTAL

MR. EDWARD HYATT
State Engineer
Sacramento, California

Dear Mr. Hyatt:

I am transmitting to you for publication by the State a report prepared by Harold C. Troxell, entitled "Ground water supply and natural losses in the valley of the Santa Ana River between Riverside Narrows and the Orange County line." The report presents the results of an intensive study to determine the quantity of ground water that percolates into this stretch of the valley and is discharged either as surface flow or by evaporation or transpiration of the vegetation in the valley. The report is believed to be of value both because of the use that can be made of the data and conclusions which it contains in the further development of the water supply of the drainage basin of the Santa Ana River and because of the contribution which it makes to quantitative methods in ground water hydrology.

Very truly yours,

N. C. Grover

Chief Hydraulic Engineer
Water Resources Branch,
U. S. Geological Survey.

Washington, D. C., July 31, 1933.

ACKNOWLEDGMENT

The author wishes to acknowledge the cooperation and help rendered by F. C. Ebert and R. S. Lord, of the United States Geological Survey, and C. A. Taylor, of the Bureau of Agricultural Engineering, United States Department of Agriculture, in preparing this report. Valuable aid was also rendered by the Orange County Flood Control District, through M. N. Thompson, chief engineer, in collecting part of the field data. The report was reviewed by W. G. Hoyt, A. C. Spencer, C. H. Pierce, and O. E. Meinzer, and was edited by B. H. Lane, all of the United States Geological Survey.

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This report was prepared by

HAROLD C. TROXELL
Associate Engineer

GROUND WATER SUPPLY AND NATURAL LOSSES IN THE VALLEY OF SANTA ANA RIVER BETWEEN RIVERSIDE NARROWS AND THE ORANGE COUNTY LINE

By Harold C. Troxell *

Description of area.

One of the most useful streams in southern California is the Santa Ana River. It rises in the heart of the San Bernardino Mountains above San Bernardino and flows westward across the San Bernardino Valley, southwestward through the Jurupa Basin and along the south edge of the Chino Basin, through the lower canyon in the Santa Ana Mountains, and across the coastal plain to the Pacific Ocean near Newport Beach. Flow through this channel from the mountains to the ocean is continuous only during the winter flood periods. The section of the river channel involved in this report extends from Riverside Narrows to the Orange-Riverside County line.

South of the Jurupa Mountains and northwest of the city of Riverside the Santa Ana River passes through a granite canyon known as Riverside Narrows. This bedrock obstruction forces most of the water to the surface, forming a stream that flows continuously as far as the intake of the canal companies in Orange County. Most of this water at Riverside Narrows is return water from the irrigated areas around Riverside. According to old settlers the channel was dry during summer periods prior to the irrigation developments. The earlier measurements of discharge at this point showing the increase in discharge are given by W. C. Mendenhall in "Hydrology of San Bernardino Valley," (U. S. Geol. Survey Water-Supply Paper 142).

About 16 miles down stream from Riverside Narrows the Santa Ana River passes through a secondary coast range, the Santa Ana Mountains. These mountains are made up of shale and sandstone and form a barrier that concentrates and forces to the surface most of the underflow. In this 16-mile stretch the Chino Basin drains into the river along the north bank. The mountain streams of this area are exceedingly steep and flow over bare rock. Many of the storms that occur in southern California are violent and, falling on these mountain drainage basins, produce floods that rush across the plains, carrying large quantities of granitic detritus. In this way the Chino Basin has been built up. These great beds of gravel and boulders have a high percentage of voids, and the flood waters passing over them are greatly reduced, if not entirely absorbed, adding to the supply in the underground reservoir. The outlet of this underground reservoir is by seepage into the Santa Ana River between Riverside Narrows and Prado and by evaporation and transpiration in the bottom land of this stretch of the river. The velocity with which the water passes through the gravel is very slow, and the water is doubtless delivered to the river valley at a nearly uniform rate.

The Santa Ana Mountains and Temescal Basin, which drain into the river along the south bank, undoubtedly make a much smaller contribution, except possibly during storm periods.

* Associate Engineer, Water Resources Branch, U. S. Geological Survey.

Between Riverside Narrows and the Prado gaging station the Santa Ana flows through an inner valley or flood channel in most places less than a mile wide, cut in the old alluvial deposits. Flood flows have deposited in this channel very absorptive gravelly material to a depth of 80 to 100 feet. Most of this bottom land is now overgrown with plant life, as shown on Plate I.

Purpose of investigation.

The purpose of this investigation was to determine the total quantity of ground water that reaches the valley or flood channel of the river in this area. It may be represented as the water passing the points marked *a* in Plate II. This quantity of water would be equal to the gain in the flow of the river if the losses by evaporation and transpiration were reduced to zero.

Classification of bottom land.

The character of the plant cover of the bottom land between Riverside Narrows and the Prado gaging station is indicated on Plate I. The various areas on this plate have been computed and the results are given in Table 1. Between Hamner Avenue and The Atchison, Topeka & Santa Fe Railway Bridge there are 2110 acres of river bottom land, classed as the area of natural losses. Throughout this area the water table ranges from ground surface to about 5 feet below it.

TABLE 1

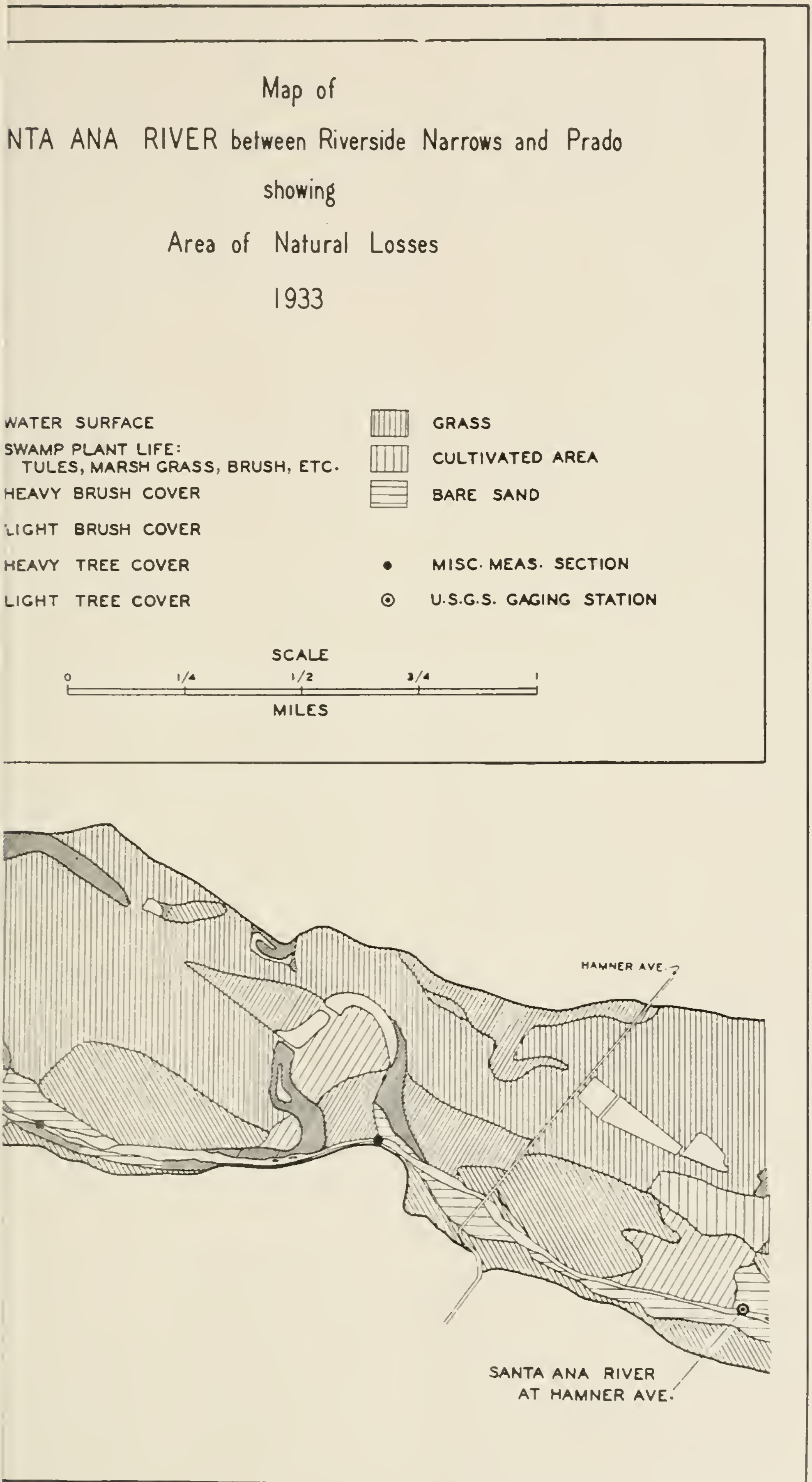
CLASSIFICATION OF BOTTOM LAND ALONG SANTA ANA RIVER, 1933

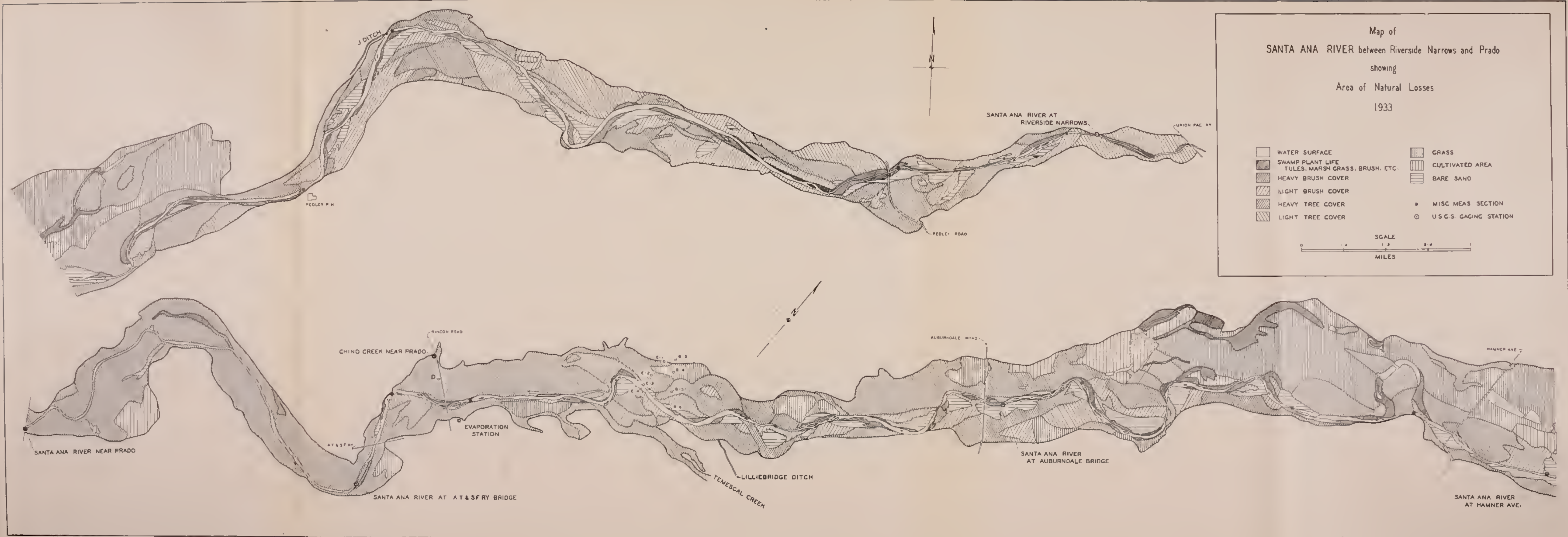
Classification	Hamner Avenue to Atchison, Topeka and Santa Fe Railway bridge	Riverside Narrows to Prado gaging station
	Per cent	Per cent
Water surface	5.5	5.2
Swamp plants, sedges, rushes, etc.	6.4	6.0
Heavy brush cover	7.1	8.8
Light brush cover	10.1	11.9
Heavy tree cover	34.9	37.6
Light tree cover	1.1	2.3
Grass	23.7	18.6
Cultivated	4.8	3.4
Bare sand	6.4	6.2
	100.0	100.0
Total area, acres	2,110	4,040

Howell [a] amply describes part of the area between the Riverside Narrows and Prado gaging stations. He classifies the flora as follows:

"Submerged aquatics of the ponds include *Potamogeton crispus, Zannichellia palustris, Lemna trisulca,* and *Myriophyllum spicatum,* and the floating flora is composed of such widely distributed species as *Azolla filiculoides, Lemna minor,* and *Wolfiella lingulata.* In the shallow water of the marshes are found *Typha angustifolia, Cyperus melanostachyus, Eleocharis rostellata, Scirpus validus, Scirpus americanus, Polygonum hydropiperoides, Radicula nasturtium-aquaticum, Jussiaea californica, Oenanthe sarmentosa, Samolus floribundus, Lycopus americanus, Bidens levis,* and *Helenium puberulum.* A large number of sedges and rushes are found on

[a] Howell, J. T., The Flora of Santa Ana Canyon Region: Madrono, Vol. 1, December, 1929.


Map of
NTA ANA RIVER between Riverside Narrows and Prado
showing
Area of Natural Losses
1933
WATER SURFACE
SWAMP PLANT LIFE:
TULES, MARSH GRASS, BRUSH, ETC.
HEAVY BRUSH COVER
LIGHT BRUSH COVER
HEAVY TREE COVER
LIGHT TREE COVER
GRASS
CULTIVATED AREA
BARE SAND
MISC. MEAS. SECTION
U.S.G.S. GAGING STATION
SCALE
0
1/4
1/2
3/4
1
MILES
HAMNER AVE.
SANTA ANA RIVER
AT HAMNER AVE.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MISC MEAS SECTION
U.S.G.S. GAGING STATION
SCALE
MILES
N
J DITCH
PEDLEY P.H.
SANTA ANA RIVER AT
RIVERSIDE NARROWS
UNION PAC RY
PEDLEY ROAD
N
RINCON ROAD
CHINO CREEK NEAR PRADO
EVAPORATION
STATION
AT & SF RY
SANTA ANA RIVER NEAR PRADO
SANTA ANA RIVER AT AT & SF RY BRIDGE
TEMESCAL CREEK
LILLIEBRIDGE DITCH
AUBURNDALE ROAD
SANTA ANA RIVER
AT AUBURNDALE BRIDGE
HAMNER AVE
SANTA ANA RIVER
AT HAMNER AVE.

the moist flats of the river bottom, among which are *Cyperus laevigatus, Cyperus esculentus, Eleocharis capitata, Eleocharis acicularis, Eleocharis montana, Scirpus cernus, Carex praegracilis, Juncus balticus, Juncus bufonius, Juncus torreyi, Juncus rugulosus,* and *Juncus xiphioides.* Other plants growing on the moist flats with the sedges and rushes are *Equisetum funstonii, Distichlis spicata, Sporobolus asperifolius, Sporobolus airoides, Cynodon dactylon, Paspalum distichum, Cenchrus pauciflorus, Anemopsis californica, Ranunculus cymbalaris, Psoralea orbicularis, Psoralea macrostachya, Lythrum californicum, Epilobium californicum, Hydrocotyle ranunculoides, Hydrocotyle umbellata, Hydrocotyle verticillata, Eustoma silenifolium, Lippia lanceolata, Petunia parviflora, Mimulus cardinalis, Plantago hirtella, Solidago occidentalis, Aster exilis, Baccharis emoryi, Baccharis viminea, Pluchea camphorata, Artemisia vulgaris,* var. *heterophylla.* On the sandy flats of the river bottom grow four species of willow—*Salix laevigata, Salix nigra* var. *vallicola, Salix argophylla,* and *Salix lasiolepis,* besides *Populus fremontii, Populus trichocarpa, Alnus rhombifolia,* and *Platanus racemosa.*"

The species found in this area are representative of the entire area between the Riverside Narrows and Prado gaging stations.

Stream flow records.

In the area discussed in this report there are five gaging stations maintained by the United States Geological Survey. The first of these stations, established in 1919 at the Orange-Riverside County line, is known as the station on the Santa Ana River near Prado. In 1929 a station was established at Riverside Narrows. During the summer periods since 1930 stations have been maintained at Hamner Avenue, the Auburndale Bridge and The Atchison, Topeka & Santa Fe Railway Bridge. The installations at these three stations are removed during the winter, and the location of the stations is subject to a slight change from year to year because of changes in the character of the channel. The approximate location of each of these stations is shown on Plate I.

In order to determine the source of the gain in discharge of the Santa Ana River between Riverside Narrows and Prado, two series of discharge measurements, in June and August, 1931, were made at numerous points along the river. The results are given in Table 2. Additional miscellaneous measurements were made at many of these points during 1931 by the Orange County Flood Control District and the United States Geological Survey, and the results are given in Water-Supply Paper 721 of the Geological Survey.

Table 2 shows that the minimum flow is at some point below the J diversion ditch and above the old Pedley power house of the Southern California Edison Company. On both dates the flow decreased 10 second-feet or more in the first 6-mile stretch of the river channel below Riverside Narrows. Much of this loss might have been caused by the demand made on the water supply by the trees and other vegetation along the river. Not only was the 10 second-feet lost, but any addition that might have been made to the flow of the river in this area from underground sources was also consumed.

This table shows that from the Pedley power house to The Atchison, Topeka & Santa Fe Railway Bridge the Santa Ana River is a gaining stream. The point of maximum flow is at or near the railway bridge. There are very few visible springs in the area, most of the water entering the gravel in the bed of the stream. Hamner Spring is the only spring of any size that contributes to the flow.

If it were not for the natural losses, which are accounted for by plant life, the gains shown in Table 2 would represent the entire contribution of the areas adjacent to the river on the two days given. As this contribution, during the summer, is entirely in the form of ground

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TABLE 2

MEASUREMENTS OF SANTA ANA RIVER BETWEEN RIVERSIDE NARROWS AND PRADO, 1931

Miles	Location	June 3		August 21	
		Time	Discharge (sec.-ft.)	Time	Discharge (sec.-ft.)
0	Riverside Narrows station	7.10 a.m.	36	7.15 a.m.	27
1.3	Pedley Bridge	7.40 a.m.	33	7.55 a.m.	27
4.9	Above J ditch; 1 mile above Pedley power house	9.00 a.m.	30	8.55 a.m.	25
	Diversion by J ditch	9.40 a.m.	5.4	9.30 a.m.	5.4
6.2	Pedley power house	7.05 a.m.	25	8.20 a.m.	17
8.2	Hamner Avenue station	8.30 a.m.	34	7.10 a.m.	24
8.7	Below Hamner Avenue Bridge	11.10 a.m.	36	8.40 a.m.	29
9.5	1 mile below Hamner Avenue Bridge	10.15 a.m.	37	7.40 a.m.	31
11.4	Above Hamner Springs	8.10 a.m.	46	7.40 a.m.	34
	Inflow from Hamner Spring	8.45 a.m.	5.8	8.30 a.m.	3.8
	Diversion Durkee Ditch	9.55 a.m.	4.9	----------	4.2
11.8	Auburndale Bridge station	9.20 a.m.	50	9.55 a.m.	29
13.3	1½ miles below Auburndale Bridge	11.00 a.m.	53	9.20 a.m.	30
	Inflow from Lilliebridge pumps	10.00 a.m.	11	10.00 a.m.	7.5
15.4	Rincon Bridge	10.00 a.m.	75	8.25 a.m.	46
	Inflow from Chino Creek	11.05 a.m.	3.4	9.00 a.m.	2.6
15.8	Below Chino Creek	11.30 a.m.	78	7.40 a.m.	48
16.6	Atchison, Topeka and Santa Fe Railway Bridge station	7.30 a.m.	84	7.10 a.m.	45
19.2	Prado station	8.30 a.m.	79	7.55 a.m.	38

water, it must pass a mass of root systems before appearing in the river as surface water. A typical cross section of the river channel is shown on Plate II. The quantity of water passing the points marked [a] would represent the gain of water in the river if the losses along the channel were reduced to zero.

Effect of natural losses on inflow.

The area along the river channel between the Hamner Avenue and The Atchison, Topeka & Santa Fe Railway Bridge gaging stations was selected for a more detailed study of these natural losses. Graph D on Plate III represents the amount of water that drained out of the

PLATE II

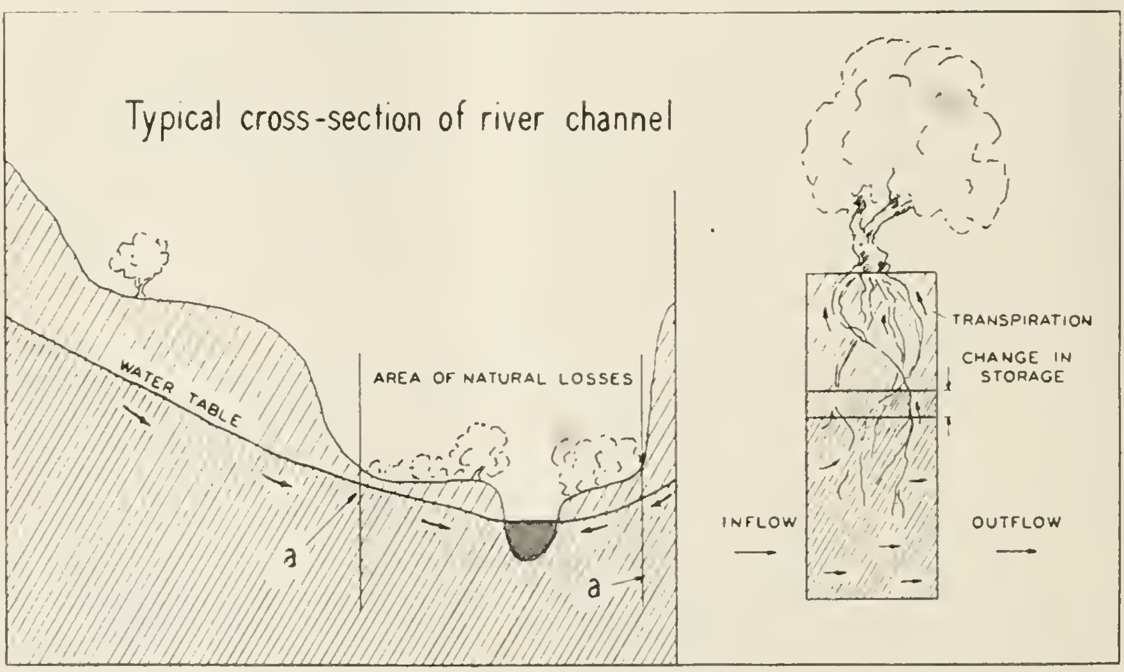
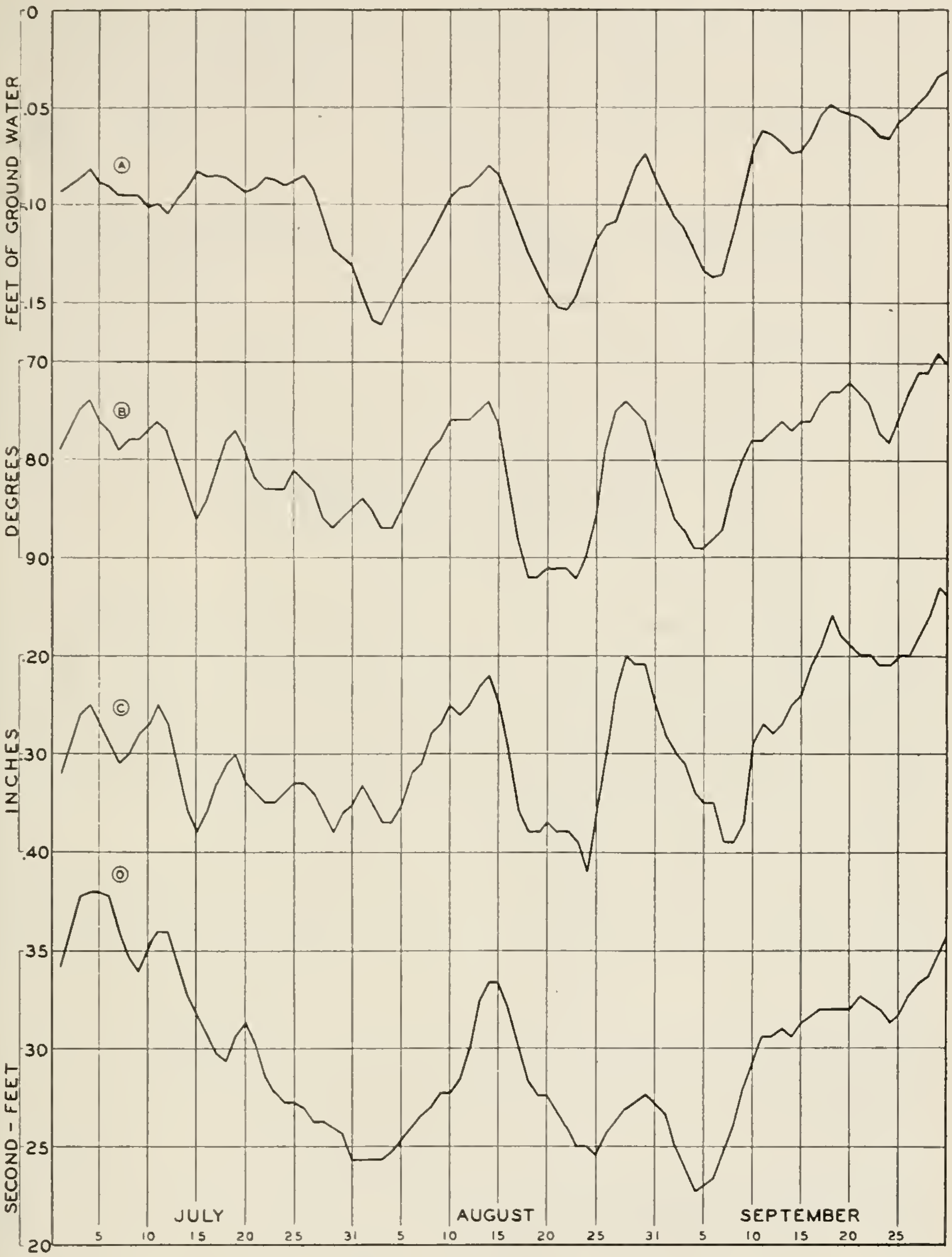


PLATE III



1932
SANTA ANA RIVER

Relationship of Outflow (Hamner Ave. to A.T.& S.F. Ry. Bridge) to Transpiration, Temperature, and Evaporation.

Ⓐ TRANSPIRATION BASED ON WELL D RECORD.
Ⓑ TEMPERATURE AT PRADO.
Ⓒ EVAPORATION AT POMONA.
Ⓞ OUTFLOW HAMNER AVE. TO A.T. & S.F. RY. BRIDGE.
NOTE: 3 DAY MEAN VALUES USED.

area between Hamner Avenue and the railway bridge as surface flow in July, August, and September, 1932. This outflow was computed by subtracting the discharge measured at the Hamner Avenue gaging station from the discharge measured at the railway bridge station. If there had been no losses by evaporation and transpiration in this stretch, this water would have represented the ground water inflow to the area.

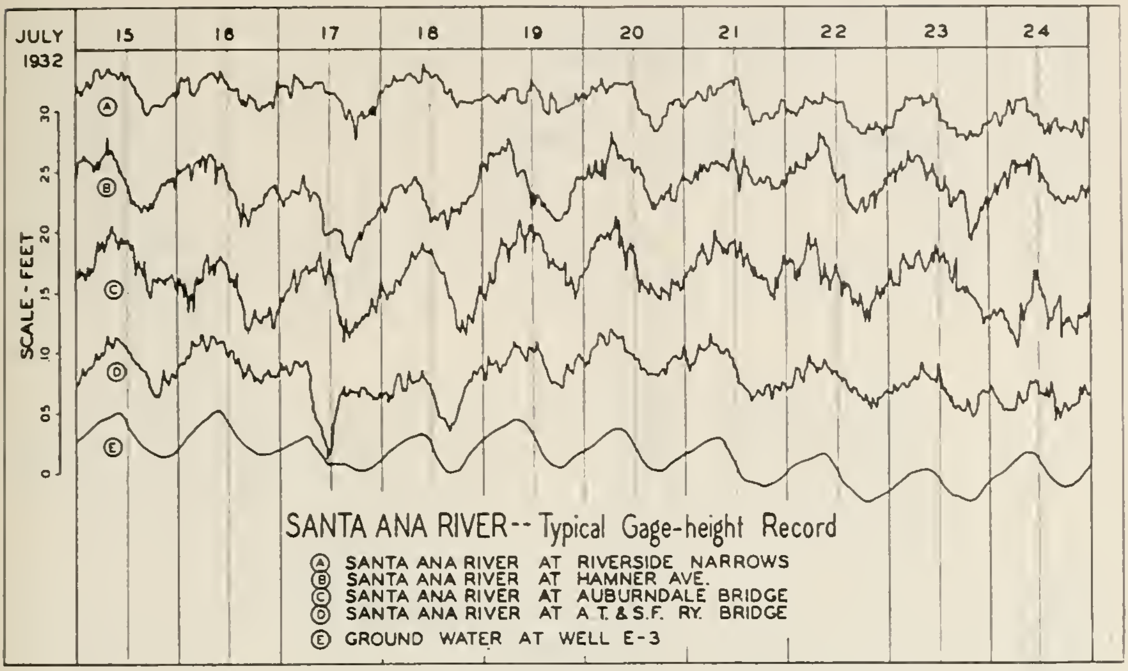
During this period weekly observations were made at Well B-3, just outside the zone of natural losses. These observations show that the water table gradually declined from the middle of May, 1932 (when the observations were begun) to September 8. The weekly decline ranged from 0.05 to 0.10 foot. After September 8 the water table showed a gradual rise until December 1, when observations were discontinued. If the stage of the water table is an indication of the rate of inflow, then the rate of inflow gradually decreased from the middle of May until September 8. Therefore, it would seem that the fluctuations in the outflow, as shown on graph D, must have been developed by the evaporation and transpiration in the area of natural losses, between the points marked [a] on Plate II.

In computing the daily outflow numerous errors arise because of the time elements and inaccuracies in the data. The effect on the water table of either a day of very heavy natural losses or a day of light losses might not be completely transmitted to the discharge into the river for several hours. For these reasons it was decided to compute all the daily data of discharge into means for overlapping three-day periods. The records for temperature, evaporation, and transpiration were converted into corresponding three-day means.

During the summer all the flow in the Santa Ana River below Riverside comes from underground sources except during periods of direct run-off due to rainfall. Records for 3 years at the summer stations seem to indicate that the water surface of the river fluctuates practically in unison at all the stations, unless affected by other than natural conditions. A 10-day period of these records has been plotted on Plate IV, which shows how closely each record follows the others. The numerous minor fluctuations exhibited in these gage-height records are caused mainly by the movement of sand waves past the stations. To some extent the scouring and building up of the downstream channel will likewise cause such fluctuations. The river is seldom more than 2 feet deep and usually less than 50 feet wide at each of these stations. Plate IV shows that the daily cycle is fairly uniform at all points. At each station the maximum stage occurs a few hours before noon and the minimum stage between 3 and 6 o'clock in the afternoon. The river can be compared to a long reservoir, the water surface of which passes through a daily cycle. Not only do the daily fluctuations occur in unison throughout this stretch of the river, but the longer cycles, such as that indicated by the record for August 5 to 25, show almost uniform change in the water surface of the river at the several gaging stations.

The E series of wells were dug and water-stage recorders installed on them during the spring of 1932, through aid furnished by the Orange County Flood Control District. Well E-1 was dug at the toe of a small bench parallel to the river channel, 1000 feet from the river.

PLATE IV



The root systems near this well form the outside edge of the zone of natural losses. The well is surrounded by a heavy growth of salt grass. Well E-2, situated 430 feet from the river, is surrounded by young trees. Well E-3 is only 30 feet from the edge of the river. Well E-4 was placed in the river at a point where it is about 130 feet wide. The locations of the wells in the E group are plotted on Plate V, which shows also the maximum and minimum altitude of the water table for July 20, 1932, as plotted from the records obtained in these wells. This plate shows the slope of the water table toward the river. Ten-day records of three of these wells, together with the gage-height record of the station at The Atchison, Topeka & Santa Fe Railway Bridge, have been plotted on Plate VI.

An inspection of plates IV and VI shows the marked similarities between the ground water table at well E-3 and the gage-height record at the railway bridge station. It appears likely that the daily fluctuations in the river are caused chiefly by the fluctuations in the discharge of ground water into the river.

As shown on Plate I, the Lilliebridge Ditch discharges water into the river above the E group of wells. For a short time on both September 5 and 6 the discharge from the ditch to the river was shut down. As a result the discharge in the river dropped. Plate VI shows that the water table at well E-3 immediately dropped also, even though it was several tenths of a foot higher than the water in the river. As shown on Plate IV, the shutting down of the ditch on July 17 caused a similar change in the water level in well E-3. Here again, the close interrelationship of the ground water and the surface water of the river is apparent.

The site of well E-4 was selected because all the recorders along the river were at relatively narrow sections, and it was desirable to determine whether or not the daily river fluctuations at wide sections would be similar to those shown on Plate IV. The season's record at this well showed that daily fluctuations were entirely obscured by the

PLATE V

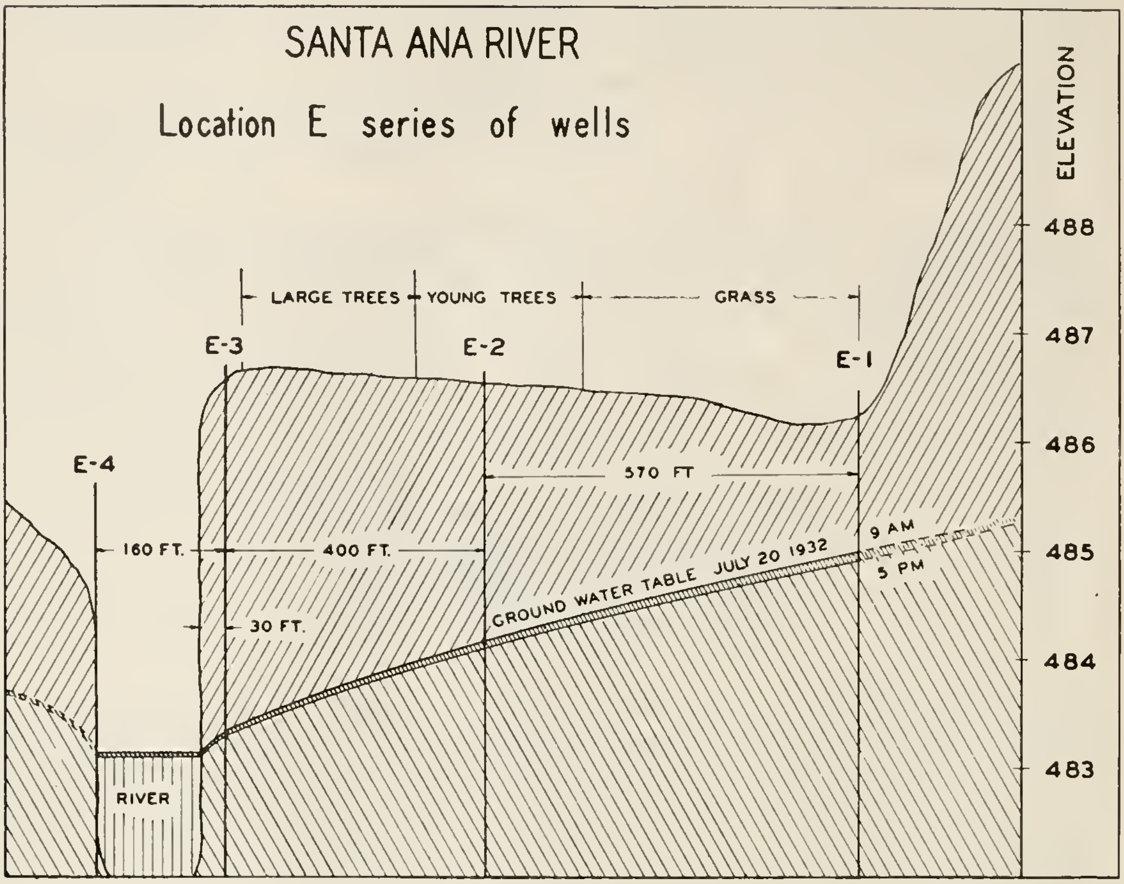
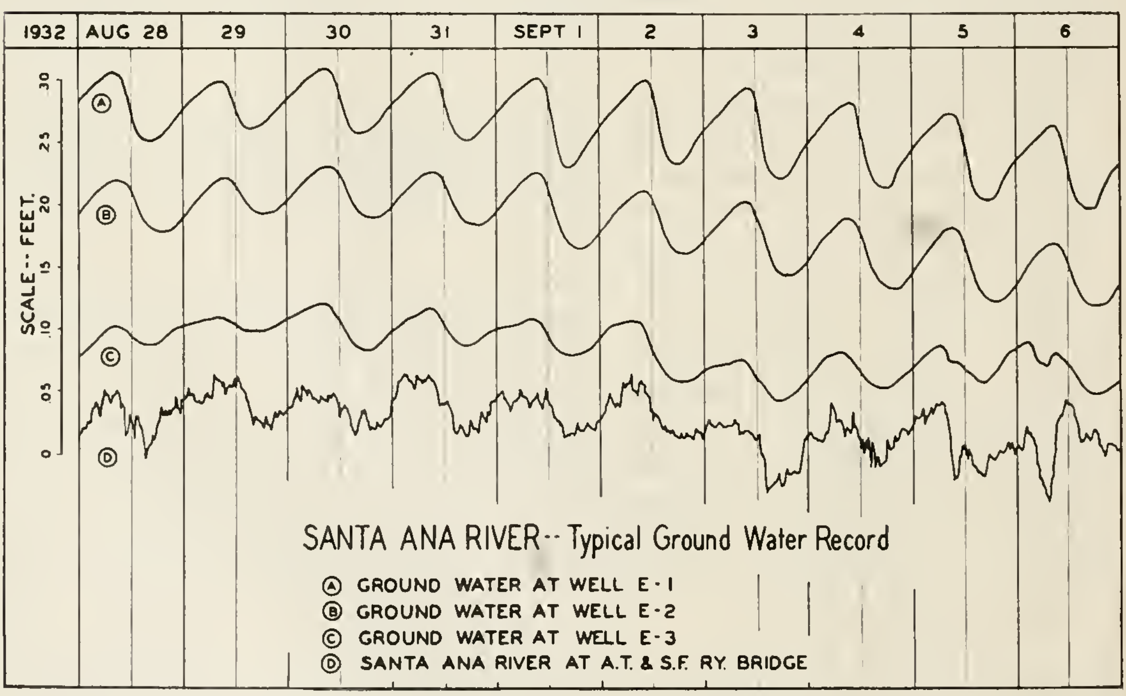


PLATE VI



movements of sand waves and scour in the channel. The record seemed to have little if any relationship to the records at well E-3 or to those of the other river stations. This would seem to indicate that on very wide sections of river channel the effect of ground water fluctuations on the stage of the water in the river is greatly reduced. In wells located along the river, such as well E-4, the condition of the channel downstream from the station apparently controls, to a major degree, the level of the water surface at the well. Plate I shows that in this stretch of the river, sections as wide as that at well E-4 are few and cover only short distances of river channel.

Computations of changes in storage and corrected outflow.

The following equation gives the entire disposal of all the water entering any area along the river:

inflow = Natural losses ± Change in ground water storage + Outflow.

On Plate II the different members of this equation are illustrated. The inflow is the quantity of ground water passing the points marked [a]; the natural losses are the quantity of water discharged through transpiration and through evaporation of both ground water and river water; and the outflow is the measured gain in the flow of the river in the area.

It is possible for the natural losses to occur either from the ground water storage or from the inflow. If the losses are drawn entirely from storage, then the measured outflow will represent the inflow to the area. On the other hand, if the losses are drawn entirely from the inflow the storage will remain unchanged, and the outflow will be equal to the inflow minus the natural losses. Practically the entire period of record falls between these two extremes. Possibly these relations can best be illustrated by inserting figures in the basic formula as follows:

	Inflow	=	Natural losses	±	Change in storage	+	Outflow.
	Second feet		*Second feet*		*Second feet*		*Second feet*
(*a*)	50	=	10	+	5	+	35
(*b*)	50	=	10	+	0	+	40
(*c*)	50	=	10	—	5	+	45

In each of these computations the inflow and natural losses remain constant, yet the measured outflow varies from 35 to 45 second-feet. In [a], 5 second-feet of the inflow was placed in storage, leaving 35 second-feet as outflow. In [b], the storage did not change; consequently the outflow represents inflow minus the natural losses. In [c], 5 second-feet of the 10 second-feet of natural losses was drawn from storage, which would leave 45 second-feet of the inflow to appear as outflow. From these computations it is evident that if the inflow remains constant, then the outflow plus or minus the change in storage must vary inversely with the natural losses. Also, on days when the changes in storage are equal, then the outflow will vary inversely with the natural losses.

The change in storage to be used in this equation was determined by the following method:

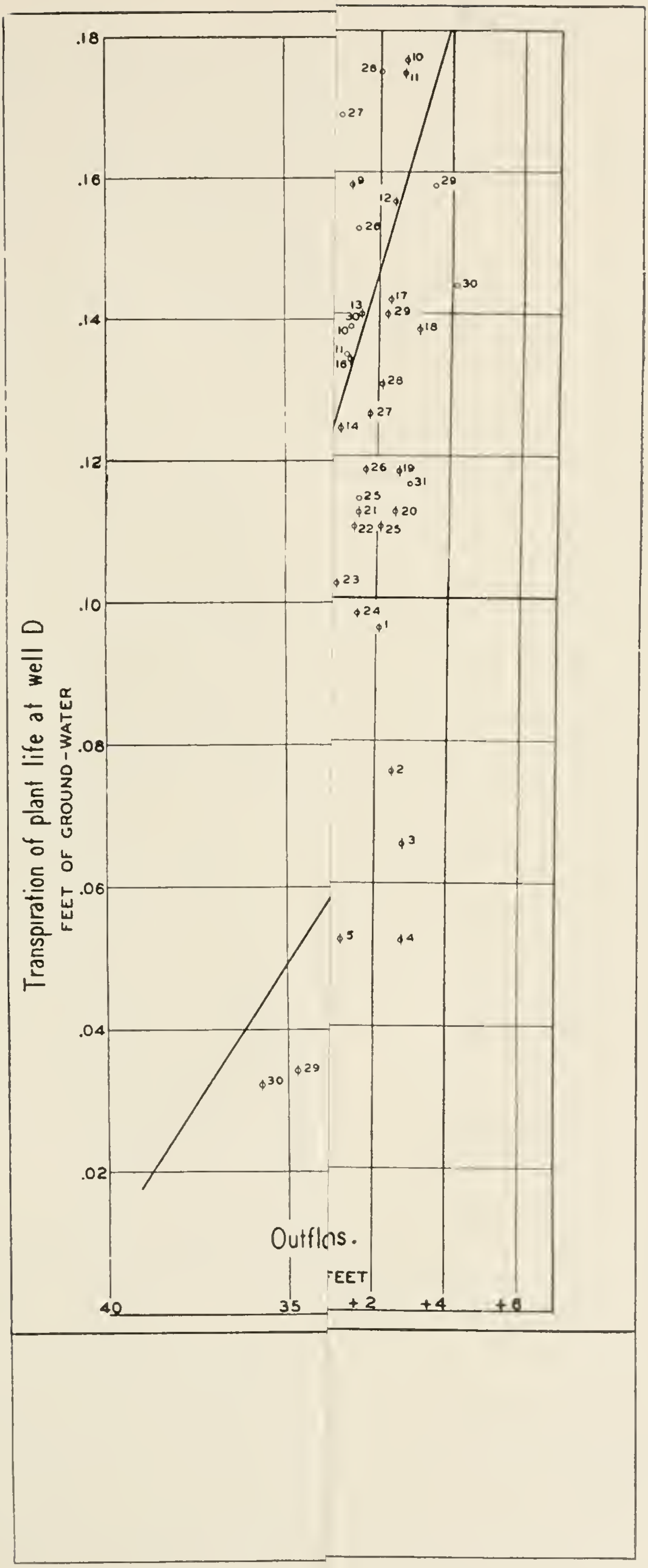
White,[a] in his work on daily fluctuations of the water table in the Escalante Valley, Utah, developed the formula $q = y\ (24r \pm s)$ in which q is the depth of water used by the plants, y is the specific yield of the water-bearing material, r is the hourly rate of rise of the water table from midnight to 4 a.m., and s is the net fall or rise of the water table during the 24-hour period. The hours of midnight to 4 a.m. were selected in determining the rate r, because during these hours the transpiration and evaporation losses would be at a minimum.

As shown at the left on Plate VII, the measured daily outflow between Hamner Avenue and The Atchison, Topeka and Santa Fe Railway Bridge was plotted against the daily transpiration $(24r \pm s)$ as computed from the record of well D. The $(24r \pm s)$ expressed in feet of ground water represents the amount the water table would have dropped if there was no recharge. The figure opposite each observation represents the day of the month. The observations were next classified as to rising or falling water table, representing increase or decrease in storage. A curve was drawn such that it represents the average slope of a series of shorter lines drawn through consecutive points, having much the same change in storage. As a rule most of the observations to the left of the curve showed a drop in storage, while those to the right showed a gain.

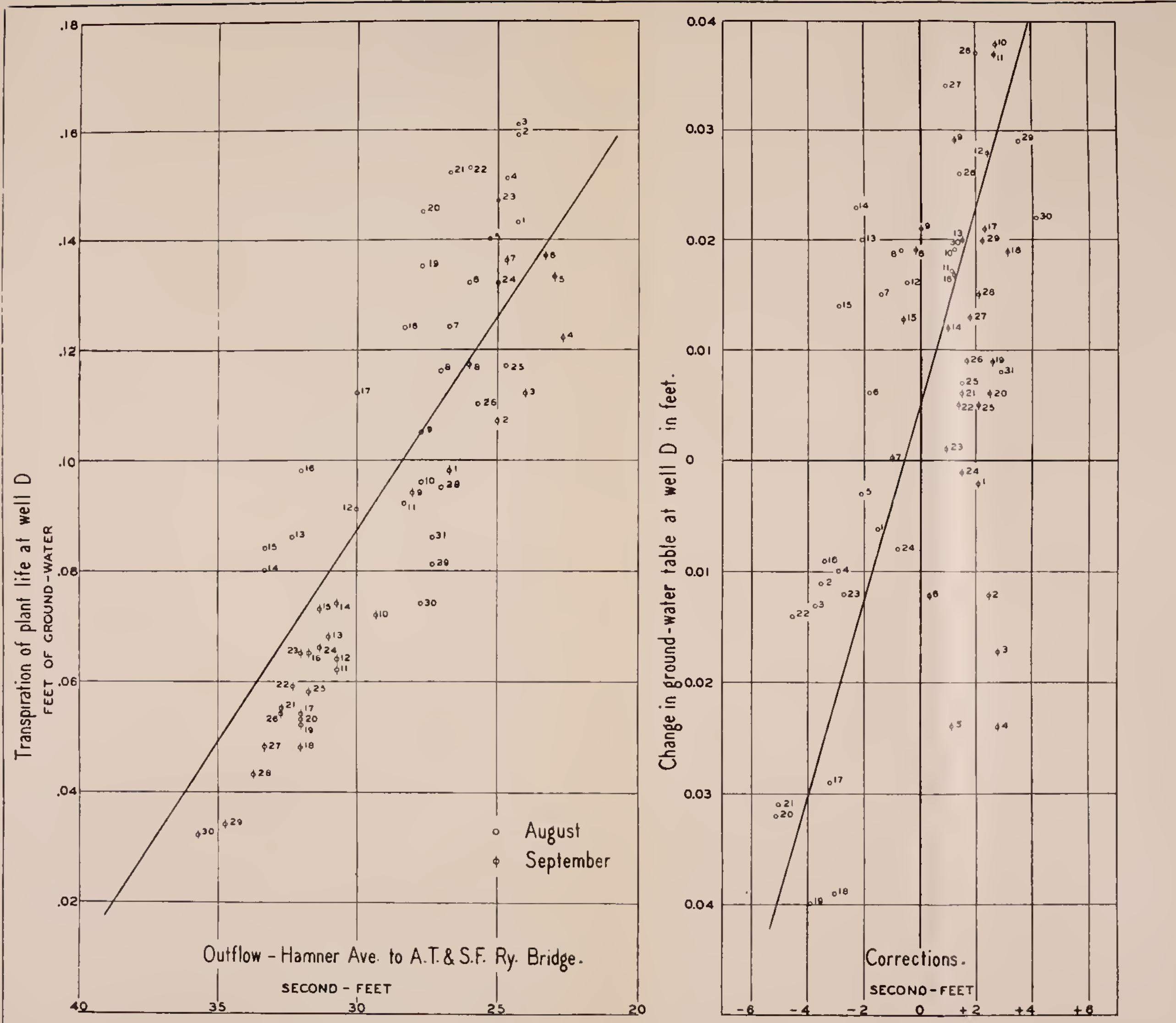
As stated before, outflow ± change in storage should vary inversely with natural losses, provided the inflow does not change. It was next assumed that the difference between the quantity computed from this curve and the actual outflow represented the change in storage. For example, on September 30 the outflow was 35.7 second-feet. The curve shows that the outflow should have been about 37.2 second-feet if there had not been any change in storage. On this day the water table at well D came up 0.020 foot. The assumption was made that the building up of this storage by 0.020 foot required the 1.5 second-feet that failed to appear in the river. Likewise on August 19 the water table dropped 0.040 foot. The outflow for this day was 27.7 second-feet. The curve indicates that the discharge should have been 23.8 second-feet if there had been no change in storage. It was therefore assumed that on this day the outflow was 3.9 second-feet greater than that shown by the curve, because its equivalent was drawn from storage to satisfy the demands represented by the natural losses.

The records of ground water fluctuations obtained on a few other wells in this area indicate that as a rule the daily change in storage was about in direct proportion to the change in storage at well D. It was therefore assumed that the changes shown by the record obtained at well D were in direct proportion to the mean changes in storage in the entire area between the Hamner Avenue and The Atchison, Topeka and Santa Fe Railway Bridge gaging stations. The daily changes in storage at well D were then plotted against the excess or deficiency in the outflow. If the inflow to the area had remained constant and the changes in storage at well D had been representative of the area, these points should have plotted a well-defined curve. The movement of certain plotted points from the left of the curve to the right indicates

[a] White, W. N., A method of estimating ground water supplies based on discharge by plants and evaporation from soil: U. S. Geol. Survey Water-Supply Paper 659, pp. 1–105, 1932. White states that the principle underlying this formula was in part suggested by G. E. P. Smith in his earlier work (p. 8).



Transpiration of plant life at well D
FEET OF GROUND-WATER
.18
.16
.14
.12
.10
.08
.06
.04
.02
Outflos.
FEET
40
35
+2
+4
+6



SANTA ANA RIVER

1932

Method used in computing changes in ground-water storage.

Based on the records from well D.

that the inflow decreased during the period. For this reason, curves were drawn through small groups of consecutive observations, as the change in inflow would be little for short periods.

The average slope of these curves indicates that a change in stage of the water table amounting to 0.001 foot represents the equivalent of a change in outflow of 0.11 second-foot. If the changes in stage at well D represent the average for the area, then the average specific yield for the section of the gravel unwatered during the season is about 12 per cent. Using the factor of 0.11 second-foot per 0.001 foot of change in water level, the change in storage for the entire record was converted into second-feet. The daily measured outflow was then corrected for changes in storage. The term "corrected outflow" as used throughout the remainder of this report represents the measured outflow plus or minus the change in storage.

Computations of natural losses and inflow between Hamner Avenue and The Atchison, Topeka and Santa Fe Railway Bridge stations.

In discussing the basic formula for the inflow, it was stated that if the inflow remains constant, the outflow plus or minus changes in storage will vary inversely with the natural losses. On Plate VIII are plotted the relations between the daily corrected outflow and the daily evaporation and temperature for July, August, and September, 1932. The figure opposite each point represents the day of the month. The fact that the observations as plotted shifted to the right is apparently due to gradual decrease in rate of inflow as the season progressed. The trend of consecutive observations had more to do in the development of the slope of the monthly curves than the mere averaging of the points, because during short periods the inflow would change little, leaving only two principal variables—namely, corrected outflow and natural losses. Thus the third variable is practically eliminated, leaving a close relation between corrected outflow and temperature or evaporation, as represented by the slope of the curve. Curves similar to those on Plate VIII were also drawn for 1931.

The temperature record was obtained from the thermograph record at the Prado evaporation station. A study of the ground water fluctuations showed that practically all the transpiration occurred between the hours of 8 a.m. and 4 p.m. each day. For this reason the daily temperature figures here used represent the average temperature for the period of 8 a.m. to 4 p.m. The data seem to indicate that little or no transpiration occurs in this area when the average daily temperature is below 60°. If the natural losses in this area varied in direct proportion with the temperature above 60°, then for each 10° more than 60° the loss would have amounted to 7.7 second-feet in 1931 and 8.0 second-feet in 1932.

For the period in 1931 the records from the evaporation pan at Prado were used in plotting the relation of evaporation to corrected outflow. In 1932, however, owing to imperfect operation of the apparatus, the daily evaporation record at Prado was not entirely satisfactory. For this reason, the record from the evaporimeter at Pomona, operated by C. A. Taylor, of the Bureau of Agricultural Engineering, was used for 1932. This evaporimeter is less than 15 miles from the Santa Ana River area, and the evaporation there should

that the inflow decreased during the period. For this reason, curves were drawn through small groups of consecutive observations, as the change in inflow would be little for short periods.

The average slope of these curves indicates that a change in stage of the water table amounting to 0.001 foot represents the equivalent of a change in outflow of 0.11 second-foot. If the changes in stage at well D represent the average for the area, then the average specific yield for the section of the gravel unwatered during the season is about 12 per cent. Using the factor of 0.11 second-foot per 0.001 foot of change in water level, the change in storage for the entire record was converted into second-feet. The daily measured outflow was then corrected for changes in storage. The term "corrected outflow" as used throughout the remainder of this report represents the measured outflow plus or minus the change in storage.

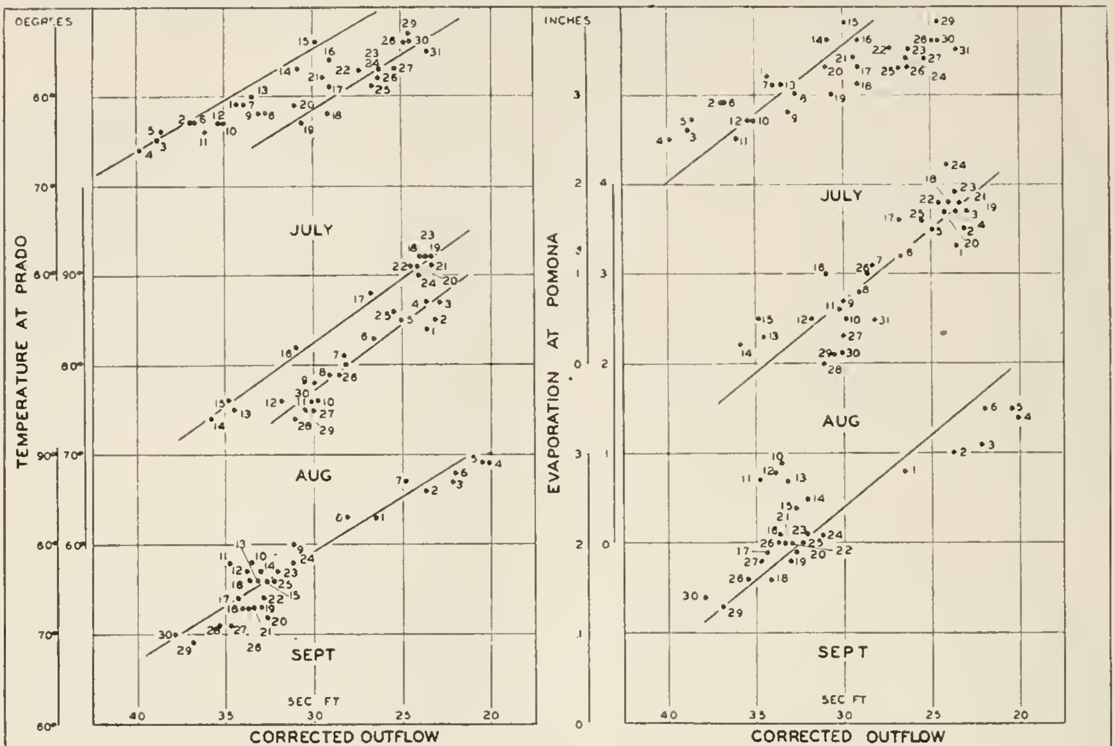
Computations of natural losses and inflow between Hamner Avenue and The Atchison, Topeka and Santa Fe Railway Bridge stations.

In discussing the basic formula for the inflow, it was stated that if the inflow remains constant, the outflow plus or minus changes in storage will vary inversely with the natural losses. On Plate VIII are plotted the relations between the daily corrected outflow and the daily evaporation and temperature for July, August, and September, 1932. The figure opposite each point represents the day of the month. The fact that the observations as plotted shifted to the right is apparently due to gradual decrease in rate of inflow as the season progressed. The trend of consecutive observations had more to do in the development of the slope of the monthly curves than the mere averaging of the points, because during short periods the inflow would change little, leaving only two principal variables—namely, corrected outflow and natural losses. Thus the third variable is practically eliminated, leaving a close relation between corrected outflow and temperature or evaporation, as represented by the slope of the curve. Curves similar to those on Plate VIII were also drawn for 1931.

The temperature record was obtained from the thermograph record at the Prado evaporation station. A study of the ground water fluctuations showed that practically all the transpiration occurred between the hours of 8 a.m. and 4 p.m. each day. For this reason the daily temperature figures here used represent the average temperature for the period of 8 a.m. to 4 p.m. The data seem to indicate that little or no transpiration occurs in this area when the average daily temperature is below 60°. If the natural losses in this area varied in direct proportion with the temperature above 60°, then for each 10° more than 60° the loss would have amounted to 7.7 second-feet in 1931 and 8.0 second-feet in 1932.

For the period in 1931 the records from the evaporation pan at Prado were used in plotting the relation of evaporation to corrected outflow. In 1932, however, owing to imperfect operation of the apparatus, the daily evaporation record at Prado was not entirely satisfactory. For this reason, the record from the evaporimeter at Pomona, operated by C. A. Taylor, of the Bureau of Agricultural Engineering, was used for 1932. This evaporimeter is less than 15 miles from the Santa Ana River area, and the evaporation there should

PLATE VIII



SANTA ANA RIVER
1932

Relationship between Temperature, Evaporation and Corrected Outflow from Hamner Ave. to A.T.&S.F. Ry.

vary directly with the evaporation at Prado. The 1931 data (Prado) seem to indicate that for each 0.10 inch of evaporation from the standard Weather Bureau gage the corrected outflow is reduced 6.0 second-feet. The 1932 data (Pomona) gave 6.3 second-feet for each 0.10 inch of evaporation from the evaporimeter.

Next, the relation of the transpiration at well D to the corrected outflow was determined by the use of the formula $(24r \pm s)$, taken from the equation $q = y\ (24r \pm s)$. The results showed that for each 0.10 foot of ground water transpired, as computed by the formula $(24r \pm s)$, there was a loss of 15.4 second-feet in the corrected outflow in 1931 and 17.6 second-feet in 1932.

From the data determined from Plate VIII and similar graphs Table 3 has been developed. This table gives the estimated inflow between the gaging stations at Hamner Avenue and The Atchison, Topeka and Santa Fe Railway Bridge. Column A represents the daily measured outflow from the area, that is, the gain in the flow of the river between the two gaging stations. The daily corrected outflow (outflow ± change in storage) is given in column B. If the natural losses in the area varied in direct proportion to the transpiration recorded at well D, the figures in column C represent these losses in second-feet. Then by adding columns B and C, the daily inflow is determined.

Likewise, columns D and E represent the natural losses in the area if evaporation and temperature, respectively, are taken as indicators of these losses. After these daily figures of natural losses were obtained, the means for each 5-day period were determined for each of the three methods. Then these results were in turn averaged. The addition of the natural losses to the corrected outflow gives the inflow to the area.

The data given in Table 3 have been plotted on plates IX and X. The estimated inflow represents the amount of water passing the points marked [a] on Plate II, or the outside edge of the area of natural losses. On plates IX and X the difference between the graphs marked "mean

PLATE IX

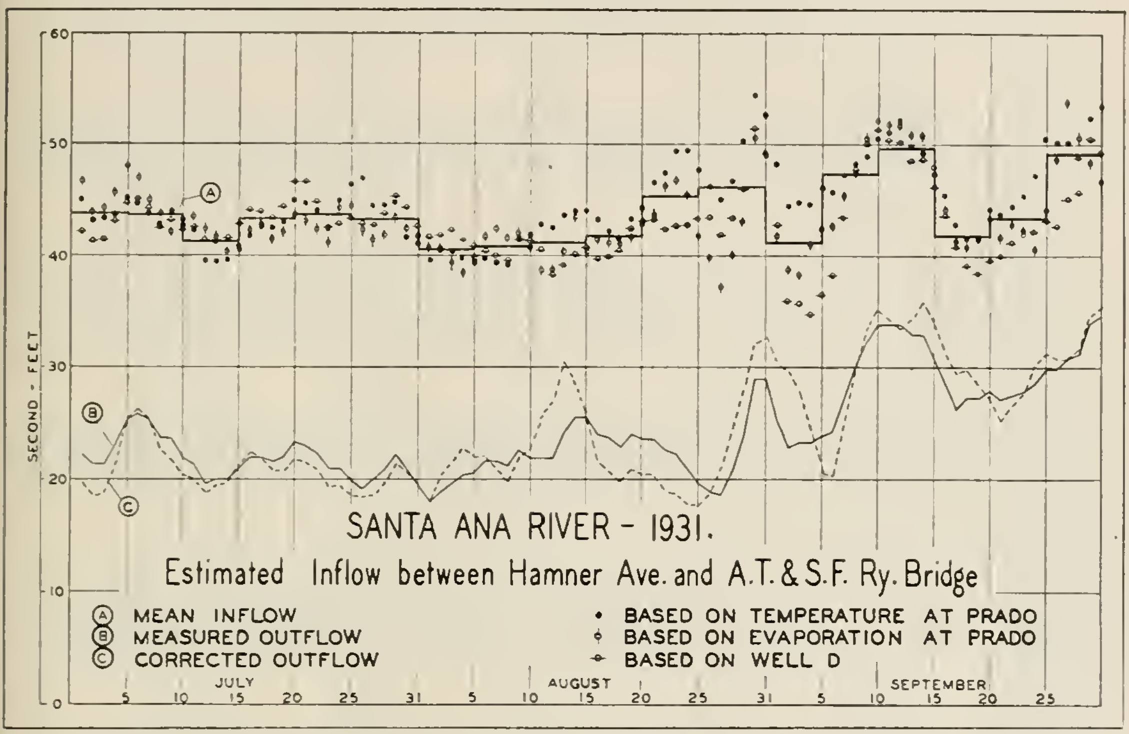


PLATE X

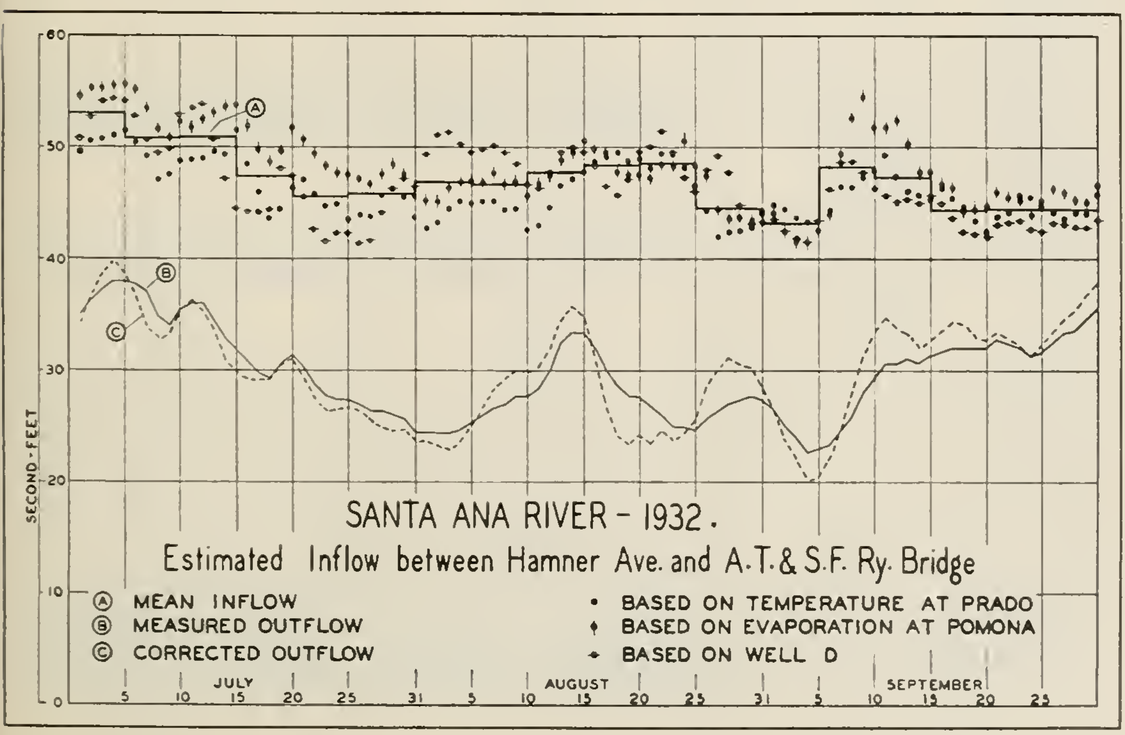


TABLE 3

NATURAL LOSSES AND INFLOW, IN SECOND-FEET, ON SANTA ANA RIVER, FROM HAMNER AVENUE TO THE ATCHISON, TOPEKA & SANTA FE RAILWAY BRIDGE

Date[1]	Measured outflow	Corrected outflow (outflow ± change in storage)	Natural losses based on: Transpiration recorded at Well D		Evaporation recorded at Prado		Temperature recorded at Prado		Average results	
			Natural losses	Inflow	Natural losses	Inflow	Natural losses	Inflow	Natural losses	Inflow
	A	B	C	B+C	D	B+D	E	B+E	(C+D+E)/3	B+(C+D+E)/3
1931—										
July 1	22.3	19.7	22.5	42.2	23.9	46.6	25.4	45.1		
July 2	21.3	18.5	22.9	41.4	25.4	43.9	25.4	43.9		
July 3	21.3	18.7	22.8	41.5	25.7	44.4	24.6	43.3		
July 4	23	21.2	21.9	43.1	24.6	45.8	22.3	43.5		
July 5	25.3	25	19.9	44.9	23.1	48.1	20.0	45.0		
July 1–5	----------	20.6	22.0	----------	24.5	----------	23.5	----------	23.3	43.9
July 6	26	26.2	19.0	45.2	20.8	47	18.5	44.7		
July 7	25.3	25.3	19.0	44.3	19.7	45	18.5	43.8		
July 8	23.7	22.6	20	42.6	21.1	43.7	20	42.6		
July 9	23.7	21.7	21.4	43.1	20.4	42.1	22.3	44		
July 10	22	20.2	22	42.2	23	43.2	22.3	42.5		
July 6–10	----------	23.2	20.3	----------	21	----------	20.3	----------	20.5	43.7
July 11	21.3	20	22.6	42.6	23.4	43.4	22.3	42.3		
July 12	19.7	18.8	22.6	41.4	23.5	42.3	20.8	39.6		
July 13	20	19.4	21.9	41.3	22.2	41.6	20	39.4		
July 14	20	19.7	21.9	41.6	20.5	40.2	20	39.7		
July 15	21	21.3	21.6	42.9	19.9	40.4	19.3	40.6		
July 11–15	----------	19.8	22.1	----------	21.7	----------	20.5	----------	21.4	41.2
July 16	22	22.4	21.7	44.1	19.7	42.1	19.3	41.7		
July 17	22	22	22	44	20.7	42.7	20.8	42.8		
July 18	21.7	20.9	22.5	43.4	20.6	41.5	21.6	42.5		
July 19	22	20.7	23.6	44.3	21.3	42	22.3	43		
July 20	23.3	21.8	24.8	46.6	22	43.8	23.1	44.9		
July 16–20	----------	21.6	22.9	----------	20.9	----------	21.4	----------	21.7	43.3

July 21	23	21.6	25.1	46.7	21.5	43.1	23.1	44.7		
July 22	22.3	20.9	24	44.9	21.3	42.2	23.1	44		
July 23	21	19.4	23.2	42.6	21.8	41.2	23.1	42.5		
July 24	21	19.6	23.2	42.8	24.5	44.1	25.4	45		
July 25	20	18.6	24.8	43.4	25.8	44.4	27.7	46.3		
July 21-25	....	20	24.1	....	23	....	24.5	....	23.8	43.8
July 26	19.3	18.4	24.5	42.9	24	42.4	28.5	46.9		
July 27	20	18.6	24.2	42.8	22.8	41.4	26.9	44.5		
July 28	21	19.9	23.9	43.8	21.9	41.8	24.6	44.5		
July 28	22.3	21.4	24	45.4	22	43.4	22.3	44.7		
July 30	21	20.8	23.6	44.4	21.7	42.5	20.8	41.6		
July 31	19.3	19.5	23.1	42.6	22.2	41.7	21.6	41.1		
July 26-31	....	19.8	23.9	....	22.4	....	24.1	....	23.4	43.2
Aug. 1	18.0	18.0	23.6	41.6	22.7	40.7	21.6	39.6		
Aug. 2	19.0	20.5	21.4	41.9	20	40.5	20	40.5		
Aug. 3	19.7	21.7	20.6	42.3	17.7	39.4	18.5	40.2		
Aug. 4	20.3	22.8	18.6	41.4	15.7	38.5	17.0	39.8		
Aug. 5	20.7	22	18.9	40.9	17.8	39.8	17.7	39.7		
Aug. 1- 5	....	21	20.6	....	18.8	....	19.0	....	19.5	40.5
Aug. 6	21.7	22.1	18.3	40.4	19.8	41.9	17.7	39.8		
Aug. 7	21.7	20.9	19.1	40	21.5	42.4	18.5	39.4		
Aug. 8	21.3	19.9	19.7	39.6	21.7	41.6	19.2	39.1		
Aug. 9	22.7	22	19.6	41.6	19.4	41.4	20	42		
Aug. 10	22	22.7	18.8	41.5	18.1	40.8	19.2	41.9		
Aug. 6-10	....	21.5	19.1	....	20.1	....	18.9	....	19.4	40.9
Aug. 11	22	25.8	14.8	40.6	13.0	38.8	17.0	42.8		
Aug. 12	22	27	11.2	38.2	11.8	38.8	15.4	42.4		
Aug. 13	24.3	30.6	8.5	39.1	9.8	40.4	13.1	43.7		
Aug. 14	25.7	28.6	11.5	40.1	14.9	43.5	15.4	44.0		
Aug. 15	25.7	25.6	15.2	40.8	14.9	40.5	18.5	44.1		
Aug. 11-15	....	27.5	12.2	....	12.9	....	15.9	....	13.7	41.2
Aug. 16	24	21.6	18.2	39.8	20	41.6	21.6	43.2		
Aug. 17	23.7	20.6	19.4	40	20.5	41.1	21.6	42.2		
Aug. 18	23	19.9	20.5	40.4	21.3	41.2	21.6	41.5		
Aug. 19	24	21	21.6	42.6	20.7	41.7	22.3	43.3		
Aug. 20	23.7	20.6	22.5	43.1	22.4	43	23.8	44.4		
Aug. 16-20	....	20.7	20.4	....	21	....	22.2	....	21.2	41.9

[1] The figures are 3-day means—for example, those given for "July 1" represent the mean for June 30 and July 1 and 2.

TABLE 3—Continued

NATURAL LOSSES AND INFLOW, IN SECOND-FEET, ON SANTA ANA RIVER, FROM HAMNER AVENUE TO THE ATCHISON, TOPEKA & SANTA FE RAILWAY BRIDGE

Date[1]	Measured outflow	Corrected outflow (outflow ±) change in storage)	Natural losses based on						Average results	
			Transpiration recorded at Well D		Evaporation recorded at Prado		Temperature recorded at Prado		Natural losses	Inflow
			Natural losses	Inflow	Natural losses	Inflow	Natural losses	Inflow	$\frac{C+D+E}{3}$	$B+\frac{C+D+E}{3}$
	A	B	C	B+C	D	B+D	E	B+E		
1931—										
Aug. 21	23.7	20.4	22.8	43.2	23.3	43.7	26.2	46.6		
Aug. 22	22.7	19.0	23.4	42.4	27.2	46.2	28.5	47.5		
Aug. 23	22.3	18.8	23.9	42.7	28.1	46.9	30.8	49.6		
Aug. 24	21	17.9	25	42.9	27.7	45.6	31.6	49.5		
Aug. 25	19.7	17.7	25.6	43.3	24.1	41.8	30	47.7		
Aug. 21-25		18.8	24.1		26.1		29.4		26.5	45.3
Aug. 26	19	18.4	25.1	43.5	21.4	39.8	27.7	46.1		
Aug. 27	18.7	21.1	20.8	41.9	16.0	37.1	23.9	45		
Aug. 28	20.7	24.5	18.8	43.3	15.6	40.1	22.3	46.8		
Aug. 29	[2]24	27.8	18.2	46	15.5	43.3	22.3	50.1		
Aug. 30	[2]29	32.1	19.2	51.3	18.4	50.5	22.3	54.4		
Aug. 31	[2]29	32.8	16.2	49.0	16.4	49.2	20	52.8		
Aug. 26-31		26.1	19.7		17.2		23.1		20.0	46.1
Sept. 1	25.3	30.5	12.3	42.8	11.4	41.9	17.7	48.2		
Sept. 2	23	29.9	7.1	37	9.0	38.9	14.6	44.5		
Sept. 3	23.3	27.9	7.8	35.7	10.4	38.3	17.0	44.9		
Sept. 4	23.3	24.7	10.2	34.7	16.3	41	20	44.7		
Sept. 5	24	20.7	15.8	36.5	21.6	42.3	25.4	46.1		
Sept. 1-5		26.8	10.6		13.7		18.9		14.4	41.2
Sept. 6	24.3	20.3	18.0	38.3	22.4	42.7	25.4	45.8		
Sept. 7	27.3	24.9	18.6	43.5	20.5	45.4	22.3	47.2		
Sept. 8	30	29.8	18.0	47.8	17.9	47.7	18.5	48.3		
Sept. 9	32.3	33.6	16.6	50.2	16.7	50.3	15.4	49		
Sept. 10	34	35.2	16.2	51.4	17.0	52.2	15.4	50.6		
Sept. 6-10		28.8	17.5		18.9		19.4		18.6	47.4

Sept. 11	34	34.2	16.2	50.4	17.6	51.8	17.0	51.2		
Sept. 12	31	33.6	16.5	50.1	18.1	51.7	18.5	52.1		
Sept. 13	33	34.3	14.3	48.6	16.6	50.9	15.4	49.7		
Sept. 14	33	36	12.8	48.8	14.6	50.6	13.1	49.1		
Sept. 15	30.7	34.1	12.0	46.1	13.9	48	13.1	47.2		
Sept. 11–15		34.4	14.4		16.2		15.4		15.3	49.7
Sept. 16	28.7	31.5	12.3	43.8	12.7	44.2	13.9	45.4		
Sept. 17	26.3	29.7	11.2	40.9	11.6	41.3	13.1	42.8		
Sept. 18	27.3	29.9	9.2	39.1	11.0	40.9	11.6	41.5		
Sept. 19	27.3	28.4	10.2	38.6	13.1	41.5	13.1	41.5		
Sept. 20	28	27.2	12.5	39.7	16.4	43.6	17.0	44.2		
Sept. 16–20		29.3	11.1		13.0		13.7		12.6	41.9
Sept. 21	27.3	25.2	14.8	40	16.5	41.7	18.5	43.7		
Sept. 22	27.7	26.6	14.5	41.1	16.2	42.8	17.7	44.3		
Sept. 23	28	27.8	14.2	42	14.3	42.1	17.7	45.5		
Sept. 24	28.7	30.3	11.9	42.2	10.4	40.7	17.0	47.3		
Sept. 25	30	31.4	11.7	43.1	12.7	44.1	19.2	50.6		
Sept. 21–25		28.3	13.4		14.0		18.0		15.1	43.4
Sept. 26	30	30.9	11.9	42.8	17.9	48.8	19.2	50.1		
Sept. 27	31	30.9	14.2	45.1	23	53.9	19.2	50.1		
Sept. 28	31.3	31.7	14.0	45.7	18.8	50.5	16.2	48.9		
Sept. 29	34	34.8	15.8	50.6	13.7	48.5	17.7	52.5		
Sept. 30	35	35.7	13.7	49.4	11.2	46.9	17.7	53.4		
Sept. 26–30		32.8	13.9		16.9		18.0		16.3	49.1

[2] Affected by surface run-off due to rainfall.

TABLE 3—Continued

NATURAL LOSSES AND INFLOW, IN SECOND-FEET, ON SANTA ANA RIVER, FROM HAMNER AVENUE TO THE ATCHISON, TOPEKA & SANTA FE RAILWAY BRIDGE

Date[1]	Measured outflow	Corrected outflow (outflow ± change in storage)	Natural losses based on: Transpiration recorded at Well D — Natural losses	Transpiration recorded at Well D — Inflow	Evaporation recorded at Prado — Natural losses	Evaporation recorded at Prado — Inflow	Temperature recorded at Prado — Natural losses	Temperature recorded at Prado — Inflow	Average results: Natural losses	Average results: Inflow
	A	B	C	B+C	D	B+D	E	B+E	$\frac{C+D+E}{3}$	$B+\frac{C+D+E}{3}$
1932—										
July 1	35	34.3	16.4	50.7	20.2	54.5	15.2	49.5		
July 2	36.3	36.9	15.8	52.7	18.3	55.2	13.6	50.5		
Sept. 3	37.3	38.8	15.3	54.1	16.4	55.2	12.0	50.8		
Sept. 4	38	39.8	14.4	54.2	15.7	55.5	11.2	51		
Sept. 5	38	38.6	15.5	54.1	17.0	55.6	12.8	51.4		
July 1–5		37.7	15.5		17.5		13.0		15.3	53
July 6	37.7	36.8	16.0	52.8	18.3	55.1	13.6	50.4		
July 7	36	33.9	16.7	50.6	19.5	53.4	15.2	49.1		
July 8	34.7	32.7	16.7	49.4	18.9	51.6	14.4	47.1		
July 9	34	33.1	16.7	49.8	17.6	50.7	14.4	47.5		
July 10	35.3	35.1	17.8	52.9	17.0	52.1	13.6	48.7		
July 6–10		34.3	16.8		18.4		14.2		16.5	50.8
July 11	36	36.1	17.4	53.5	15.7	51.8	12.8	48.9		
July 12	36	35.3	18.5	53.8	17.0	52.3	13.6	48.9		
July 13	34.3	33.5	17.1	50.6	19.5	53	16.0	49.5		
July 14	32.7	30.9	16.2	47.1	22.7	53.6	18.4	49.3		
July 15	31.7	29.9	14.6	44.5	23.9	53.8	21.6	51.5		
July 11–15		33.1	16.8		19.8		16.8		17.8	50.9
July 16	30.7	29.1	15.1	44.2	22.7	51.8	19.2	48.3		
July 17	29.7	29.1	15.0	44.1	20.8	49.9	16.8	45.9		
July 18	29.3	29.2	15.1	44.3	19.5	48.7	14.4	43.6		
July 19	30.7	30.7	17.4	48.1	18.9	49.6	13.6	44.3		
July 20	31.3	31	16.4	47.4	20.8	51.8	15.2	46.2		
July 16–20		29.8	15.8		20.5		15.8		17.4	47.2

July 21	30.3	29.4	16.2	45.6	21.4	50.8	17.6	47		
July 22	28.7	27.4	15.1	42.5	22.0	49.4	18.1	45.8		
July 23	27.7	26.3	15.3	41.6	22.0	48.3	18.4	44.7		
July 24	27.3	26.4	15.8	42.2	21.4	47.8	18.4	44.8		
July 25	27.3	26.7	15.5	42.2	20.8	47.5	16.8	43.5		
July 21-25		27.2	15.6		21.5		17.9		18.3	45.5
July 26	27	26.3	15.0	41.3	20.8	47.1	17.6	43.9		
July 27	26.3	25.4	16.2	41.6	21.4	46.8	18.4	43.8		
July 28	26.3	24.9	19.2	44.1	22.7	47.6	20.8	45.7		
July 29	26	24.6	21.6	46.2	23.9	48.5	21.6	46.2		
July 30	25.7	24.7	22.4	47.1	22.7	47.4	20.8	45.5		
July 31	24.3	23.6	23	46.6	22	45.6	20	43.6		
July 26-31		24.9	19.6		22.2		19.9		20.8	45.7
Aug. 1	24.3	23.6	25.7	49.3	21.6	45.2	19.2	42.8		
Aug. 2	24.3	23.1	28	51.1	22	45.1	20	43.1		
Aug. 3	24.3	22.9	28.4	51.3	23.3	46.2	21.6	44.5		
Aug. 4	24.7	23.6	26.6	50.2	23.3	46.9	21.6	45.2		
Aug. 5	25.3	25	24.6	49.6	22	47	20	45		
Aug. 1- 5		23.6	26.7		22.4		20.5		23.2	46.8
Aug. 6	26	26.7	23.2	49.9	20.2	46.9	18.4	45.1		
Aug. 7	26.7	28.3	21.8	50.1	19.5	47.8	16.8	45.1		
Aug. 8	27	29.1	20.4	49.5	17.6	46.7	15.2	44.3		
Aug. 9	27.7	30	18.5	48.5	17.0	47	14.4	44.4		
Aug. 10	27.7	29.8	16.9	46.7	15.8	45.6	12.8	42.6		
Aug. 6-10		28.8	20.2		18.0		15.5		17.9	46.7
Aug. 11	28.3	30.2	16.2	46.4	16.4	46.6	12.8	43		
Aug. 12	30	31.8	16.0	47.8	15.8	47.6	12.8	44.6		
Aug. 13	32.3	34.5	15.1	49.6	14.5	49	12.0	46.5		
Aug. 14	33.3	35.8	14.1	49.9	13.8	49.6	11.3	47.1		
Aug. 15	33.3	34.8	14.8	49.6	15.8	50.6	12.8	47.6		
Aug. 11-15		33.4	15.2		15.3		12.3		14.3	47.7
Aug. 16	32	31	17.2	48.2	18.9	49.9	17.6	48.6		
Aug. 17	30	26.8	19.7	46.5	22.7	49.5	22.4	49.2		
Aug. 18	28.3	24	21.8	45.8	23.9	47.9	25.6	49.6		
Aug. 19	27.7	23.3	23.8	47.1	23.9	47.2	25.6	48.9		
Aug. 20	27.7	24.2	25.5	49.7	23.3	47.5	24.8	49		
Aug. 16-20		25.9	21.6		22.5		23.3		22.5	48.4

TABLE 3—Continued

NATURAL LOSSES AND INFLOW, IN SECOND-FEET, ON SANTA ANA RIVER, FROM HAMNER AVENUE TO THE ATCHISON, TOPEKA & SANTA FE RAILWAY BRIDGE

Date[1]	Measured outflow	Corrected outflow (outflow ±) change in storage)	Natural losses based on						Average results	
			Transpiration recorded at Well D		Evaporation recorded at Prado		Temperature recorded at Prado		Natural losses	Inflow
			Natural losses	Inflow	Natural losses	Inflow	Natural losses	Inflow		
	A	B	C	B+C	D	B+D	E	B+E	$\frac{C+D+E}{3}$	$B+\frac{C+D+E}{3}$
1932—										
Aug. 21	26.7	23.3	26.8	50.1	23.9	47.2	24.8	48.1		
Aug. 22	26	24.5	27	51.5	23.9	48.4	24.8	49.3		
Aug. 23	25	23.7	25.9	49.6	24.6	48.3	25.6	49.3		
Aug. 24	25	24.1	23.2	47.3	26.5	50.6	24	48.1		
Aug. 25	24.7	25.5	20.6	46.1	22.7	48.2	20.8	46.3		
Aug. 21–25		24.2	24.7		24.3		24		24.3	48.5
Aug. 26	25.7	28.6	19.4	48	18.9	47.5	15.7	44.3		
Aug. 27	26.3	30	19.2	49.2	14.5	44.5	12.0	42		
Aug. 28	27	31.1	16.7	47.8	12.6	43.7	11.3	42.4		
Aug. 29	27.3	30.5	14.3	44.8	13.2	43.7	12.0	42.5		
Aug. 30	27.7	30.1	13.0	43.1	13.2	43.3	12.8	42.9		
Aug. 31	27.3	28.2	15.1	43.3	15.8	44	16.0	44.2		
Aug. 26–31		29.8	16.3		14.8		13.3		14.8	44.6
Sept. 1	26.7	26.5	17.1	43.6	17.6	44.1	18.4	44.9		
Sept. 2	25	23.7	18.8	42.5	18.9	42.6	20.8	44.5		
Sept. 3	24	22.1	19.7	41.8	19.5	41.6	21.6	43.7		
Sept. 4	22.7	20.1	21.4	41.5	21.4	41.5	23.2	43.3		
Sept. 5	23	20.4	23.4	43.8	22	42.4	23.2	43.5		
Sept. 1– 5		22.6	20.1		19.9		21.4		20.5	43 1

Sept. 6	23.3	22	24.1	46.1	22	44	22.4	44.4		
Sept. 7	24.7	24.8	23.9	48.7	24.6	49.4	21.6	46.4		
Sept. 8	26	28.1	20.6	48.7	24.6	52.7	18.4	46.5		
Sept. 9	28	31.2	16.6	47.8	23.3	54.5	16.0	47.2		
Sept. 10	29.3	33.5	12.7	46.2	18.3	51.8	14.4	47.9		
Sept. 6–10	----------	27.9	19.6	----------	22.6	----------	18.6	----------	20.3	48.2
Sept. 11	30.7	34.8	10.9	45.7	17.0	51.8	14.4	49.2		
Sept. 12	30.7	33.8	11.3	45.1	17.6	52.4	13.6	47.4		
Sept. 13	31	33.2	12.0	45.2	17.0	50.2	12.8	46		
Sept. 14	30.7	32	13.0	45	15.8	47.8	13.6	45.6		
Sept. 15	31.3	32.7	12.9	45.6	15.1	47.8	12.8	45.5		
Sept. 11–15	----------	33.3	12.0	----------	16.5	----------	13.4	----------	14.0	47.3
Sept. 16	31.7	33.6	11.4	45	13.2	46.8	12.8	46.4		
Sept. 17	32	34.3	9.5	43.8	12.0	46.3	11.2	45.5		
Sept. 18	32	34.1	8.4	42.5	10.1	44.2	10.4	44.5		
Sept. 19	32	33	9.2	42.2	11.3	44.3	10.4	43.4		
Sept. 20	32	32.7	9.3	42	12.0	44.7	9.6	42.3		
Sept. 16–20	----------	33.6	9.6	----------	11.7	----------	10.9	----------	10.7	44.3
Sept. 21	32.7	33.4	9.7	43.1	12.6	46	10.4	43.8		
Sept. 22	32.3	32.9	10.4	43.3	12.6	45.5	11.2	44.1		
Sept. 23	32	32.1	11.4	43.5	13.2	45.3	13.6	45.7		
Sept. 24	31.3	31.2	11.6	42.8	13.2	44.4	14.4	45.6		
Sept. 25	31.7	32.3	10.2	42.5	12.6	44.9	12.8	45.1		
Sept. 21–25	----------	32.4	10.7	----------	12.8	----------	12.5	----------	12.0	44.4
Sept. 26	32.7	33.7	9.5	43.2	12.6	46.3	10.4	44.1		
Sept. 27	33.3	34.7	8.4	43.1	11.3	46	8.8	43.5		
Sept. 28	33.7	35.3	7.6	42.9	10.1	45.4	8.8	44.1		
Sept. 29	34.7	36.9	6.0	42.9	8.2	45.1	7.2	44.1		
Sept. 30	35.7	37.9	5.6	43.5	8.8	46.7	8.0	45.9		
Sept. 26–30	----------	35.7	7.4	----------	10.2	----------	8.6	----------	8.7	44.4

inflow" and "measured outflow" gives the quantity of water consumed in the area of natural losses. The inflow has been plotted for every day by use of the three methods on these plates. Most of the apparent irregularities during August and September, 1931, were due to surface run-off from rainfall, which could not be evaluated. The true relation holds only when all the water comes from subsurface sources.

Relation of natural losses to evaporation.

In order to make the data computed in Table 3 applicable elsewhere on the Santa Ana River, the natural losses over the area were determined as a function of evaporation. The results are given in Table 4, in which the natural losses for each 5-day period have been converted into acre-feet. The average loss in feet over the whole area was computed by dividing the losses in acre-feet by the area in acres. This average was compared with the evaporation from a standard Weather Bureau pan at Prado for the same periods, expressed in feet, and the ratio computed. This ratio gives the losses as a percentage of evaporation. For example, for the period July 1–5, 1931, the natural losses amounted to 0.109 foot, or 61 per cent of the evaporation from a standard Weather Bureau pan for the same period. The means of these percentages were computed for the three months in both 1931 and 1932. They were 68 per cent for 1931 and 64 per cent for 1932. The average for the two seasons was 66 per cent. These ratios do not, however, apply where the natural losses are compared to evaporation from a reservoir or other relatively large free water surface. By using the coefficient of 1.427 determined by Rohwer [a] for the correction of the standard pan record, the natural losses for 1931 and 1932 are found to be nearly equal to the evaporation from a reservoir or other large free water surface.

Natural losses and inflow between Riverside Narrows and the Prado gaging station.

Between the gaging stations at Riverside Narrows and Prado there is 4040 acres of land subject to substantial natural losses. By means of the coefficient determined in the preceding tables, the natural losses within this area were computed and converted into acre-feet for each 5-day period from January to November, 1932. The results of these computations are expressed graphically on Plate XI.

A check on the computations for inflow for the area above the Prado gaging station was made by using the data collected at The Atchison, Topeka and Santa Fe Railway Bridge for the period May to November. The area of natural losses above this station is 3580 acres. With the coefficient of 66 per cent the natural losses were computed from the evaporation pan record at Prado. The addition of these losses to the flow at the railway bridge gaging station gave the total inflow for the area between Riverside Narrows and the railway bridge. These results have been plotted on the graph in the form of a dotted line.

The $2\frac{1}{2}$ miles of river channel between The Atchison, Topeka and Santa Fe Railway Bridge and the Prado gaging stations is cut through

[a] Rohwer, Carl, Evaporation from free water surfaces: U. S. Dept. Agri., Bull. 271, 1932.

TABLE 4

RELATION BETWEEN EVAPORATION AND NATURAL LOSSES FOR AREA BETWEEN HAMNER AVENUE AND THE ATCHISON TOPEKA AND SANTA FE RAILWAY BRIDGE ON THE SANTA ANA RIVER

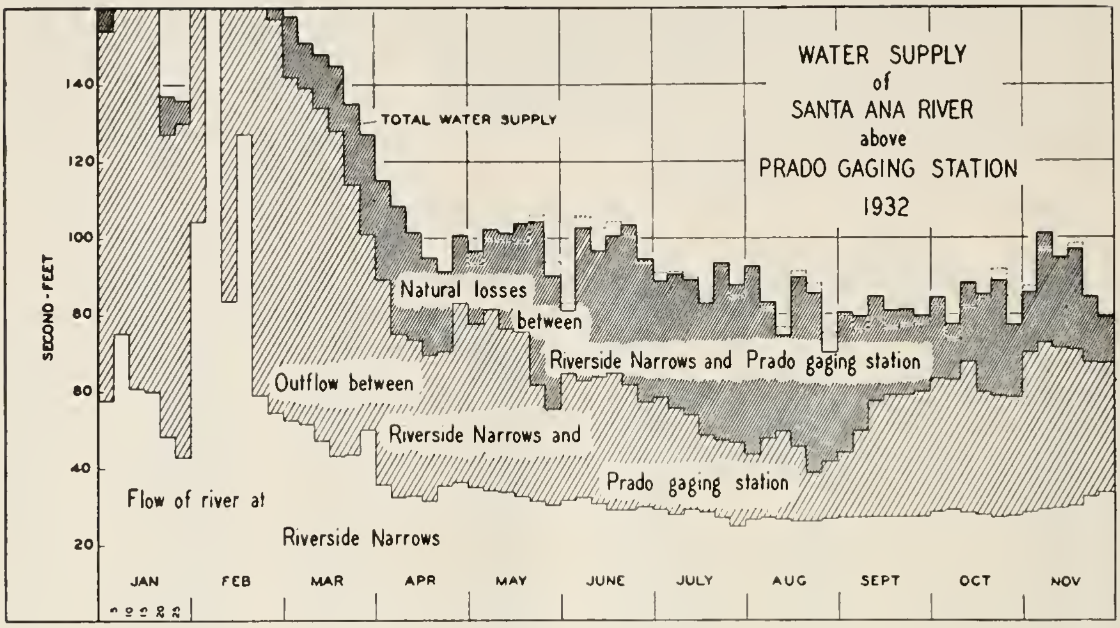
(Area, 2,110 acres)

Date	Natural losses			Evaporation at Prado		Ratio
	Mean (second-feet)	Acre-feet	Feet	Inches	Feet	
1931—						
July 1- 5	23.3	231	0.109	2.12	0.178	0.61
July 6-10	20.5	203	.096	1.76	.147	.65
July 11-15	21.4	212	.100	1.80	.150	.67
July 16-20	21.7	215	.102	1.74	.145	.70
July 21-25	23.8	236	.112	1.92	.160	.70
July 26-31	23.4	279	.132	2.22	.185	.71
Aug. 1- 5	19.5	193	.092	1.57	.131	.70
Aug. 6-10	19.4	192	.091	1.70	.142	.64
Aug. 11-15	13.7	136	.064	1.10	.092	.70
Aug. 16-20	21.2	210	.100	1.71	.142	.70
Aug. 21-25	26.5	263	.125	2.24	.187	.67
Aug. 26-31	20.0	238	.113	1.72	.143	.79
Sept. 1- 5	14.4	143	.068	1.12	.093	.73
Sept. 6-10	18.6	184	.087	1.57	.131	.66
Sept. 11-15	15.3	152	.072	1.35	.112	.64
Sept. 16-20	12.6	125	.059	1.07	.089	.66
Sept. 21-25	15.1	150	.071	1.07	.089	.80
Sept. 26-30	16.3	162	.077	1.56	.130	.59
Mean						.68
1932—						
July 1- 5	15.3	152	0.072	1.362	0.114	0.63
July 6-10	16.5	164	.078	1.565	.131	.60
July 11-15	17.8	177	.084	1.571	.131	.64
July 16-20	17.4	173	.082	1.528	.127	.65
July 21-25	18.3	182	.086	2.056	.172	.50
July 26-31	20.8	248	.118	2.203	.184	.64
Aug. 1- 5	23.2	230	.109	2.205	.184	.59
Aug. 6-10	17.9	178	.084	1.578	.132	.64
Aug. 11-15	14.3	142	.067	1.112	.093	.72
Aug. 16-20	22.5	224	.106	1.980	.165	.64
Aug. 21-25	24.3	241	.114	2.085	.174	.65
Aug. 26-31	14.8	176	.083	1.523	.127	.65
Sept. 1- 5	20.5	204	.097	1.622	.135	.72
Sept. 6-10	20.3	201	.095	1.327	.110	.86
Sept. 11-15	14.0	139	.066	1.225	.102	.65
Sept. 16-20	10.7	106	.050	.978	.082	.61
Sept. 21-25	12.0	119	.056	1.004	.084	.67
Sept. 26-30	8.7	86	.041	.884	.074	.55
Mean						.64

the Santa Ana Mountains. There are no live streams feeding the river in this section. If there is little inflow during the summer between these stations, the inflow for the area above the railway bridge gaging station should be nearly the same as that above the Prado gaging station. Plate XI shows that the two sets of figures for inflow agree remarkably well, the decrease in stream flow between the two stations being about equal to the computed natural losses.

One purpose of this plate is to show the extent of the losses between Riverside Narrows and the Prado gaging station. Of an inflow which was computed to be 48.5 second-feet, only 12.8 second-feet left the area as surface water during the 5-day period August 21–25, 1932. During the period August 1–5, 1930, only 5 second-feet were recovered from an inflow equally great.

PLATE XI



In order to show more clearly the disposition of all the rising water above Prado, Table 5 was prepared. This table shows the estimated water supply above the Prado gaging station for two seasons, 1930–31 and 1931–32. The natural losses were computed, based on the evaporation pan record collected at Prado, except for three months, October, 1930, and February and May, 1932. During these months the record at Prado was incomplete. For the month of October, 1930, the record collected by the Bureau of Agricultural Engineering at Santa Ana was used. The record collected by the same bureau at Pomona was used for the months of February and May, 1932.

During the season of 1930–31 there was very little storm run-off due to rainfall, consequently the main source of the water passing the Prado gaging station was from the ground water inflow. Table 5 shows that of the 74,900 acre-feet of inflow into the area above Prado for this season, 17,500 acre-feet, or 23.4 per cent, were consumed by the natural losses in this area.

If the water of the Santa Ana River is more valuable at any one period of the year than another, it is during the summer irrigation season. During this period the entire flow of the river is diverted by the Santa Ana Valley Irrigation and Anaheim Union water companies. To augment this supply additional water is pumped along the canal systems in Orange County. An inspection of Table 5 shows that for the months of May to September, 18,090 acre-feet entered the valley or flood channel of the Santa Ana River between Riverside Narrows and Prado during the season of 1930–31. Of these 18,090 acre-feet, 10,180 acre-feet were consumed by natural losses. This represents a loss of 56 per cent. For the same period during 1931–32, 18,280 acre-feet entered the flood channel of the river. During this season 9790 acre-feet were consumed by natural losses, or a loss of 54 per cent.

TABLE 5

ESTIMATED WATER SUPPLY OF THE VALLEY OF THE SANTA ANA RIVER ABOVE THE PRADO GAGING STATION, 1930-1932

Month	Flow of river at Riverside Narrows		Water supply between Riverside Narrows and Prado gaging station				Total water supply	
			Outflow		Natural losses			
	Mean daily discharge, second-feet	Acre-feet	Mean daily discharge, second-feet	Acre-feet	Mean daily discharge, second-feet	Acre-feet	Mean daily discharge, second-feet	Acre-feet
1930-31—								
October	33.8	2,080	33.1	2,030	19.8	1,220	86.7	5,330
November	35.7	2,120	41.2	2,460	19.3	1,150	96.3	5,730
December	36.3	2,230	44.0	2,710	13.7	844	94.0	5,780
January	48.5	2,980	55.5	3,420	14.6	895	119	7,300
February	61.1	3,390	99.1	5,500	9.7	540	170	9,430
March	43.1	2,650	58.9	3,620	20.8	1,280	123	7,550
April	41.5	2,470	40.9	2,430	22.7	1,350	105	6,250
May	37.8	2,320	38.3	2,360	28.0	1,720	104	6,400
June	32.2	1,920	32.6	1,940	33.9	2,020	98.8	5,880
July	28.0	1,720	16.0	990	41.6	2,560	85.7	5,270
August	27.8	1,710	15.8	970	35.6	2,190	79.2	4,870
September	29.7	1,770	27.7	1,650	28.4	1,690	85.9	5,110
The year	37.8	27,400	41.5	30,000	24.2	17,500	103	74,900
1931-32—								
October	36.7	2,260	34.8	2,140	19.5	1,200	91.0	5,600
November	41.6	2,480	43.9	2,610	13.1	780	98.6	5,870
December	92.8	5,710	68.1	4,190	9.0	555	171	10,500
January	56.9	3,500	93.0	5,720	15.2	935	166	10,200
February	23.3	13,400	205	11,800	9.3	535	447	25,700
March	46.4	2,850	79.7	4,900	18.7	1,150	145	8,900
April	33.9	2,020	42.7	2,540	23.2	1,380	99.8	5,940
May	32.5	2,000	38.2	2,350	27.0	1,660	97.7	6,010
June	30.3	1,800	32.1	1,910	34.1	2,030	96.5	5,740
July	27.5	1,690	24.1	1,480	36.1	2,220	87.6	5,390
August	26.5	1,630	17.9	1,100	37.7	2,320	82.1	5,050
September	27.1	1,610	27.7	1,650	26.2	1,560	81.0	4,820
The year	56.4	41,000	58.3	42,300	22.5	16,300	137	99,700

Utilization of Water Supply.

The water which under natural conditions is consumed by uneconomic plant life could in large part be recovered by pumping from wells, whereby the ground water table would be drawn down below the root zone. The installation of pumps in this area would make available the large underground reservoir that now lies unused. The storage in this underground reservoir, as well as the summer inflow, could be drawn upon to meet the fluctuating demands for irrigation. During the winter the underground reservoir would be replenished by the inflow from the sides and also by at least some of the storm run-off that may otherwise be wasted into the ocean.

PUBLICATIONS

DIVISION OF WATER RESOURCES

PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First Report, State Water Commission, March 24 to November 1, 1912.
Second Report, State Water Commission, November 1, 1912 to April 1, 1914.
*Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.
Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.
Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

*Bulletin No. 1—Hydrographic Investigation of San Joaquin River. 1920–1923.
*Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.
*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.
*Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference, and Water Supervisor's Report, 1924.
*Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.
Bulletin No. 6—San Gabriel Investigation—Basic Data, 1926–1928.
Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.
*Biennial Report, Division of Water Rights, 1920–1922.
*Biennial Report, Division of Water Rights, 1922–1924.
Biennial Report, Division of Water Rights, 1924–1926.
Biennial Report, Division of Water Rights, 1926–1928.

DEPARTMENT OF ENGINEERING

*Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.
*Bulletin No. 2—Irrigation Districts in California. 1887–1915.
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