STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES

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IRRIGATION REQUIREMENTS OF CALIFORNIA CROPS

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LETTER OF TRANSMITTAL

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

Dear Sir: The material transmitted herewith for publication is a cooperative report on "Irrigation Requirements of California Crops."

The report, prepared by Arthur A. Young, is a comprehensive compilation of data that have been published or made available from public and private files as well as unpublished findings resulting from our cooperative research studies pertaining to agricultural crops common to California.

These data are of practical economic importance in determining the water supplies for and their uses in irrigation. The conservation and disposal of the water supplies of California for agriculture are based ultimately upon such information.

Respectfully submitted.

Chief, Division of Irrigation, Soil Conservation Service,
United States Department of Agriculture.

Berkeley, California,
November 8, 1945.

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DIVISION OF WATER RESOURCES

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UNITED STATES DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, DIVISION OF IRRIGATION

Cooperating in Studies on Use of Water in Irrigation

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Irrigation Requirements of California Crops

INTRODUCTION

In California, as in all western States, water is the limiting factor in the expansion of irrigated areas. The increasing cost of new projects not only approaches the capital values that newly irrigated lands may profitably support but in many cases exceeds them and other benefits are evaluated to justify construction. Conservation of existing water supplies is therefore of the first importance in the economy of the irrigated west. Savings in irrigation seldom exist where water is plentiful but where it is scarce conserving methods are the rule, wasteful practices are avoided, and water is carefully applied. It is axiomatic that the most economical use prevails where there is a diminishing supply and water is high priced. Such conditions prevail in parts of California.

Under these conditions economy in irrigation methods, involving a better understanding of the water requirements of agricultural plants, will benefit all irrigated areas. It is the purpose in this bulletin to make available in a single report existing data on the irrigation requirements of crops grown in the several physiographic subdivisions of the State. Not all the areas are included because for many localities irrigation data are lacking. In some areas high ground water makes available data of dubious value, and they are omitted. Practically all crops in California require irrigation in various amounts ranging from those that need but one or two irrigations to supplement a scanty rainfall, to high water requirement forage crops such as alfalfa and rice, which requires submergence for a considerable part of the growing season.

The irrigation data available throughout the State are divided into three groups. First, irrigation requirements for some of the principal crops have been determined through experimental studies by State and Government agencies, frequently in cooperation with the Division of Irrigation, Soil Conservation Service.[1] Such data are based on soil moisture investigations, measurements of water applied in irrigation, estimation of rainfall stored in the soil that is used by the crop prior to the irrigation season, evaporation from soil after irrigation, and determination of the efficiency with which irrigation water is applied. With a knowledge of these items the irrigation requirement may be computed. Complete data for such computations, however, are seldom available in the published reports, which are the basis of this bulletin.

The second group includes information on plant use of water as measured by soil moisture studies in determination of consumptive use or the transpiration use of water by crops. In Southern California nearly all investigators have taken soil samples below the three or four inches of dry surface soil, thus excluding soil evaporation losses, and the resulting measurement is one of transpiration use only, assuming that deep percolation losses are negligible. In Northern California soil samples generally have been obtained beginning at the soil surface so

[1] Formerly Division of Irrigation, Bureau of Agricultural Engineering.

that the measurement of water consumed is consumptive use as it includes both transpiration by the plant and evaporation from the soil. In estimating the irrigation requirement of a crop it is necessary to have an understanding of the definitions of consumptive use and transpiration use in order that all the factors of soil moisture disposal may be taken into consideration. Definitions of terms appear later in this report.

The third group of data includes records of depths of water applied in ordinary irrigation practice, estimated water requirements by engineers, appraisers and experienced water administrators. These data are less reliable than those obtained by intensive soil moisture investigations, but in the absence of investigational results they may be accepted as indicative, with the reservation that they generally exceed the actual requirements except where there is a definite scarcity of water for irrigation use.

Crops for which soil moisture studies have been made usually are those that are the most important in the areas in which they are grown. In Imperial Valley high ground water within the root zone causes a condition that makes it impossible to determine the consumptive use of many crops. For the South Coastal Basin, results of experimental studies in citrus and avocado orchards and in walnut groves are available. In the San Joaquin Valley the consumptive use by cotton has been determined in the principal cotton producing areas. Consumptive use by the principal crops has been determined by experiments in the delta area; and in the Sacramento Valley, at the University Farm and elsewhere, irrigation treatments of a number of the principal crops have been studied. Portions of the coastal area northward from Los Angeles County are intensively cultivated as an irrigated area. In the extreme northeastern part of the State several thousand acres are reported under irrigation but data on the irrigation requirements are not available.

For the purpose of discussion the State has been divided into six general subdivisions representing the geographical distribution of water resources and agricultural lands. They are generally, although not always, separated by topographical features designating natural boundaries and in most cases there are some climatic differences. Irrigation requirements are influenced by various factors to be discussed later, but temperatures in the different sections of the State frequently control the choice of crops. Citrus trees can not be grown where subfreezing weather is usual and cotton does not grow unless summers are long and warm. Within these areas agriculture is successful only through the general practice of irrigation.

The six subdivisions are as follows:

1. South Pacific Basin
2. Great Basin Desert Area
3. San Joaquin Valley
4. Sacramento-San Joaquin Delta
5. Sacramento Valley
6. Coastal Area north of Los Angeles County

The South Pacific Basin includes northern San Diego County, the Santa Ana River Valley and its tributaries extending to Beaumont Plains and San Jacinto Basin; the San Gabriel Valley, and the San Fernando Valley in Los Angeles County. In this area are a majority of all the citrus and subtropical fruits grown within the State. The Great Basin Desert Area includes the irrigated sections of Imperial, Coachella and Antelope Valleys, occupying desert areas at low altitudes where the climate is hot and the seasons long. Crops are principally alfalfa, vegetables and cotton, with dates in the Coachella Valley. The San Joaquin Valley is the largest single farming area in the State. It grows a variety of crops including cotton, citrus, grapes, rice, potatoes, and many others. Its water supply is derived partly from mountain streams and partly by pumping from underground basins. The Sacramento-San Joaquin Delta area is important agriculturally and its method of supplying water to crops by subirrigation differs from irrigation methods commonly used elsewhere. It is noted for its crops of potatoes, asparagus and celery. The delta differs also from the other areas mentioned in respect to its elevation at sea-level and its large acreage of peat soil which is extensively farmed. The Sacramento Valley grows alfalfa, peaches, grapes, rice, and grains. Because the University Farm and the California Agricultural Experiment Station are located in the valley, many of their irrigation studies are the basis of the irrigation data used in this report. Portions of the coastal area lying north of Los Angeles County are important from an agricultural standpoint but they are not discussed here, as irrigation data are lacking.

DEFINITION OF TERMS

Irrigation Requirement: The quantity of water, exclusive of precipitation, that is required for crop production. It includes surface evaporation and other economically unavoidable wastes. Usually expressed in depth for given time (volume per unit area for given time). (See also water requirement.)

Water Requirement: The quantity of water, regardless of its source, required by a crop in a given period of time, for its normal growth under field conditions. It includes surface evaporation and other economically unavoidable wastes. Usually expressed as depth (volume per unit area) for a given time. (See also irrigation requirement.)

Consumptive Use (evapo-transpiration): The sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the given area. If the unit of time is small, such as a day or a week, the consumptive use is expressed in acre-inches per acre or depth in inches, whereas, if the unit of time is large, such as a crop growing season or a 12-month period, the consumptive use is expressed as acre-feet per acre or depth in feet.

Transpiration: The quantity of water absorbed by the crop and transpired and used directly in the building of plant tissue, in a specified time. It does not include soil evaporation. It is expressed as acre-feet or acre-inches per acre or as depth in feet or inches.

Duty of Water: The quantity of irrigation water applied to a given area for the purpose of maturing its crop, expressed as acre-feet or acre-inches per acre or as depth in feet or inches.

Irrigation Efficiency: The percentage of irrigation water delivered to the farm or field that is available in the soil for consumptive use by the crops. When measured at the farm headgate it is called farm irrigation efficiency and when measured at the field or plot it is designated as field irrigation efficiency.

Field Capacity: The moisture percentage, on a dry weight basis, of a soil after rapid drainage has taken place following an application of water, provided there is no water table within capillary reach of the root zone. The moisture percentage usually is reached within two to four days after an ordinary irrigation, the time interval depending on the soil type.

Permanent Wilting Percentage: The moisture content of a soil at which plants wilt and do not recover unless water is added. It is expressed as percentage of moisture based on the oven-dry weight of the soil.

Moisture Equivalent: The quantity of water retained by a soil in a standardized apparatus (soil centrifuge) when the moisture content is reduced by means of a constant centrifugal force of 1,000 times gravity until brought into a state of equilibrium with the applied force. It is expressed as a percentage of the dry weight. It agrees closely with the field capacity of most of the fine textured soils but not of the sands.

Available Moisture: The quantity of water in the soil that is available for plant use, as limited by the field capacity and the permanent wilting percentage. It is expressed as percentage of the dry weight of the soil or as depth of water in inches per foot depth of soil. The desirable practice is to replenish the moisture before the wilting percentage is reached.

Moisture Percentage: The percentage of moisture in the soil based on the weight of the oven-dry material.

Apparent Specific Gravity (volume weight): The ratio of the weight of a unit volume of oven-dry soil of undisturbed structure to that of an equal volume of water, under standard conditions.

Soil Moisture: The water in unsaturated soil. It is expressed as a percentage on a dry weight basis, or in inches per foot depth of soil.

Sub-irrigation: Irrigation by the application of water below the ground surface or by absorption from a high water table which may be controlled or fluctuated for this purpose; colloquially termed ''subbing.''

FACTORS AFFECTING THE NEED AND QUANTITY OF IRRIGATION WATER APPLIED IN PRACTICE

CLIMATE

Extremes in rainfall occur in different parts of California, ranging from three inches in Imperial Valley to 100 inches in the northwestern coastal area. Rainfall is deficient throughout the fertile interior valleys and along the slope of the southern coastal plain, with the greater part of the area receiving less than 20 inches annually and one-third receiving less than 10 inches. This precipitation, coupled with an almost complete absence of rain during the growing period forces the practice of irrigation for the satisfactory growing of crops.

All the rain falling upon a field is not effective in promoting plant growth. A light rain, falling upon dry soil, will soon be dissipated by evaporation and no benefit will be derived by the plant. If a light rain precedes or follows a heavy rain within a few hours both storms combined will provide the plant with moisture. The effective rainfall is designated in irrigation as one that becomes available for plant use and is not lost by evaporation into the atmosphere. Usually, effective rains are those exceeding one-half inches falling within a few consecutive hours. Thus it is seldom advisable to accept a record of total rainfall as a measure of moisture available for plant growth. As a result of the winter rains, moisture stored in the soil is available for the plant during spring months, postponing the time of the first irrigation until the soil moisture is nearly depleted. This period varies according to the amount of soil storage and the seasonal demands of the crop but often irrigations are not required before April or May and sometimes as late as June.

The equable temperatures of the coastal region are in sharp contrast to the hot summers of the interior valleys. In Southern California Vaile (61)[2] has drawn a distinction between coastal, intermediate, and interior climates in which the basis of the divisions is taken as the mean maximum temperature during the summer. On this basis the coastal zone includes most of Orange County and the Whittier and Pasadena sections of Los Angeles County, the intermediate zone includes the San Gabriel and Pomona Valleys, and the interior zone includes the San Fernando, Fillmore, Redlands, Highlands and Riverside districts. The mean monthly maximum temperature of the month of August in each zone was found to be:

Coastal	87° F.
Intermediate	91° F.
Interior	94° F.
(Tulare County)	98° F.

All crops in these areas are irrigated except winter grains which are usually grown on a summer fallow rotation system, vineyards in western Riverside and San Bernardino Counties, and lima beans grown in the coastal area during years of sufficient rainfall. Improved production

[2] Numbers in parenthesis refer to literature cited.

of beans could be expected if rainfall was supplemented with irrigation, especially during years of rainfall deficiency.

The frost-free period in valley areas decreases northward from 365 days per year at San Diego to an average of 273 days at Red Bluff in Sacramento Valley and shorter periods occur at higher elevations. The frost-free period is designated by the Weather Bureau as the period between days when temperatures of 32 degrees or lower are reported. Evaporation from water surfaces is nearly proportional to the irrigation requirement, but the absence of evaporation data in many areas prevents use of this criterion in this report.

SOILS

The agricultural soils of California fall into one of three general classifications: the unweathered alluvial soils, weathered soils developed on unconsolidated materials, and the weathered soils developed on consolidated rock. The first group consists of recent alluvial deposits that are deep, friable and productive. Some are still in process of accumulation. The second group represents progressive stages in weathering of the older sedimentary deposits of the valleys. They occupy stream and coastal terraces and more elevated valley plains now undergoing erosion. The third group has been developed on the sandstone, shale, granitic and volcanic bedrocks. The soils comprising it occupy hilly and mountainous areas which are susceptible of irrigation only in sections of the more favorable topography and water supply.

In low-lying areas drainage and disposal of alkali salts involve problems limiting the number of crops to those that are tolerant of salinity. Salts carried in irrigation waters add to the salinity of the soil, and in order to maintain a satisfactory salt balance excess water is required in irrigation to carry accumulated salts below the reach of roots and maintain the soil in a satisfactory degree of productivity. In extreme conditions, salts render the soil unfit for cropping. Where irrigation supplies are obtained from streams of doubtful character the water should be analyzed before use. Surface waters originating in low hilly areas are sometimes found to contain quantities of salts detrimental to agriculture. Waters originating in mountain areas and fed by snow melt are of good quality. Most of the agricultural sections of California have been mapped for soils by the U. S. Department of Agriculture and the California Agricultural Experiment Station (53) (68).

Soil Characteristics Affecting the Use of Water by Plants

The objective in irrigation is to maintain moisture in the soil, in an adequate amount, to enable the plant to reach maturity and produce a profitable crop. The measurement of soil moisture requires the systematic collection of many soil samples taken at intervals within the limitations of root activity. For this purpose soil samples, usually one foot in length, are obtained by means of soil tubes driven by hand or by air-driven hammers. The samples are dried in an electric oven and the equivalent depth of water in the sample is computed by the formula $D = \frac{PVd}{100}$, in which D is the equivalent depth of water in inches held in the sample; P, the percentage of moisture in the sample; V, the apparent specific gravity (volume weight) of the soil in place; and d, the depth of soil sample in inches. The depths to which samples should be taken depend on the depths to which roots go in search of moisture, and vary from four to as much as 18 feet; the average depth usually is about six feet for most crops and six to 12 feet for alfalfa and walnut trees.

The amount of soil moisture available for plant use depends upon a number of factors such as plant spacing, volume, porosity of soil occupied by the root system, and such characteristics as field capacity, wilting percentage (sometimes called wilting range) and readily available moisture. The depth and spread of root systems outlines the volume of soil from which the plant may extract moisture and greatly affects the total amount of water available. Wide spacing tends to prevent intermingling of roots with those of adjacent plants, but it also encourages evaporation from the soil owing to reduced shading. Permanent crops such as trees and alfalfa have deeply rooted systems that can draw moisture from full depth early in the season, if necessary, as compared with annuals which produce new roots each season, drawing moisture from shallow depths early in the year and at successively greater depths as the season advances. Thus deeper rooted crops are able to withstand early drouth when annuals can not survive.

Field capacity is a measure of the water a soil will hold after it has been wetted and allowed to dry enough to work easily; an interval usually of two to four days, depending on the soil texture and structure. The time interval is dependent on the percolation rate and on soil evaporation. In homogeneous soils the lowest percolation rates correspond to the highest field capacities and the highest rates correspond to the lowest field capacities. Clay and adobe soils, which drain slowly, have the highest capacities; sandy soils drain rapidly and have the lowest capacities, while loamy soils are intermediate.

The moisture equivalent agrees closely with the field capacity of fine textured soils and often is used in place of it, but it does not agree well with the field capacity of sand. It is a standardized centrifuge method of estimating the amount of water a soil will hold shortly after it has been thoroughly wet and usually it has a slightly lower value than the field capacity. Both field capacity and moisture equivalent are expressed as a percentage of the dry weight of the soil (62).

The wilting point, or permanent wilting percentage, indicates the moisture content of a soil at which plants can not obtain sufficient water and therefore wilt. The best method of measuring the wilting point is to allow growing plants to dry out the soil until they wilt. Usually dwarf sunflowers are used for this purpose. Since plants wilt gradually, it is not possible to determine their exact wilting point, and it is becoming customary to use the term "wilting range" to cover a narrow range of soil moisture within which wilting occurs. It is expressed as a percentage of the dry weight of the soil.

Water available for plant use is the quantity between the field capacity and the wilting point. It varies for different soils, being less for sands than for fine grain materials. While plants are able to reduce soil moisture to approximately the wilting point it is unwise to permit so large a degree of extraction as danger of damage to the plant is increased. Among the better irrigators it is customary to irrigate when the soil moisture has reached a point about midway between field capacity and wilting point, a method requiring more frequent irrigations but less water at each irrigation, as full replenishment of the soil volume is unnecessary.

The water-holding capacity of the root zone of plants depends on the depth and volume of soil within which roots function, and on soil texture. Amounts vary for different soils but in general average sandy soils will hold from one-half to one inch of available water per foot of depth, sandy loams from one to one and one-half inches, silt and clay loams from one and one-half to two inches, and some clays as high as three inches of water per foot of soil (37). For example, if a four-foot root zone in a sandy loam soil should dry down to the wilting point, it would require an irrigation of four to six acre-inches per acre to recharge it to field capacity.

A few of the items of moisture relations of California soils, compiled from various sources, are shown in Table 1. Variations occur for the same type of soils, as might be expected, because no two soils are exactly alike; but in most cases the differences shown for the same soil types are not serious.

TABLE 1

SOME MOISTURE RELATIONS OF CALIFORNIA SOILS

Soil type	Depth of soil	Moisture equivalent	Wilting percentage	Field capacity	Depth of available water per foot of soil	Literature cited
	Feet	*Per cent*	*Per cent*	*Per cent*	*Inches*	*Ref. No.*
Oakley fine sand	—	3.29	1.33	—	0.34	(38)
Salinas fine sandy loam	—	28.23	20.05	—	1.34	(38)
Yolo fine sandy loam	—	16.80	8.93	—	1.26	(38)
Delano sandy loam	—	9.09	4.17	—	.80	(38)
Fresno sandy loam	—	11.09	3.08	—	1.31	(38)
Aiken clay loam	—	31.12	25.70	—	.71	(38)
Salinas silt clay loam	—	28.33	12.49	—	2.53	(38)
Salinas clay	—	34.50	16.80	—	2.83	(38)
Yolo clay	—	27.33	12.53	—	2.36	(38)
Yolo silt loam	0- 6	—	—	20.6	—	(20)
Yolo silt loam	0-15	—	—	25.0	—	(20)
Yolo fine sandy loam	0- 5	—	—	20.1	—	(20)
Yolo fine sandy loam	0- 7	—	—	21.1	—	(20)
Yolo fine sandy loam	0- 6	—	—	14.5	—	(20)
Yolo very fine sandy loam	0- 6	—	—	18.2	—	(20)
Coarse gravelly sand	—	—	—	4.0	—	(13)
Fine sandy loam	0- 6	—	—	9.5	—	(13)
Hanford sand	0- 4	—	—	7.5	—	(13)
Hanford loam	0- 6	—	—	11.0	—	(13)
Placentia loam	0- 4	—	—	12.5	—	(13)
Delano sandy loam	0- 5	10.1	3.5	11.0	—	(12)
Sorrento clay loam	—	20.1	8.5	—	—	(4)
Panoche clay	—	30.8	16.5	—	—	(4)
Panoche silty clay	—	30.0	18.1	—	—	(4)
Panoche adobe	—	32.0	17.0	—	—	(4)
Panoche clay loam	—	25.2	13.6	—	—	(4)
Hesperia fine sandy loam	—	20.0	8.3	—	—	(4)
Yolo loam	—	23.5	—	—	—	(4)
Yolo clay loam	—	—	—	26-32	—	(4)

CHARACTER OF THE PLANT

Characteristics of plant growth, such as length of growing season, rooting habits, age of trees, extent of aerial growth, and tolerance of plants to saline conditions, have separate effects on the water requirement. Plants use water most rapidly when making the fastest growth, and alfalfa, which grows rapidly between the several cuttings per year, has a high irrigation requirement. Each cutting requires one or two irrigations in order to force new growth, and the total requirement is affected by the number of cuttings and the crop yield.

Beans have a short growing season and a low water requirement. In some areas, beans may be planted as late as May or June. In the delta, the growing season appears to be June to September with a consumptive use of about 16 acre-inches per acre as compared with 38 acre-inches for alfalfa in the same area. In the cool, moist air of the coastal area of Southern California lima beans may be grown without irrigation, but they do not stand the heat of the interior.

The irrigation requirements of trees, both citrus and deciduous, vary with age and extent of aerial growth, the water use increasing as the trees approach a mature size (10), (7). Citrus trees are relatively shallow rooted but roots of deciduous trees may extend to depths of 15 or 20 feet, thus providing a large volume of soil for storage of moisture. The absorption of water by trees has been found by Weaver (67) to occur throughout the depth of the rooting system, but to take place most actively at the root tips in the younger portions of the root system. In the older portions the roots are more of a woody nature that provide strength for anchorage against winds. Regardless of the maximum depths at which roots occur it has been found by soil sampling methods, that the actively working portion of the rooting system occurs at some medium depth below the surface and that the lower roots abstract but little moisture from the soil. This is a reasonable finding since the bulk of the roots occur in the middle section. Thus, for citrus trees as much as 80 per cent of the moisture absorbed is obtained from the upper three feet of soil while for walnut trees the most moisture appears to be absorbed in the upper six to eight feet of soil.

The root depths of vegetables differ considerably according to variety, as is shown in Table 2.

TABLE 2

ROOT DEPTHS OF VEGETABLE PLANTS (57)

Shallow-rooted (2 ft.)	Moderately deep-rooted (4 ft.)	Deep-rooted (6 ft.)
Broccoli, sprouting	Beans, bush	Artichokes
Brussels sprouts	Beans, pole	Asparagus
Cabbage	Beets	Beans, lima
Cauliflower	Carrots	Cantaloupes
Celery	Chard	Parsnips
Corn, sweet	Cucumbers	Pumpkins
Lettuce	Eggplant	Squash, winter
Onions	Mustard	Potatoes, sweet
Potatoes, Irish	Peas	Tomatoes
Radishes	Peppers	Watermelons
Spinach	Squash, summer	
	Turnips	

Under normal soil and moisture conditions root development occurs to its full depth and spread, but local conditions may prevent normal action. For instance, a high water table limits the depth of growth to the water level, the roots are stunted and increase in length laterally rather than vertically. The same effect may be caused by shallow layers of hardpan or by coarse gravel which can not maintain sufficient moisture for plant use. Root development is stimulated by fertilization, and concentration of roots have been found (57) where organic matter was abundant, the soil in such areas drying out more rapidly than in zones fertilized more lightly.

The relative sensitivity or tolerance of agricultural plants to soluble salts in soils occupied by root systems is shown in Table 3 (40), (35). In assuming these classifications, it is presumed that the soil is not exceedingly sandy as sandy soils hold less water than fine grained soils, and in them a given percentage of salt produces a more concentrated solution. Such classifications are made on the basis of percentage of salts to the dry weight of the soil. In this table the relative tolerance of plants to salt constituents in the soil solution is in four groups, as follows: (1) sensitive crops that do well when the soil contains light concentrations between 0.1 and 0.4 per cent; (2) medium sensitive plants that can produce profitably when the salinity is between 0.4 and 0.6 per cent; (3) medium tolerant plants that do reasonably well on a soil containing salts within the range 0.6 to 0.8 per cent; and (4) tolerant plants that are adapted to concentrations between 0.8 and 1.0 per cent.

In reaching decisions as to which are the best crops to grow on saline land, it is necessary to know something about the kinds of salts and their degrees of concentration. White alkali salts in reasonably low concentration are not particularly dangerous to plant life although in the case of cereals, hay crops may be produced profitably when grain is unable to mature. Sodium carbonate or "black alkali" is detrimental to all plant life and any attempt at cropping on soil permeated with it will end in disappointment. A few crops are sensitive to an excess of boron, particularly lemon and walnut trees which are subject to injury when the concentration is more than 0.5 p.p.m. (47).

TABLE 3

RELATIVE TOLERANCE OF AGRICULTURAL PLANTS TO DIFFERENT DEGREES OF SALINITY IN THE SOIL SOLUTION (40), (35)

Sensitive crops able to stand salinity of 0.1 to 0.4 per cent	Medium sensitive crops able to stand salinity of 0.4 to 0.6 per cent	Medium tolerant crops able to stand salinity of 0.6 to 0.8 per cent	Tolerant crops able to stand salinity of 0.8 to 1.0 per cent
Peaches	Onions	Barley, hay	Tall oatgrass
Corn	Squash	Tomatoes	Smooth bromegrass
Beans	Carrots	Cotton	Western wheatgrass
Red clover	Ladino clover	Alfalfa, mature	Bermuda grass
Field peas	Sunflower	Sorgo	Rhodes grass
Potatoes	Rice	Kale	Sugar beets
Horse bean	Rye, grain	Rape	Milo
Vetch	Barley, grain	Meadow fescue	Table beets
Proso	Oats, hay	Italian ryegrass	Salt grass
Oats, grain	Wheat, hay	Crested wheatgrass	
Emmer, grain	Grain sorghum	Slender wheatgrass	
Wheat, grain	Foxtail millet	Asparagus	
Alfalfa, young	Strawberry clover		
	Sweet clover		
	Cowpeas		
	Flax		

The tolerance of only a few of the crops listed above will be discussed. Alfalfa, the most important forage crop in the west, has a medium tolerance of saline soils, except young growth, which is very sensitive. It is difficult to start, even on moderately saline soil, unless leaching prior to seeding or heavy rains carries the surface concentrations into the soil. If alfalfa roots are able to penetrate to some depth before the salts again return to the surface, alfalfa may continue to grow even though sometimes surrounded by light deposits.

Certain meadow and pasture grasses may be safely recommended for subirrigated bottom lands that contain salts up to 1 per cent, especially as the customary heavy irrigation of pastures in California will leach out much of the salt content. Bermuda and Rhodes grasses are high in tolerance of salinity. Where leaching is not carried on extensively, fertilization of irrigated pastures is a worthy practice that will bring marked results when the pastures are several years of age.

Sweetclover is a common weed in many localities, but it is valuable for pasturage and hay and useful as a green manure crop. It is tolerant of medium salinity. Of the cereals, rye is one of the most tolerant. Cotton and flax, both ranking crops in California, are tolerant of salinity, cotton being markedly so while flax is only moderately tolerant. Sugar beets are highly tolerant of salt concentrations but, as with alfalfa, difficulty is often experienced in obtaining a stand on saline soils although once well rooted it is possible for satisfactory yields to be obtained. However, as the salt concentration in the soil increases, the effect of the salt tends to decrease the sugar content.

Date palms will stand some salinity, but citrus and deciduous fruit trees are sensitive to alkali in the soil. Apples, pears and peaches are very sensitive. Among citrus trees, lemons are the most sensitive, grapefruit trees tolerate the most salt, and oranges are in between. Grapes are believed to be highly tolerant of salt.

Of the garden vegetables and truck crops, wax beans are very sensitive, onions, carrots, and squashes are medium sensitive, tomatoes and asparagus are medium tolerant while table beets are most tolerant. Asparagus is grown extensively in the Sacramento-San Joaquin Delta area where in some cases it is believed to receive saline water by subirrigation from tidal effects.

METHODS OF APPLYING IRRIGATION WATER

In planning a farm irrigation system, the farmer should have a knowledge of the slopes of his land, the quantity and time of delivery of his water supply, and a basic understanding of irrigation practices, in order that he may design a system best suited to his needs. Methods of irrigating vary according to slope of the land, soil type, crop to be raised, and availability of the water supply. The principal methods used in California are the corrugation or furrow method, the border method and its modifications, subirrigation method, the sprinkling method, and methods adapted to the underground pipe system. A contour map of the area showing the elevation and slope of the land is one of the first requirements.

THE FURROW OR CORRUGATION METHOD

Cultivated crops are irrigated by means of small ditches between the rows, designated as furrows; when the furrows are small they are called corrugations. The spacing of furrows is regulated by the spacing of the crop rows. Corrugations are sometimes spaced to conform to soil characteristics, and on sandy soils the spacing is close. Steep slopes, likewise require the corrugation method of irrigation, as small streams of water will move down the slope with less danger of erosion than would larger flows. The length of furrows or corrugations should be governed by soil conditions, the time rate of flow being such that water reaches the lower end of the furrow before the upper end receives more water than can be held in the root zone. Average lengths of 300 feet or less should be satisfactory for corrugations on steep slopes; the length of furrows should not exceed 400 to 600 feet in loam soils, while 1,000 feet may be satisfactory on moderate slopes of tight soils (37).

THE BORDER METHOD

The border, or controlled flooding method, is best adapted to irrigation of alfalfa, clover and grains, and can best be used where canals are able to deliver water to the borders in large heads. It is especially suitable for light sandy soils as the use of a large stream confined within the border levees makes it possible to force water over the surface without excessive percolation losses. It consists of the division of a field to be irrigated into narrow strips or lands by low flat levees sufficiently smooth to permit operation of farm machinery over the levee without personal discomfort to the operator or damage to the equipment.

The length and width of border strips can be determined experimentally for any head of water available. Assuming a given width, the length will be governed by the time rate of flow of the sheet of water contained in the border. At some point in the strip, the flow will show a slowing down in its advance over the ground surface, this point indicating the distance from the head ditch at which the border should end. If the border strip extends beyond this point, seepage losses may become excessive. Widths vary from 20 feet on steeper slopes to 50 or 60 feet on flat slopes, and they also depend on the head of water available. At the upper end of the border strip for a distance equal to its width a flat area without slope will distribute the flow evenly and obtain complete coverage of the full border width. Careful leveling between levees prevents high or low spots and is essential for careful practice.

The slope of the border, its length and width, and the head of water used are all factors in erosion or its prevention. A smooth surface having a slope of two to three inches per 100 feet may be adaptable to heads as high as eight to 10 cubic feet per second without damage to the surface. If the surface is exceptionally well leveled it is possible to make borders on minimum slopes of one inch per 100 feet; maximum slopes of two feet per 100 feet are possible, but care should be taken on the steeper slopes that erosion does not occur. Large volumes of water can not be handled on steeper slopes.

Lengths of border runs vary according to soil type and size of irrigating stream, the shorter runs being most adaptable to open porous soils and the longer runs to heavy soils. The border dimensions of three grades of soil for different rates of flow are set out in Table 4 (28).

TABLE 4

BORDER STRIP DIMENSIONS FOR THREE GRADES OF SOIL (28)

Head	Sand		Loam		Clay	
	Width	Length	Width	Length	Width	Length
Cubic feet per second	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1	20- 30	200-300	30	300-400	30	440-660
1 to 2	30- 40	300-400	30- 40	440-660	30- 40	660
2 to 4	30- 40	440	40	440-660	50	660-800
4 to 8	40	440-600	50	660-880	50	880-1,320

THE SUBIRRIGATION METHOD

Subirrigation is practiced in parts of the Sacramento-San Joaquin delta area on low lands which have a high water table. Crops grown are sugar beets, asparagus, potatoes, celery, and various short-rooted crops. Water is admitted to a given area from the river to raise the groundwater level to the height presumed to be required for the best welfare of the crop. Much of this area is peat formation and water tables are maintained at higher levels than would be permitted in other irrigated sections. After the irrigation, pumping removes excess water from the soil, thus preventing waterlogging of the lands during the winter months (52).

THE SPRINKLING METHOD

The sprinkling or spray method of applying water for irrigation has been used in California since approximately 1920 (19). The early systems of permanent overhead sprinklers were expensive, costing from $300 to $500 per acre for installation, but the operation costs were negligible except for the cost of the water. Several years later, through the availability of quick-coupling pipe, portable sprinkling systems came into use and for these the initial cost was low but the cost of labor in moving the pipe over the fields was relatively high. At about the same time low head sprinklers set under orchard trees also came into use, most of these being portable, so as not to interfere with cultural practices.

The overhead systems are used principally for irrigation of trees. Growers report them to be generally satisfactory where properly installed and to use about the same amount of water that would be required by a furrow system of irrigation. Low-head portable sprinklers are also used in orchards. Portable sprinklers are popular in some districts for irrigation of field and truck crops to which they are well adapted. They have been used on bean land, in Orange County, on truck crops, in the Salinas Valley, and on sugar-beets and other crops in the Delta area and the Sacramento Valley. In some cases sprinkling systems have been used for irrigation of lands unfit for surface irrigation because of lack of proper land preparation. In areas formerly subirrigated but where groundwater levels have since receded below the reach of root systems, sprinkling systems are applicable.

UNDERGROUND PIPE SYSTEMS

In southern California, and other areas where water is scarce and costs are high, underground pipe systems for irrigation are conserving of water. Use of such systems results in high irrigation efficiencies. Concrete pipe is used extensively in California, with risers from the buried pipe delivering water into surface ditches or borders, and where the pipe is under enough pressure water can be delivered to sprinklers. The cost of the first installation is high, but it is economical in the end, as it has a long life, is out of the way beneath the surface, does not encourage the growth of weeds as do surface ditches, and does not interfere with farming operations.

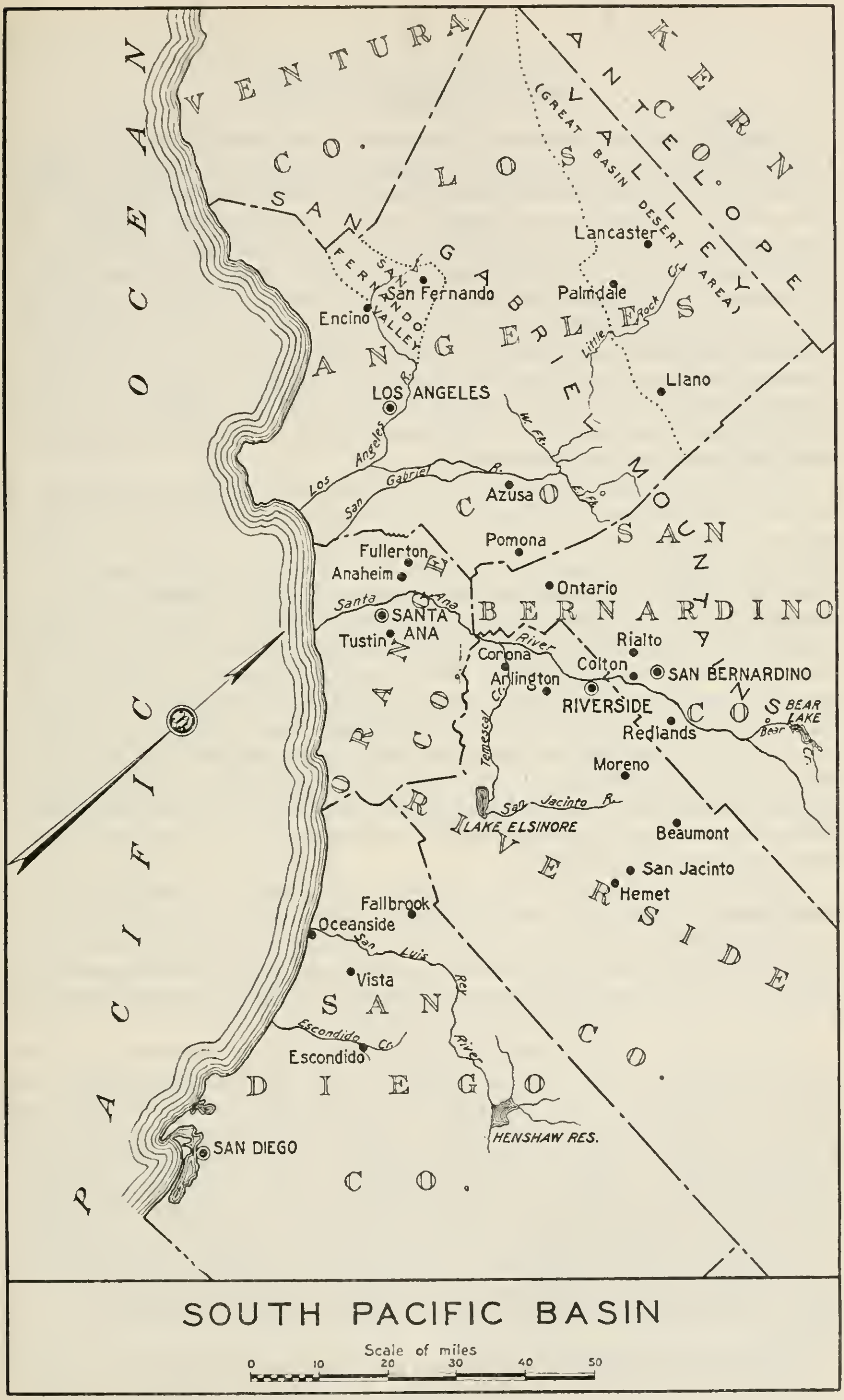
PACIFIC OCEAN
VENTURA CO.
KERN CO.
LOS ANGELES CO.
ANTELOPE VALLEY (GREAT BASIN DESERT AREA)
SAN FERNANDO VALLEY
SAN GABRIEL MTS.
Lancaster
Palmdale
San Fernando
Encino
Little Rock Cr.
Llano
LOS ANGELES
Los Angeles R.
San Gabriel R.
W. Fk.
Azusa
Pomona
SAN BERNARDINO CO.
Fullerton
Anaheim
Ontario
Santa Ana
SANTA ANA
Tustin
River
Rialto
Corona
Colton
SAN BERNARDINO
Arlington
RIVERSIDE
ORANGE CO.
BEAR LAKE
Bear Cr.
Redlands
Temescal Cr.
Moreno
San Jacinto R.
LAKE ELSINORE
Beaumont
RIVERSIDE CO.
San Jacinto
Hemet
Fallbrook
Oceanside
San Luis Rey River
Vista
SAN DIEGO CO.
Escondido Cr.
Escondido
HENSHAW RES.
SAN DIEGO
SOUTH PACIFIC BASIN
Scale of miles
0 10 20 30 40 50

Fig. 1

SOUTH PACIFIC BASIN

The South Pacific Basin includes the agricultural area adjacent to the Pacific Ocean between the westerly boundary of Ventura County on the northwest and the Mexican boundary on the south. Its northerly and easterly limitations are defined by the summits of San Gabriel, San Bernardino and San Jacinto Mountains, and the mountain ranges in San Diego County. It includes all of Orange County and those portions of Ventura, Los Angeles, San Bernardino, Riverside and San Diego Counties in which the watersheds are tributary to the Pacific Ocean. The agricultural lands are principally in alluvial valleys, but in places crops are grown at higher elevations. The total area capable of producing crops, including valley floors and marginal plains and foothills is in excess of 2,000,000 acres, of which 594,600 was irrigated in 1939, according to the 1940 census of agriculture (58).

The South Pacific Basin (Fig. 1) has the most meager supply of surface run-off of any of the major subdivisions of the State. Torrential winter rains that sometimes occur in mountain regions create serious flood problems, but summer rains are inconsequential and in few instances do they provide surface flow in streams. Flow available for irrigation is thus limited to small streams emerging from the mountains during early summer months, to a sustained flow in the middle Santa Ana River and the San Gabriel River, and to storage in mountain reservoirs. Even if the total flow were available for irrigation there would still be less than sufficient water for irrigated areas; much of this insufficient supply is lost into the ocean, or through evaporation and by seepage into underground basins. It is necessary, therefore, to supplement the surface supply with pumped water, and in portions of the south Coastal Basin as much as 75 per cent of the water pumped for irrigation comes from underground storage.

Without irrigation few crops can be raised, as precipitation is insufficient during the growing season. Dry land farming is confined principally to the growing of grains on a summer fallow rotation in the interior valleys, wine grapes near Ontario, and beans in the coastal area. The principal irrigated crops are subtropical fruits and nuts, deciduous fruits, hay, truck crops, sugar-beets and beans.

The climate of the South Pacific Basin is characterized by a long rainless summer extending from April to October or November. Seasonal rainfall along the coast varies from 10 to 20 inches with totals of 30 to 40 inches in mountain areas. Temperatures are moderate and freezing weather seldom occurs except inland, and then only for a few hours at night. Average frost-free periods usually are from February to late November and in many years frosts do not occur at all except in colder areas. Winter rains provide soil moisture for winter growth but not always in sufficient quantity to forestall the necessity of some winter irrigation. Uneven distribution of rainfall throughout the winter may, under conditions of cover cropping, require additional moisture by irrigation.

Individual irrigation methods and practices for the various crops and soil types found in the basin usually follow neighboring practices and customs as regards distribution of water to crops, and where water deliveries are on regular rotation schedules the irrigation intervals depend on the time of delivery rather than on the supply of moisture in the soil available for plant use. Such practices often result in applications in excess of crop needs and cause over-irrigation and additional water costs. In this report efforts are made to estimate reasonable average irrigation requirements for various crops and localities without estimating the irrigation intervals.

Experimental work carried on for many years by the Division of Irrigation, Soil Conservation Service, and the California Agricultural Experiment Station, either separately or cooperatively, provides much of the basis on which many of the irrigation requirement values may be estimated. Such experiments include soil moisture studies throughout the growing season to discover the transpiration use of water by crop plants. With this value known, estimated irrigation requirements may be derived if data are available concerning moisture lost by evaporation, penetration of water below the zone of root activity, and waste of water at the ends of irrigation furrows. Such experiments usually are of sufficient duration to provide average values for the usual climatic variations.

Experiments on consumptive use of water may be conducted with tanks in which plants are grown with measured quantities of water applied according to adopted schedules. In tank studies the water used by the plants includes evaporation from the soil surface of the tank as well as transpiration from the leaves so that the total use becomes consumptive. For such studies it also is possible to estimate average irrigation requirements. In the South Pacific Basin, however, tank studies, other than for grasses, have not been undertaken.

In localities where no experimental work has been undertaken the nearest approach to the requirements is through records of water applied, especially if pumped from wells, and irrigation requirements derived from soil moisture studies.

In the South Pacific Basin experimental studies have been conducted by the Division of Irrigation or the California Agricultural Experiment Station on irrigation requirements of citrus, avocados, deciduous fruits, walnuts, and alfalfa in San Diego, Orange, Riverside, San Bernardino and Los Angeles Counties. Depths of water applied in direct irrigation also are tabulated for various valleys and sub-basins.

NORTHERN SAN DIEGO COUNTY

Northern San Diego County includes portions of Escondido Creek, and the San Luis Rey and Santa Margarita River watersheds. The area is principally mountainous except for small interior valleys adjacent to a narrow coastal plain. Within these watersheds lies a considerable acreage of arable land for which there is a limited water supply for irrigation. Most of the supply is dependent upon the storage of river flow although pumping from wells is also practiced. Irrigated crops include oranges, lemons, avocados and some grapes and vegetables.

The principal farming localities within this area are those surrounding the towns of Escondido, Vista and Fallbrook, which lie generally within a zone ranging from 100 to 1,000 feet above sea level. The principal soils of agricultural value are residual sandy loams with heavier subsoils that grade into decomposed granitic bedrock at depths ranging from 30 to 60 inches. The surface is rolling hill land separated by narrow valleys, which in spite of the shallow depths to bedrock produces profitable crops.

Climatic conditions are extremely favorable for growth of citrus and subtropical trees, and crops grow throughout the year. The distribution of rainfall varies according to location and ranges from an average of 10 inches at San Diego to about 20 inches at Fallbrook. A summary of temperature, rainfall and length of growing season, in Table 5, shows increases in rainfall according to elevation. Irrigation seldom is necessary before May or June and over a 25-year period the average time between effective rains was 236 days, ranging from a maximum of 332 days to a minimum of 130 days. Effective rainfall here is considered as being an amount that adds to the soil moisture supply. Usually rains of less than one-half inch are of no value to crops unless the soil has previously been moistened without opportunity to dry out. In order to provide for normal water requirements one winter irrigation in three years out of 10 and two winter irrigations in two years out of 10 have been found necessary.

The average length of time between killing frosts at Escondido is 255 days, killing frosts being defined as temperatures at or below 32°F. Frostfree periods vary from place to place and from year to year. As a rule frosts are not serious and frost protection is practiced less here than in some other areas in Southern California.

The water supply for irrigation by the Escondido Mutual Water Co. and Vista Irrigation District comes from storage in Lake Henshaw, located on the upper waters of San Luis Rey River. The reservoir is owned by the San Diego County Water Company, which sells water on an acre-foot basis. In the Fallbrook area water is pumped by individual owners in addition to the Fallbrook Public Utility District supply which is pumped from wells in the sands and gravels of San Luis Rey River. Individual wells in the Fallbrook area frequently are limited in production because of their shallow depth which is controlled by bedrock formation.

TABLE 5

SUMMARY OF TEMPERATURE, RAINFALL AND LENGTH OF GROWING SEASON IN NORTHERN SAN DIEGO COUNTY, CALIFORNIA

Location	Elevation	Climatic zone	Mean annual temperature	Mean annual rainfall	Mean length of growing season[1]
	Feet		*°F.*	*Inches*	*Days*
San Diego	26	Coastal	61.4	10.30	365
Oceanside	50	Coastal	61.4	14.25	----
Escondido	750	Intermediate	61.0	16.60	255
Vista	120	Intermediate	----	16.64	----
Fallbrook	750	Intermediate	----	20.08	----

[1] Average number of days between the dates of the last killing frosts in the spring and the first killing frosts in the fall which are designated by the Weather Bureau as temperatures of 32° F. or less.

Irrigation Requirements of Citrus and Avocados

Cooperative studies of transpiration use of water by lemon, orange and avocado trees, including also water used by winter cover crops in the groves, were undertaken in 1926 and 1927 by the Division of Irrigation and the California Agricultural Experiment Station (11). Soil sampling methods were employed to determine the depths of soil moisture used by the crops, the dry soil mulch being first removed before samples were taken. Determinations of moisture, therefore, were of transpiration use rather than consumptive use which includes soil evaporation.

As a result of the studies the depths of moisture consumed from rainfall, the depths used from irrigation deliveries, and the total depths transpired are shown in Table 6. The total transpiration use varied from 5.8 inches of depth to a maximum of 13.4 inches for the 6½-month irrigation period. The causes of these low values in northern San Diego County are a deficiency of water, a shallow root zone overlying the parent rock, and the high cost of water. Average applications of water to six groves out of seven totaled 11.4 acre-inches per acre during the season.

Cover cropping between trees during winter months is the usual practice in southern California, the crop being planted in the fall and disked under for green manure usually about March when the crop begins to compete with the trees for moisture. The effect of cover crops is to increase the winter water use of a grove, but as the crop is grown during the wet season there is no additional demand upon irrigation requirements provided disking is done while a sufficient amount of moisture from rainfall is retained in the soil. Table 7 shows transpiration losses from October 15, 1925 to April 1, 1926 for seven groves of citrus and avocado trees having cover crops. The different amounts of water consumed may be attributed in a large degree to the size of the trees and the growth and density of the cover crop. Comparison of this tabulation with the summer use by clean cultivated trees, shown in Table 6, indicates nearly 50 per cent higher average use of water per month during the rainy winter season than during the dry summer irrigation season.

TABLE 6

TRANSPIRATION USE OF WATER BY CITRUS AND AVOCADO TREES IN SAN DIEGO COUNTY, CALIFORNIA, 1927 (11)

Location	Soil type	Depth of soil	Crop	Age of trees	Relative size of trees	Method of irrigation	Depth of irrigation water applied	Depth of transpiration, April 1 to October 15, from—			Depth of estimated seasonal irrigation requirements under present irrigation practice
								Rain	Irrigation	Total	
		Feet		*Years*	*Per cent*		*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Escondido	Sierra sandy loam	4.0	Lemons	16	100	Furrow	19.60	4.0	9.4	13.4	18.5
Fallbrook			Lemons[1]	11	60	Sprinkling	11.19	2.1	4.9	7.0	13.5
Vista	Sierra sandy loam	2.5	Lemons	13	76	Furrow	11.49	1.6	4.7	6.3	10.5
Escondido	Sierra sandy loam	4.0	Valencia oranges	7	40	Furrow	8.24	2.5	4.3	6.8	18.0
Fallbrook	Holland sandy loam	5.0	Navel oranges	31	78		11.78	3.0	6.2	9.2	16.5
Fallbrook	Holland sandy loam	4.0	Navel oranges	7	36		12.50	2.4	3.4	5.8	18.5
Vista	Sierra sandy loam	[1]2.5	Avocados[1]	13	90	Furrow	13.25	1.7	7.5	9.2	17.0

[1] Deficiency in water supply.

TABLE 7

SUMMARY OF WINTER TRANSPIRATION USE OF WATER BY TREES AND COVER CROPS, OCTOBER 15, 1925, TO APRIL 1, 1926, IN THE VICINITY OF ESCONDIDO, VISTA AND FALLBROOK, CALIFORNIA (11)

Crop	Cover crop	Depth of transpiration use		
		October 15 to January 15	January 16 to April 1	October 15 to April 1
		Inches	*Inches*	*Inches*
Lemons	Purple vetch—medium	4.46	4.11	8.57
Lemons	Weeds and grass—medium	5.37	3.74	9.11
Lemons	Purple vetch—medium	4.95	5.73	10.68
Oranges	Purple vetch—medium	5.26	6.22	11.48
Oranges	Purple vetch—heavy	5.21	6.77	11.98
Oranges	Weeds and grass—medium	------	6.88	------
Avocados	None	3.18	3.34	6.52

As a result of this investigation it was the conclusion of the investigators that:

"* * * with a 60 per cent efficiency in irrigation and 90 to 100 per cent of the soil mass moistened at each irrigation, mature citrus groves in the Escondido and Fallbrook areas have a net seasonal summer irrigation requirement of 18 acre-inches of water per acre. Similar groves in the Vista district under similar conditions require at least 15 acre-inches per acre. In fully mature groves where smaller quantities than these are available and where furrow irrigation is practiced, a correspondingly smaller percentage of the soil mass should be moistened at each irrigation. Citrus groves, 6 to 8 years of age and 40 to 50 per cent of their probable ultimate size, will have a net summer water requirement of 6 to 8 acre-inches per acre. * * * Normal rainfall when properly distributed is adequate to meet the winter needs of both trees and cover crops." (11)

Irrigation Water Applied

Irrigation deliveries by the Vista Irrigation District (63) to small groves of avocado trees or to farms supporting both avocados and citrus are tabulated in Tables 8 and 9. These values differ from transpiration use in that they include losses by evaporation from wet soil and water

TABLE 8

IRRIGATION WATER APPLIED TO MIXED ACREAGES OF AVOCADOS AND CITRUS, VISTA IRRIGATION DISTRICT, 1937-43 (63)

Crop	Depth of water delivered per acre							
	1937	1938	1939	1940	1941	1942	1943	Mean
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Avocados with some oranges or lemons	12.6	19.7	19.1	18.8	13.9	20.3	19.9	17.7
Avocados with some oranges or lemons	14.5	14.5	8.3	7.8	7.4	8.6	9.5	10.1
Avocados with some oranges or lemons	19.3	24.7	19.6	19.0	14.6	19.6	19.3	19.4
Avocados with some oranges or lemons	15.6	19.2	14.8	16.9	9.5	14.2	15.4	15.1
Avocados with some oranges or lemons	11.6	17.2	13.3	14.3	13.9	27.5	33.2	18.7
Avocados with some oranges or lemons	8.9	16.7	10.3	24.2	9.2	17.4	22.4	15.6
Avocados with some oranges or lemons	11.9	16.6	24.5	16.9	11.0	18.7	19.3	17.0
Avocados with some oranges or lemons	12.6	14.9	12.2	13.9	10.4	14.2	16.0	13.5
Avacados with some oranges or lemons	8.0	9.1	11.4	11.3	9.2	14.0	16.0	11.3
Mean irrigation	12.8	16.9	14.8	15.9	11.0	17.2	19.0	15.3
Annual mean rainfall[1]	22.3	23.6	13.6	25.8	31.0	11.2	21.4	21.3

[1] Rainfall record from Escondido.

MEAN DEPTHS OF WATER APPLIED ACCORDING TO SOIL TYPES

Soil	Depth of water delivered per acre							
	1937	1938	1939	1940	1941	1942	1943	Mean
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Adobe	15.8	19.8	16.0	16.7	12.5	16.8	17.6	16.4
Sandy loam	11.9	16.1	14.5	15.7	10.6	17.3	19.4	15.1

surfaces, possibly some deep percolation, and such water as may be wasted. However, because of the high cost of water in this area deep percolation and waste are kept minima and the water applied to the grove approaches the irrigation requirement. Records are available for 19 groves covering a period of seven years. Irrigation methods include principally furrowing but sprinkling was also used in a few cases. Two groves were on adobe soil and the rest on sandy loam.

The average seven-year mean depth of water applied to nine groves that were principally avocados (although some plantings included also lemons or oranges) amounted to 15.3 acre-inches per acre. Mean water deliveries ranged from 11 acre-inches per acre, for the wettest year of the period, to 19.0 acre-inches for the season following the dryest year. Segregating the deliveries by soil type shows slightly less water applied to sandy loam soils than to adobe soil.

Water deliveries to 10 avocado groves, totaling 72 acres, averaged 18.5 acre-inches per acre for the seven-year period reported by the Vista Irrigation District. Mean rainfall was 21.2 inches. The highest mean delivery of 22.3 acre-inches per acre was during the dry year of 1939 when annual rainfall was but 13.6 inches; the lowest mean delivery to the 10 groves was 13.2 acre-inches per acre in 1941, following a high annual rainfall of 25.8 inches. Since most of the rain occurred during winter months only a portion was held in the shallow soil for summer use.

TABLE 9

IRRIGATION WATER APPLIED TO 10 AVOCADO GROVES, VISTA IRRIGATION DISTRICT, 1937-43 (63)

Crop	Depth of water delivered per acre							
	1937	1938	1939	1940	1941	1942	1943	Mean
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Avocados	20.6	27.0	28.9	29.3	17.9	25.2	23.8	24.8
Avocados	25.6	28.8	26.8	24.0	9.8	21.5	20.3	22.4
Avocados	12.7	14.0	17.2	26.0	14.4	19.4	22.9	18.1
Avocados	9.6	15.6	17.8	15.5	10.4	18.1	19.4	15.2
Avocados	16.1	19.7	19.6	15.1	7.8	8.2	8.0	13.5
Avocados	24.4	26.8	25.1	27.0	19.2	22.8	20.5	23.9
Avocados	17.8	18.2	32.0	20.6	13.8	18.0	15.1	19.3
Avocados	8.4	15.4	17.6	17.8	10.9	21.2	7.8	14.2
Avocados	18.8	16.9	17.9	15.2	13.7	17.8	8.2	15.5
Avocados	11.4	19.6	20.4	16.6	14.3	24.1	24.0	18.6
Mean irrigation	16.5	20.2	22.3	20.7	13.2	19.6	17.0	18.5
Annual mean rainfall[1]	22.3	23.6	13.6	25.8	30.7	11.2	21.4	21.2

[1] Rainfall at Escondido.

MEAN DEPTHS OF WATER APPLIED ACCORDING TO IRRIGATION METHOD

Method	Depth of water delivered per acre							
	1937	1938	1939	1940	1941	1942	1943	Mean
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Sprinkling	25.0	27.8	25.9	25.4	20.5	22.1	20.4	23.9
Furrow	14.2	18.1	21.7	20.2	14.0	20.5	17.3	18.0

Sprinkling or furrow methods of irrigation were customary except for one grove in which a combination of sprinkling, furrow and basin method was used for different portions of the area. The soil was sandy loam. Mean water deliveries to groves using sprinkling systems exceeded those to groves with furrows by 5.9 acre-inches per acre per year.

In summarizing, the estimated irrigation requirement of citrus and avocados in northern San Diego County averages 18 acre-inches per acre as determined by soil moisture investigations (11). An average water delivery of 18.5 acre-inches per acre was made to avocado trees in the Vista area by the Vista Irrigation District, while the average deliveries to avocados mixed with some oranges and lemons was only 15.3 acre-inches per acre. It is evident that water was economically used and that the depths of water applied were approximately equal to the irrigation requirements of the area.

SANTA ANA RIVER VALLEY

The Santa Ana River Valley contains the coastal plains and foothills in Orange County and the interior areas in Riverside and San Bernardino Counties. It embraces portions of the Beaumont Plains, lying astride San Gorgonio Pass, which separate the Santa Ana Basin from Coachella Valley, and the entire area of San Jacinto Basin, which is tributary to the Santa Ana River through Lake Elsinore and Temescal Creek. It extends from the Pacific Ocean to the San Bernardino Mountains on the north and the San Jacinto Mountains on the east, and includes large areas of agricultural land which produce annually crops of great value. Of the tree crops, citrus, avocados and deciduous fruits and nuts are the most prominent. Dry land wine grapes are grown on a considerable area and in interior valleys grain is grown in a summer fallow or alternate-year crop rotation.

Climate of the valley varies according to locality, whether it be coastal, intermediate, or interior. In the coastal area summer temperatures are slightly lower than in the interior valleys where the higher temperatures continue into September. High fogs moderate coastal temperatures. Dry winds occur at intervals during fall and winter months and unless there is sufficient moisture in the soil to provide for transpiration needs during these periods, trees will suffer from windburn.

As in all southern California, rainfall occurs from November to April, thus providing moisture for winter crops, with some carry-over in the soil available at the beginning of the normal irrigation season. Rainfall distribution, however, may bring about the need for periods of winter irrigation, a requirement that varies widely from year to year. Mean total rainfall varies from 11 inches at Riverside to 19 inches at the higher elevation at Beaumont, but is approximately the same on the Coastal area at Santa Ana as in the interior valley of the San Jacinto River where it averages 13 to 14 inches.

The growing season varies from year to year according to the period between the first and the last killing frosts. The longest growing period is found on the Coastal Plain where an average of 304 days is frost-free at Santa Ana, and although records are not available the shortest period doubtless occurs at a higher elevation at Beaumont. Frost protection for citrus trees is necessary during the coldest nights. A summary of temperatures, rainfall and length of growing season is shown in Table 10.

TABLE 10

SUMMARY OF TEMPERATURE, RAINFALL, AND LENGTH OF GROWING SEASON IN THE SANTA ANA RIVER VALLEY, CALIFORNIA (59)

Location	Elevation	Climatic zone	Mean annual temperature	Mean annual rainfall	Mean length of growing season [1]
	Feet		*°F.*	*Inches*	*Days*
Santa Ana	133	Coastal	62.8	13.40	304
Riverside	851	Interior	62.9	11.11	270
San Bernardino (near)	1,172	Interior	63.0	15.87	262
Redlands	1,352	Interior	62.9	14.21	282
San Jacinto	1,550	Interior	62.6	13.23	247
Beaumont	2,558	Interior	59.7	19.00	----------

[1] Average number of days between the dates of the last killing frost in the spring and the first killing frost in the fall. Killing frosts are designated by the Weather Bureau as temperatures of 32° F. or less.

Agricultural soils of the area are classed in three groups based on the process by which the soil material was accumulated. They are the residual soils, the soils of the Coastal Plain and old valley fill material, and recent alluvials which are the most prominent agricultural soils.

The topography ranges from steeply sloping on the alluvial fans to nearly level along stream bottoms. Areas generally are smooth but may be modified by drifts or erosion.

Water supply for irrigation is obtained by gravity from streams of which Santa Ana River is the largest, or by pumping from underground basins. Important diversions are in Orange County where, during the irrigation season, the entire flow of the river is divided between irrigation systems. Water is pumped for irrigation from underground basins in all areas where gravity flow is not sufficient. Pumping lifts vary from less than 50 feet in coastal regions to as much as 500 feet high up on alluvial cones. Ground water has been receding in most areas for many years and pumping lifts have increased consistently. Cost of gravity water is reasonable but pumping costs vary with the lift necessary for delivery to cropped fields.

Production of citrus fruits is the principal industry of the Santa Ana River Valley and irrigation is the most important item in growth of the crop as rainfall provides insufficient moisture, little of which occurs in the growing season. Citrus trees grow in many types of soil but generally are found on loams and sandy loams. They are shallow rooted, roots usually extending to depths of not more than five or six feet. Irrigation experiments have determined that more than 60 per cent of all roots function in the upper two feet of soil and perhaps only about 10 per cent in the lower two feet. The furrow method of irrigation is commonly used although on lighter soils the basin method frequently is practiced.

Transpiration Studies of Citrus and Walnut Trees

Studies of the transpiration use of water by citrus and walnut trees in the Santa Ana River valley were made by the California Agricultural Experiment Station cooperating with the Division of Irrigation between 1928 and 1935 (10) (44), using the soil moisture method from which it was possible to determine the quantity of water consumed within the root zone of the tree below the upper dry mulch. Soil samples were taken from plots in selected orchards to depths of six feet and determination of moisture was made for each foot of soil. Selection of orchards was according to soil type, on groves where the water supply was reliable, so that there would be no deficiency in applications for irrigation.

In the coastal region plots were located on loam and sandy loam soils of alluvial origin and in the interior they were distributed between loams and sandy loams of the Yolo, Tujunga and Hanford series and the Placentia and Ramona loams. Principal characteristics of the plots in Riverside and San Bernardino Counties are shown in Table 11 (44).

In Orange County differentiation was made between mature citrus trees and young trees 12 to 14 years old. Experiments also were made with mature walnuts on the same basis with the exception that since walnuts are deep rooted, soil moisture samples were taken to greater depths. The experimenters found two-thirds of the root activity and an equal ratio of transpiration loss from citrus trees in the top two feet of soil for the older trees and three-quarters of the loss in the same depth by young trees. Below a depth of four feet transpiration loss was very small. In the Corona area, in shallow soil sampled to a depth of six feet, root activity in the top foot was about 35 per cent and in the sixth foot five per cent.

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TABLE 11

LOCATIONS AND MAIN CHARACTERISTICS OF PLOTS IN INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, CALIFORNIA

Seasons of 1930 to 1935 (44)

Orchard	Location	Crop	Year planted	Condition of trees	Method of irrigation	Soil	Remarks
No. 6a	1½ miles S.W. of Corona	Navel oranges	1900	Excellent	Furrow	Yolo loam	Gravel with depth
No. 6b	2.7 miles S. of Corona	Navel oranges	Mature	Excellent	Furrow		
No. 6c	3.5 miles S.W. of Corona	Eureka lemon	Mature	Good	Furrow		
No. 6d	2.5 miles S.W. of Corona	Lisbon lemon	Mature	Excellent	Furrow		
No. 6e	1.2 miles S. of Corona	Navel oranges	Mature	Very good	Furrow	Yolo gravelly loam	Gravel below 4 feet
No. 6f	2.4 miles S.E. of Corona	Navel oranges	Mature	Fair	Furrow		
No. 6g	3.3 miles S.E. of Corona	Eureka lemon	Mature	Fair	Furrow		
No. 6h	South of Corona	Navel oranges	Mature	Fair	Furrow		
No. 6i	3.0 miles S.E. of Corona	Navel oranges	Mature	Excellent	Furrow		
No. 7	2 miles S.W. of Arlington	Navel oranges	Mature	Fair	Furrow	Hanford sandy loam	Heavier subsoil
No. 8a	1½ miles S.E. of Arlington	Navel oranges	1910	Excellent	Furrow	Placentia loam	
No. 8b	1½ miles S.E. of Arlington	Valencia oranges	1910	Excellent	Furrow	Hanford sandy loam	
No. 9a	2 miles E. of Riverside	Navel oranges	1916	Fair	Furrow		
No. 9b	2 miles E. of Riverside	Grapefruit	1916	Fair	Furrow	Ramona loam	Subsoil uniformly heavy
No. 9c	2 miles E. of Riverside	Valencia oranges	1916	Fair	Furrow		
No. 9d	2 miles E. of Riverside	Navel oranges	1916	Fair	Furrow		
No. 10	1 mile E. of Riverside	Navel oranges	Before 1900	Excellent	Furrow	Greenfield sandy loam	Soil uniform
No. 11	At Highgrove	Navel oranges	About 1910	Excellent	Furrow	Ramona loam	Fine texture on top
No. 12	3 miles S.W. of Redlands	Valencia oranges	1913	Excellent	Furrow	Hanford sandy loam	Very uniform
No. 13a	1 mile S. E. of Redlands	Navel oranges	Mature	Good	Furrow	Placentia loam	Dense clay loam below 2½ feet
No. 13b	1 mile S.E. of Redlands	Navel oranges	Mature	Good	Furrow	Hanford sandy loam	
No. 14	1 mile N.E. of Highland	Navel oranges	Before 1900	Excellent	Furrow	Ramona loam	Some clay below 3 feet
No. 15	3 miles N.W. of Rialto	Grapefruit	Mature	Excellent	Furrow	Hanford sandy loam	Increasing coarseness with depth
No. 16	Near Colton	Navel oranges	Mature	Fair	Sprinkler	Placentia loam	Subsoil heavy below 2 feet

Transpiration use of water by crops varies for many reasons, one of which is age and size of trees; the older and more mature trees use more water than those that are young and small. This is indicated in Table 12, which shows monthly transpiration use of water by citrus trees in Orange County. In these areas mean transpiration loss for mature trees was equivalent to a depth of 15.5 inches for the seven-month irrigation period but only 10.7 inches for the young trees from 12 to 14 years of age. Transpiration from mature walnut trees during the growing season averaged 25 acre-inches per acre over a two-year period at Tustin because the trees were larger and the root system deeper and more extensive. The average monthly distribution of transpiration for these trees was as reported in Table 13 (10).

TABLE 12

TRANSPIRATION USE OF WATER BY CITRUS TREES IN THE ANAHEIM, TUSTIN, AND SANTA ANA AREAS IN ORANGE COUNTY, CALIFORNIA, 1928-29 (10)

Year	Crop	Depth of water transpired								Soil moisture carry-over from rainfall	Seasonal[1] irrigation requirement
		April	May	June	July	August	September	October	Total		
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1928	Mature citrus	1.48	2.00	2.90	3.32	2.98	2.38	1.65	16.71	4.19	16.6
1929	Mature citrus	1.28	1.74	2.19	2.48	2.60	2.33	1.70	14.32	3.65	14.2
Mean		1.38	1.87	2.54	2.90	2.79	2.35	1.67	15.52	3.92	15.4
1928	12-14 year old citrus	1.35	1.50	1.82	1.85	1.72	1.52	1.27	11.03	2.32	12.00
1929	12-14 year old citrus	1.15	1.57	1.52	1.50	1.85	1.60	1.25	10.44	2.70	10.00
Mean		1.25	1.53	1.67	1.67	1.79	1.56	1.26	10.73	2.51	11.00

[1] Estimated by the investigators on the basis of 75 per cent efficiency in irrigation.

TABLE 13

TRANSPIRATION USE OF WATER BY MATURE WALNUT TREES, ORANGE COUNTY, CALIFORNIA, 1928-29

Month	Transpiration use	Month	Transpiration use
	Inches		*Inches*
April	0.50	August	5.35
May	4.07	September	3.22
June	3.82	October	1.68
July	6.38	Total	25.02
Estimated seasonal irrigation requirement, inches			18.0

In the upper counties of Riverside and San Bernardino more extensive soil moisture studies were conducted on plots by the California Experiment Station and the Division of Irrigation (44) to determine transpiration losses by citrus trees during the years 1931 to 1935, inclusive. Location of the plots and their main characteristics are described in Table 11. Results of these investigations, reported in Table 14 to Table 17, show water transpired by months and total depth, depth of water applied in irrigation, and other irrigation data. Methods employed and water applied were according to the owner's usual practice except that water was measured where possible.

Examination of the tabulations shows variation in the depth of water applied to different orchards in the same month, owing to differences in soils and personal management. In 1930 the maximum depth applied to a grove was 34.5 acre-inches per acre as compared with a minimum of 21.6 inches applied on another grove. Irrigation practices varied also in regard to the number of irrigations during a season. In 1930 the greatest transpiration loss was from a field which had eight irrigations while the least transpiration came from five irrigations. In the same year, the transpiration in July varied from 8.0 to 3.2 acre-inches per acre for different orchards. For all years, the average seasonal transpiration loss was nearly 21 acre-inches per acre, ranging from 18.8 to 23.5 inches.

TABLE 14

MONTHLY TRANSPIRATION USE OF WATER BY CITRUS, AND IRRIGATION DATA FOR INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, CALIFORNIA, APRIL THROUGH OCTOBER 1930 (44)

Orchard number and year	Depth of water transpired								Irrigation data		
	April	May	June	July	August	September	October	Total April 1 to November 1	Irrigations	Interval between irrigations	Depth of water applied
1930	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Number*	*Days*	*Inches*
6a[1]	1.5	2.1	3.0	3.8	4.3	3.4	3.0	21.1	6	28	33.0
8a, 8b[1]	2.6	3.0	3.6	4.4	4.4	3.1	2.7	23.8	6	30	25.9
9a	1.6	2.1	3.2	4.5	3.9	2.1	1.1	18.5	5	30-38	21.6
9b	1.2	2.5	2.9	3.3	3.0	2.0	1.2	16.1	5	30-38	21.6
9c	1.2	1.2	1.8	4.0	3.3	1.8	1.7	15.0	5	30-38	21.6
10[2]	2.2	1.8	2.2	3.2	2.7	2.4	2.3	16.8	12	15	26.8
11[1]	1.9	2.6	3.6	4.2	3.5	2.8	2.7	21.3	6	30	25.9
12[1]	1.8	2.2	3.7	4.1	4.0	3.3	2.9	22.0	6	25	----------
13a[3]	1.6	3.3	7.0	8.0	5.0	3.7	2.7	31.3	8	15-30	34.5
13b[4]	2.0	2.5	5.4	6.0	4.4	4.3	2.2	26.8	8	15-30	34.5
14[1]	1.8	2.4	3.4	4.5	4.5	3.2	2.9	22.7	6	30	28.0
15	2.3	2.6	3.0	3.4	3.3	3.2	2.7	20.5	9	18	21.6
Maximum	2.6	3.3	7.0	8.0	5.0	4.3	3.0	31.3	12	----------	34.5
Minimum	1.2	1.2	1.8	3.2	2.7	1.8	1.1	15.0	5	----------	21.6
Mean	1.8	2.4	3.6	4.4	3.9	2.9	2.3	23.5	7	----------	26.7

[1] Average of two plots in orchard.
[2] Alternate middles watered at each irrigation.
[3] Heavy cover crop until August 12th.
[4] Cover crop on plot kept hoed down.

TABLE 15

MONTHLY TRANSPIRATION USE OF WATER BY CITRUS, AND IRRIGATION DATA FOR INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, CALIFORNIA, APRIL THROUGH OCTOBER, 1931 (44)

Orchard number and year	Depth of water transpired								Irrigation data		
	April	May	June	July	August	September	October	Total April 1 to November 1	Irrigations	Interval between irrigations	Depth of water applied
1931	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Number*	*Days*	*Inches*
6a[1]	2.0	2.2	3.4	4.4	3.2	2.6	2.4	20.2	7	28	31.0
7	2.0	3.1	4.0	4.0	3.2	3.1	3.0	22.4	6	30	29.7
9d	2.1	1.9	3.6	4.1	3.2	2.6	1.8	19.3	8	21-30	31.3
10[1]		3.0	3.3	4.0	2.6	1.7	2.0		7	30	30.2
11[1]	1.6	1.9	3.7	5.4	4.5	3.1	3.3	23.5	6	30	27.1
14[1]	1.8	2.6	3.8	4.1	3.7	3.0	2.4	21.4	7	30	34.3
15[2]	2.5	3.5	4.4	5.1	4.6	3.6	2.8	26.5	10	18	24.5
16[1]	1.4	2.6	2.9	3.2	4.0	3.9	2.7	20.7	17	10-15	30.6
Maximum	2.5	3.5	4.4	5.4	4.6	3.9	3.3	26.5	17		31.3
Minimum	1.4	1.9	2.9	3.2	2.6	1.7	1.8	19.3	6		24.5
Mean	1.7	2.6	3.6	4.3	3.6	3.0	2.6	21.4	8.5		29.8

[1] Average of two plots in orchard.
[2] Alternate middles watered at each irrigation.

TABLE 16

MONTHLY TRANSPIRATION USE OF WATER BY CITRUS, AND IRRIGATION DATA FOR INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, CALIFORNIA, APRIL THROUGH OCTOBER, 1933 (44)

Orchard number and year	Depth of water transpired								Irrigation data			
	April	May	June	July	August	September	October	Total April 1 to November 1	Irrigations	Interval between irrigations	Depth of water applied	Irrigation efficiency
1933	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*		*Number*	*Days*	*Inches*	*Per cent*
6b[1]	----------	----------	3.2	3.4	4.0	2.7	2.6	Data incomplete	5	12-34	73.0	21
6c[1]	----------	----------	2.4	3.9	4.2	2.8	2.0		10	12-25	33.3	54
6d[1]	----------	----------	2.6	3.0	3.0	2.6	2.0		6	28-35	32.5	37
6e[1]	----------	----------	2.8	2.8	2.8	3.2	2.6		6	28	25.4	62
6f[1]	----------	----------	2.0	2.0	2.4	2.6	2.1		5	28	19.0	54
6g[1]	----------	----------	1.5	1.8	2.0	2.2	1.9		6	28	39.3	26
6h[1]	----------	----------	1.8	1.8	1.2	1.2	1.2		6	26-30	20.4	39
9d	1.7	2.2	2.9	3.6	4.2	2.8	1.8		7	20-50	37.3	53
Maximum	----------	----------	3.2	3.9	4.2	3.2	2.6		10	----------	73.0	54
Minimum	----------	----------	1.5	1.8	1.2	1.2	1.2		5	----------	19.0	21
Mean	----------	----------	2.4	2.8	3.0	2.5	2.0		6	----------	35.0	43

[1] Porous subsoil, sampling only to four-foot depth.

TABLE 17

MONTHLY TRANSPIRATION USE OF WATER BY CITRUS, AND IRRIGATION DATA FOR INTERIOR ZONE, RIVERSIDE AND SAN BERNARDINO COUNTIES, CALIFORNIA, APRIL THROUGH OCTOBER, 1934-35 (44)

Orchard number and year	Depth of water transpired									Irrigation data			
	March	April	May	June	July	August	September	October	Total April 1 to November 1	Irrigations	Interval between irrigations	Depth of water applied	Irrigation efficiency
1934	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Number*	*Days*	*Inches*	*Per cent*
6b[1]	....	2.4	3.2	2.2	3.8	4.2	3.7	2.4	21.9	8	17-34	57.8	34
6d[1]	....	1.8	3.2	3.4	3.0	2.6	3.6	3.4	21.0	7	28-32	41.4	46
6e[1]	....	2.0	3.3	2.1	3.5	3.4	2.2	2.3	18.8	9	28	37.2	74
6f[1]	....	1.6	1.7	2.4	2.0	2.8	2.6	2.2	15.3	8	28	33.0	41
6i[1]	....	2.4	2.6	2.0	3.5	3.2	2.9	2.2	18.8	8	28	33.1	51
Maximum	....	2.4	3.2	3.4	3.5	4.2	3.7	3.4	21.9	9	....	57.8	74
Minimum	....	1.6	1.7	2.0	2.0	2.6	2.2	2.2	18.8	7	....	33.1	34
Mean	....	2.0	2.8	2.4	3.2	3.2	3.0	2.5	19.2	8	....	40.5	49

Orchard number and year	Depth of water transpired									Irrigation data			
	March	April	May	June	July	August	September	October	Total April 1 to November 1	Irrigations	Interval between irrigations	Depth of water applied	Irrigation efficiency
1935	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Number*	*Days*	*Inches*	*Per cent*
6b[1]	0.6	2.1	2.5	2.6	3.8	3.8	2.6	3.0	20.4	10	25-34	64.8	34
6d[1]	0.4	1.7	2.0	2.2	2.8	3.5	3.3	2.3	17.8	9	22-33	47.9	42
6e[1]	2.0	2.0	2.6	2.7	3.2	3.8	3.2	2.8	20.3	10	24	37.8	44
6f[1]	0.4	1.2	2.4	2.8	3.2	2.8	2.6	1.8	16.8	10	24	34.7	42
Maximum	2.0	2.1	2.6	2.8	3.8	3.8	3.3	3.0	20.4	10	....	64.8	44
Minimum	0.4	1.2	2.0	2.2	2.8	2.8	2.6	1.8	16.8	9	....	34.7	34
Mean	0.8	1.8	2.4	2.6	3.2	3.5	2.9	2.5	18.8	10	....	46.3	40

[1] Porous subsoil, sampling only to four-foot depth.

Irrigation Requirements of Citrus and Walnuts

Table 18 lists estimated seasonal irrigation requirements for both young and mature citrus trees in Orange County in which values are based on the maximum transpiration losses during the irrigation season and an estimated 75 per cent water application efficiency, which allows for reasonable losses by evaporation and by percolation below the root zone.

TABLE 18

ESTIMATED DEPTH OF MAXIMUM SUMMER IRRIGATION REQUIREMENT FOR CITRUS TREES IN ORANGE COUNTY, CALIFORNIA (10)

Crop	May	June	July	August	Sept.	October	Total
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Mature citrus	1.00	3.50	4.00	4.00	3.50	2.50	18.50
Citrus 12 to 14 years old	.75	2.25	2.50	2.50	2.25	1.75	12.00
Per cent by months	5	19	22	22	19	13	100

Slight differences will be noted in the estimated seasonal irrigation requirements shown in Tables 12 and 18, but they may be accounted for by the fact that Table 12 is based on exact figures from transpiration studies while Table 18 shows estimated requirements based on a full moisture supply in the soil throughout the irrigating season, with a reasonable allowance for waste. On this basis mature citrus growing in Orange County would require a summer application of 18.5 acre-inches per acre while younger trees could get along as well on 12.0 acre-inches. The figures will vary somewhat according to location, adequacy of the water supply and personal management of the orchards.

Additional records of transpiration losses by vigorous, mature citrus trees without cover crop, growing in Orange County during 1929, are shown in Table 19.

TABLE 19

ANNUAL TRANSPIRATION LOSS BY MATURE CITRUS TREES IN ORANGE COUNTY, CALIFORNIA (44)

Month	Depth of water transpired	Month	Depth of water transpired
	Inches		*Inches*
January	1.0	July	3.1
February	1.0	August	3.0
March	.8	September	2.6
April	1.3	October	1.8
May	1.9	November	1.3
June	2.7	December	1.1
April 1 to November 1			16.4
January 1 to April 1 and November 1 to December 31, without cover crop			5.2
			21.6

Transpiration from mature walnut trees in Orange County has been shown to be 25 acre-inches per acre (10) of which 10.25 acre-inches was moisture carry-over from spring rainfall. The limited observations made on walnuts in this study did not warrant the investigators to make definite decisions on values of irrigation requirements and they have limited themselves to estimating a seasonal requirement of 18 inches.

The Agricultural Extension Service in Orange County has published a summary of a 10-year study of walnut production, (65) including annual yield and depths of water applied, as listed in Table 20. The average age of trees was 31 years and the average yield 1,500 pounds per acre. Cost of irrigation water was $10.73 per acre. Depths of irrigation applied varied from 13.8 acre-inches per acre to a maximum of 24.5 acre-inches, with an average of 19.3 inches, which is approximately equal to the depth of irrigation requirement of 18 acre-inches per acre set up in the soil moisture analysis study for walnuts in Orange County (10).

The highest yield occurred during the year when both irrigation and rainfall were lowest for the period, but it is not necessarily certain that the low water supply was the controlling factor in producing the greater yield.

TABLE 20

TEN-YEAR AVERAGE IRRIGATION AND YIELD FOR WALNUT TREES IN ORANGE COUNTY, CALIFORNIA (65)

Year	Orchards in study	Total area	Average age of trees	Average yield per acre	Water cost per acre	Depth of irrigation water applied per acre	Annual rainfall at Santa Ana
	Number	*Acres*	*Years*	*Pounds*	*Dollars*	*Inches*	*Inches*
1929	7	135	28	2,287	17.55	------------	6.38
1930	23	309	28	1,148	12.61	23.8	16.18
1931	19	250	29	1,044	9.97	22.3	18.33
1932	22	309	29	2,301	11.80	21.6	10.52
1933	21	307	30	1,220	9.55	24.5	12.11
1934	20	281	32	1,291	8.09	18.5	16.34
1935	20	305	30	2,163	8.41	13.8	11.86
1936	15	231	32	1,219	13.13	20.7	17.44
1937	17	252	35	1,758	8.73	14.4	18.23
1938	18	245	35	690	7.48	13.9	27.87
Mean	18	262	31	1,506	10.73	19.3	15.53

Estimates of irrigation requirements of citrus in Riverside and San Bernardino Counties are not included in the published report (44) of the investigators. The authors assert that although "efficiencies of 70 per cent are obtainable with furrow irrigation, many orchards operate at much lower ones," and such efficiencies as are listed in Tables 16 and 17 average about 44 per cent. The authors have stated (44) that transpiration from the better class of citrus trees included in their study averaged 21 inches from April through October, and that for trees in fair condition it was 17 inches. Assuming an average irrigation efficiency of 70 per cent, which is considered possible, and four inches of carry-over, an irrigation requirement based on 21 inches of transpiration would be 24 acre-inches per acre. This agrees with Beckett's observation (10) that:

> "Investigations with mature groves in the citrus areas of Riverside and San Bernardino Counties from April to September of 1930 indicate that the use of water in these localities will be about one-third greater than that found in the Santa Ana area."

General information on the use of water by citrus trees in the area covering eastern Los Angeles County, is given by Taylor (56) on the basis of investigations for the Division of Irrigation. This investigator analyzed the production records of more than 100,000 orange and lemon trees in connection with amounts of water applied in irrigation over a six-year period. The records represent the experience of practical orchardists in irrigation and profitable crop production. The average use of water on the group of orchards that had the lowest crop yields was 20.1 inches per season with a 25.7-inch average for the group having the highest yields. The greatest number of growers used between 20 to 24 inches per season, but the yields from their orchards were less than yields obtained from groves which used from 24 to 28 inches. The author makes the assertion (56):

> "In the area covered by this study the average annual use of 26 inches of irrigation water on mature orchards * * * represents an efficiency of about 60 to 65 per cent in the application of water. The remaining 35 to 40 per cent must have been lost by evaporation, run-off, and deep percolation below the root zone."

In most groves and for many other crops an efficiency of 60 to 65 per cent would be a fair average representing southern California where water often is pumped from the owner's well and delivered to the field through underground pipes; but there is no reason why better efficiencies can not be obtained. Improvements in methods of application would increase irrigation efficiencies and decrease the amounts of water applied.

Records of soil moisture extraction by mature citrus trees grown on Hanford fine sandy loam on the Ebert grove near Azusa were made by the Division of Irrigation during 1929-30 (13). Soil sampling was carried on to a depth of six feet for determination of transpiration losses, which are shown in Table 21.

TABLE 21

TRANSPIRATION USE OF WATER BY CITRUS TREES WITH COVER CROP IN THE EBERT GROVE, NEAR AZUSA, CALIFORNIA, 1929-30 (13)

Month	Depth of transpiration	Month	Depth of transpiration
1929	*Inches*	*1930*	*Inches*
July	3.28	January	1.29
August	3.15	February	1.16
September	1.91	March	1.50
October	2.16	April	1.95
November	1.53	May	2.09
December	1.35	June	2.18
		Total	23.55

Estimates of the seasonal irrigation requirement for this grove were not made by the investigators but may be determined approximately. The transpiration loss during the irrigation season, April to October, inclusive, was 16.7 inches, of which three inches may be assumed to be carry-over moisture from spring rains, making a total of 13.7 inches to be supplied by irrigation. Assuming a water application efficiency of 65 per cent would result in a requirement of 21 inches to be applied during the seven-month irrigation season.

As a check on this value, average depths of water applied to 56 orchards in the general vicinity of the Ebert grove during 1934 were found to be 19.6 acre-inches per acre. This was an area of high-priced water, underground water deliveries, and minimum losses; hence it may be assumed that depths of water delivered were reasonably close to the irrigation requirements of the area.

It is believed from the above information that an average irrigation requirement for eastern Los Angeles County would lie between the limitations of 18 and 22 acre-inches per acre.

Transpiration Studies of Deciduous Fruit Trees

Soil moisture studies for determination of transpiration from Tuscan cling peach trees growing on Hanford sand four miles east of Ontario were made by the Division of Irrigation in 1928 (13). The soil was uniform to a depth of 15 feet and the trees were 12 years old at the time of observation. Irrigation was accomplished by the furrow and cross-check system. Transpiration losses for the year 1928 are given below in inches of depth from the upper 15 feet of soil. Evaporation from soil

Month	Transpiration use	Month	Transpiration use
	Inches		*Inches*
January	0.0	July	8.0
February	.0	August	6.0
March	.0	September	2.7
April	.5	October	.9
May	3.0	November	.2
June	6.2	December	.0
Total transpiration			27.5
Evaporation from winter rains			4.3
Evaporation from irrigation			2.0
Total consumptive use			33.8

after winter rains depends upon the number and distribution of storms; in 1928 this loss was estimated 4.3 acre-inches per acre. In summer, evaporation following irrigation is estimated at one-half inch per irrigation; in this case 2.0 inches, making an annual consumptive use for this experiment of 33.8 acre-inches per acre.

The transpiration use, from April to October, inclusive, was 27.3 inches and winter carry-over was approximately 7.3 inches, leaving 20.0 inches to be supplied by irrigation, which on a basis of 65 per cent efficiency would amount to 31.0 inches of irrigation requirement. If a higher efficiency could be obtained, the requirement would be correspondingly less.

SAN FERNANDO VALLEY, LOS ANGELES COUNTY

Irrigation Requirements for Citrus

San Fernando Valley is an urban-suburban district occupying about 40 per cent of the area within the boundaries of the City of Los Angeles north of the main business and residential areas. It is a mountain-enclosed basin, the floor of which is formed by alluvial soils.

The climate is warmer than the coastal region and may be classed as interior, as temperatures may be as high as 110°F. Frost conditions vary over different portions of the valley, but at the town of San Fernando, the average length of the growing season is 306 days between the dates February 15th and December 18th. The winters are wet and cool with rainfall varying considerably in different portions. At San Fernando it averages 15.7 inches. The climate is suited to most crops, but water for irrigation must be supplied because of lack of rainfall during the growing season.

Use of water by citrus in San Fernando Valley was studied in 1940 by Blaney and Stockwell of the Division of Irrigation, cooperating with the Department of Water and Power, City of Los Angeles (15). Results are shown in Table 22.

TABLE 22

MONTHLY TEMPERATURE, RAINFALL AND ESTIMATED TRANSPIRATION USE OF WATER BY CITRUS PLOTS AT ENCINO, SAN FERNANDO VALLEY, CALIFORNIA, 1940 (15)

Month	Mean temperature	Rainfall	Depth of transpiration	
			Plot A permanent cover crop	Plot B clean cultivated
	°F.	*Inches*	*Inches*	*Inches*
January	56	5.51	1.1	0.8
February	56	5.98	2.2	1.1
March	60	1.33	2.3	1.4
April	61	1.01	4.0	1.7
May	66	0	4.4	2.2
June	69	0	4.6	2.6
July	73	T	4.0	2.9
August	74	0	3.4	2.7
September	69	0	2.8	2.6
October	68	1.14	2.6	2.4
November	62	.14	2.0	1.6
December	59	9.75	1.6	1.3
Totals		24.86	35.0	23.3
Mean	64.4			
Totals April 1 to October 31			25.8	17.1

Transpiration loss was determined by soil sampling to a depth of 4 feet below the mulch in Plot A, which had a permanent cover crop, and in Plot B, which was clean cultivated. Plot A lost 25.8 acre-inches per acre by transpiration between April 1st and October 31st. Of this amount, at least three inches was supplied by winter rainfall held over as soil moisture storage, leaving 22.8 inches to be supplied by irrigation. Assuming a water application efficiency of 70 per cent the seasonal irrigation requirement would be 32.5 inches. On Plot B the seasonal transpiration loss was 17.1 acre-inches per acre, of which three inches was received from rainfall, leaving 14.1 inches to be supplied by irrigation. At 70 per cent efficiency the irrigation requirement would be 20.1 acre-inches per acre. Plot A had a greater water requirement than Plot B because of its permanent cover crop. Usually cover crops are plowed under in March for fertilization and to decrease the depth and cost of irrigation. In this study and on the basis of requirement estimates, the seasonal increase in the irrigation requirement by reason of the cover crop would amount to 12.4 inches.

Further information on soil evaporation and crop transpiration losses during winter months is provided in Table 23 which shows, for the San Fernando Valley, such values for several permanent crops, some of which have cover crops between the trees, on soils ranging from sand to clay adobe. Regardless of soil type, there were no great differences in soil evaporation, which averaged about four acre-inches per acre for the winter season while crop transpiration for the same period varied according to the growth and density of the cover crop and was further affected by the leaf area of the tree.

TABLE 23

SUMMARY OF DISPOSAL OF RAINFALL AND IRRIGATION IN SAN FERNANDO VALLEY, CALIFORNIA, SEPTEMBER 23, 1939 TO MARCH 6, 1940 (15)

Crop	Soil type	Depth of soil sampling	Total rainfall and irrigation	Evaporation from the soil	Transpiration by crop	Winter consumptive use	Remarks
		Feet	*Inches*	*Inches*	*Inches*	*Inches*	
Citrus							
Lemons	Hanford sandy loam	6	20.49	4.63	5.65	10.28	No cover crop
Lemons	Hanford sandy loam	7	22.58	5.38	11.02	16.40	Heavy cover crop—3 months
Oranges	Yolo loam	10	18.48	3.63	11.26	14.89	Light cover crop
Oranges	Yolo loam	7	19.63	4.86	7.59	12.45	Average cover crop
Oranges	Diablo clay adobe	6	16.09	4.15	3.28	7.43	No cover crop
Deciduous							
Peaches	Tujunga sand	10	17.92	3.75	3.47	7.22	No cover crop
Peaches	Tujunga fine sandy loam	10	17.92	3.75	6.18	9.93	Light cover crop
Walnuts	Yolo loam	10	18.48	3.63	6.32	9.95	Average cover crop—oats and weeds
Walnut-peaches	Yolo loam	10	28.23	4.05	4.88	8.93	Very light cover crop
Walnuts	Yolo gravelly sandy loam	10	16.96	4.48	3.15	7.63	Very light cover crop
Truck							
Melons	Yolo clay loam	7	18.37	3.88	4.52	8.40	Plowed in mid-winter
Field crops							
Alfalfa	Hanford fine sandy loam	8	28.82	5.13	13.27	18.40	Average stand
Asparagus	Yolo loam	7	18.48	3.63	7.20	10.83	Soil in wilting range first part of season
Alfalfa	Yolo loam	10	21.10	4.13	3.84	7.97	Young alfalfa short growth
Alfalfa	Yolo sandy loam	10	22.36	4.55	15.54	20.09	Average alfalfa
Alfalfa	Yolo gravelly sandy loam	5	16.96	4.36	3.19	7.55	Light stand
Asparagus	Yolo loam	9	17.23	4.63	10.21	14.84	
Uncultivated							
Bare	Tujunga sand	7	15.06	3.78	5.05	8.83	Slight cover late in season
Weeds	Yolo gravelly sandy loam	5	16.96	4.48	6.39	10.87	Planted to new alfalfa
Mean				4.25			

Citrus trees bear leaves throughout the winter months and they, together with a cover crop between trees, effect a high rate of winter transpiration loss per acre. Deciduous trees, on the other hand, lose their leaves and the acreage they occupy has a low rate of loss which is almost entirely from the cover crop. Transpiration from winter growth of alfalfa varies with age, density, and vigor of growth. Only in exceptional cases of poor stand is the winter transpiration by alfalfa less than evaporation from the soil.

Irrigation Requirements of Alfalfa

Data obtained by the Division of Irrigation on the consumptive use of water by alfalfa in San Fernando Valley are listed below (15):

Month	Consumptive use by alfalfa[1]	Month	Consumptive use by alfalfa[1]
1940	*Inches*		*Inches*
January	1.3	July	7.8
February	1.6	August	4.2
March	3.1	September	5.6
April	3.3	October	4.4
May	6.7	November	3.1
June	5.4	December	1.3
		Total for year	47.8
		Total, April 1 to October 31	37.4

[1] Computed from soil moisture observations.

Water Deliveries in San Fernando Valley

Water for irrigation of crops in San Fernando Valley is supplied by the Los Angeles Department of Water and Power through underground pipe systems, and all water delivered is measured through meters on a quantity basis. Thus the department has complete files of water delivered as well as crop acreages and is able to determine the water use per acre for many crops. The annual and average uses of water per acre for the principal irrigated crops grown in the valley for years 1930 to 1937, inclusive, together with the annual rainfall, are shown in Table 24 (26). The average values agree with similar data obtained for other areas in some instances and disagree in others. For instance, the average depth of water delivered to alfalfa, 1.86 feet (22.3 inches) per acre is low, which may be because of high ground water in some sections from which alfalfa roots obtain a portion of their water supply, although no evidence is given that they do so. In some areas water is used sparingly where it is thought that crops may be affected by its quality. The average depth of water delivered to citrus trees agrees closely with similar data obtained elsewhere for the water requirement of the crop; thus the depth of water delivered appears to be a fair value of the water requirement. Use of water by walnut trees, shown as 0.84 acre-feet per acre or 10 acre-inches, is considerably less than the requirement in Orange County, where it has been estimated (10) as 18 acre-inches per acre. Walnut trees have more extensive root systems than citrus and may have obtained a portion of their supply from ground water in some areas. The same may apply to deciduous trees, shown to have used 0.54 acre-feet per acre or 6.48 acre-inches, which is extremely low for such trees. For shallow rooted crops the data appear more consistent.

TABLE 24

USE OF IRRIGATION WATER PER ACRE, BY PRINCIPAL IRRIGATED CROPS IN SAN FERNANDO VALLEY, CALIFORNIA, BY YEARS, 1930 TO 1937

Records furnished by Los Angeles Department of Water and Power (26)

Year	Annual rain-fall	Alfalfa	Asparagus	Beans	Sugar beets	Citrus trees	Deciduous fruits	Fig trees	Grapes	Olive trees	Roses and bulbs	Walnut trees	Miscel-laneous truck
	Acre-feet	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*
1930	1.17	1.92	2.23	1.20	----------	1.96	0.57	0.99	0.49	0.89	1.92	0.77	1.32
1931	1.80	1.67	2.47	1.16	0.89	2.05	.57	1.13	.47	1.96	1.94	.88	1.33
1932	.97	1.65	2.22	.92	.80	1.72	.59	1.03	.39	1.00	1.87	.75	1.27
1933	1.32	1.85	1.83	1.09	1.00	1.70	.53	1.16	.49	.83	2.27	.80	1.30
1934	1.35	1.90	1.78	.90	1.06	1.65	.45	1.09	.59	.60	2.37	.75	1.34
1935	1.04	1.76	1.62	.93	1.08	1.59	.47	.98	.43	.49	1.91	.78	1.35
1936	1.52	2.15	1.71	1.10	1.55	1.99	.58	1.06	.52	.92	2.20	1.07	1.54
1937	1.47	1.97	1.52	.98	.84	1.79	.59	1.13	.59	.56	2.06	.93	1.52
Mean in feet	1.33	1.86	1.92	1.04	1.03	1.81	.54	1.07	.50	.91	2.07	.84	1.37
Mean in inches	16.0	22.3	23.0	12.5	12.4	21.7	6.5	12.8	6.0	10.9	24.8	10.1	16.4

Irrigation of Tomatoes in Los Angeles County

Few records are available on irrigation of vegetables, but in 1940 the Agricultural Extension Service, as a part of a tomato production study, obtained depth of irrigation water applied to tomatoes and yield of crop on nine farms in Los Angeles County (30), as listed in Table 25. While these records are not conclusive they show that five irrigations were applied to heavy soils and that as a rule the best yields were obtained from applications of from 16 to 20 acre-inches per acre.

TABLE 25

IRRIGATION AND YIELD OF TOMATOES GROWN IN LOS ANGELES COUNTY, CALIFORNIA, 1940 (30)

Area	Soil type	Irrigations	Depth of water applied	Yield per acre
Acres		*Number*	*Inches*	*Tons*
52	Heavy clay loam	6	23.7	4.73
22	Fine silt loam	5	21.7	5.09
45	Medium clay loam	5	19.7	12.45
70	Heavy black adobe	5	19.6	10.71
80	Medium clay loam	5	18.6	7.23
70	Heavy sandy loam	5	16.5	10.08
60	Medium sandy loam	5	14.9	9.10
65	Heavy clay loam	5	14.4	9.17
60	Heavy clay loam	5	12.8	14.89
Maximum 80		6	23.7	14.89
Minimum 22		5	12.8	5.09
Mean 58		5	18.0	9.49

BEAUMONT PLAINS, RIVERSIDE COUNTY

Beaumont Plains lie in San Gorgonio Pass which separates the watersheds of San Gorgonio River and San Timoteo Creek. Elevations range from 2,500 to 3,500 feet. The climate is mild. Rainfall is limited to winter months and averages 19 inches on the valley floor. It varies little in the several districts where elevation is not a factor, but at the mouth of Edgar Canyon, some 500 feet higher, the average rainfall is about 22 inches. Average monthly rainfall for 45 years, 1888 to 1899 and 1906 to 1939, is shown in Table 26.

TABLE 26

MEAN MONTHLY AND SEASONAL RAINFALL, 45 YEAR RECORD ENDING 1939, AT BEAUMONT, CALIFORNIA, ELEVATION 2,558 FEET

Authority United States Weather Bureau (59)

Month	Rainfall	Month	Rainfall
	Inches		*Inches*
July	0.06	January	3.63
August	.24	February	3.86
September	.23	March	3.34
October	.96	April	1.40
November	1.08	May	.87
December	3.18	June	.15
		Seasonal mean	19.00

Prevailing winds are from the west and carry more moisture than the dry easterly winds which blow off the desert. The latter are particularly damaging to vegetation in their drying effect on plant tissue, and sometimes they attain sufficient velocity to move appreciable quantities of unprotected soil surface.

About 6,000 acres of land in the Beaumont Plains may be classed as excellent farm land capable of development under irrigation and constituting the bulk of the cropped area. Some 15,000 acres is fair in quality, limited in use and productivity. Topography varies from gently sloping fields to steep rolling hill lands.

Crops are limited generally to deciduous fruits and nuts. All orchards are irrigated and irrigation furrows frequently run down the principal slope, causing erosion. Winter cover crops, usually vetch or a cereal, are grown in many of the orchards and most of the others contain some growth of weeds or grass. Being dependent upon rainfall, their growth is not far advanced when the more intense rains fall and gullying of the soil results.

Noble Creek and Little San Gorgonio Creek drain most of the northerly portion of the watershed and outside of direct rainfall, provide most of the area water supply. Water from these and smaller streams sinks into the alluvial fans to augment the underground supply. Precipitation on the valley floor is in addition to this amount. The narrowing shape of the watershed in its upper regions precludes any possibility of water production in large quantities except occasional flash floods which are of little value as they pass rapidly beyond the confines of the basin.

The Beaumont Irrigation District supplies water for irrigation of approximately 2,300 acres of deciduous fruits and sufficient other crops in small acreages to bring the total area irrigated to about 3,000 acres (72). Water for irrigation is pumped from underground basins. The supply is limited and in some years has been insufficient for the best crop production. The irrigation season is from April to November, inclusive. As of 1939, deliveries were made to all lands every 20 days, the average annual delivery being about $1\frac{1}{2}$ acre-feet per acre. The system of regular rotated distribution may lead to inefficient use of water.

Three water schedules were in force prior to 1939. From 1927 to 1933 the schedule called for delivery of seven runs of three miners inches per acre per month. In 1933 this was increased to seven runs of 3.6 miners inches per acre and in 1938 there was a further increase to six miners inches per acre per month. Fields are watered principally by the furrow method.

Depths of Irrigation Water Applied to Deciduous Fruits

Table 27 shows monthly depths of water applied for irrigation of deciduous orchards under each of the preceding schedules, together with maximum and minimum deliveries for the orchards listed. They represent measured farm deliveries under conditions where there was little opportunity for over-irrigation.

Water deliveries prior to 1938 were less than what may be considered as a normal amount of water for mature trees, averaging about 10 inches in depth annually. During the listed periods, trees were productive although not to a maximum extent, and in 1938 the Beaumont Irrigation District made efforts to obtain additional water in order to bring production to higher levels. During 1938-39 the average depth of water applied amounted to 18.3 inches as compared with 10 inches in previous years. While there is no basis for estimating the irrigation requirement of deciduous trees in the Beaumont area it may be assumed that 18 inches is sufficient, especially as deciduous trees are deep rooted and there is an average rainfall of 19 to 22 inches for replenishment of moisture to a large volume of soil occupied by the tree roots.

SAN JACINTO BASIN, RIVERSIDE COUNTY

The climate of the San Jacinto Basin is classed as interior, being similar to that of upper portions of the Santa Ana Valley, except that winter temperatures as low as 7°F. have been recorded at San Jacinto. Summers are hot and dry, temperatures frequently exceeding 100°F. Frost conditions prevail over the area, limiting crops to those not greatly affected by cold. Average frost-free period at San Jacinto is 247 days, between March 17th and November 19th. Precipitation is limited to winter months and averages about 14 inches annually over the entire area but increases to 17 inches east of Hemet. Mean monthly temperature and rainfall are shown in Table 28.

TABLE 27

WATER APPLIED FOR IRRIGATION OF DECIDUOUS FRUITS, BEAUMONT IRRIGATION DISTRICT (72)

Years	Depth of water applied per acre									
	Area irrigated	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
	Acres	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1930 to 1932	10	1.4	1.5	1.5	1.5	1.5	1.5	1.5	0.2	10.6
	10	1.0	1.0	1.5	1.5	1.5	1.4	.2	.0	8.1
	10	.5	1.0	1.4	1.5	1.5	1.5	.0	.0	7.4
Maximum		1.4	1.5	1.5	1.5	1.5	1.5	1.5	.2	10.6
Minimum		.5	1.0	1.4	1.5	1.5	1.4	.0	.0	7.4
Mean		1.0	1.2	1.5	1.5	1.5	1.5	.6	.1	8.9
1933 to 1937	10	1.5	1.6	1.5	1.6	1.6	1.6	1.5	.0	10.9
	5	.0	1.7	1.8	1.9	1.5	1.5	1.2	.0	9.6
	10	.4	1.7	1.3	1.6	1.5	1.5	1.5	.0	9.5
	5	1.6	1.8	1.8	1.8	1.9	1.9	1.9	.0	12.7
	10	1.4	1.7	1.7	1.6	1.6	1.6	1.3	.0	10.9
	10	.0	1.8	1.8	1.9	1.9	1.7	1.9	.0	11.0
	10	2.4	1.7	.9	2.7	2.3	2.6	2.3	.0	14.9
	10	.9	1.6	1.4	1.6	1.6	1.6	1.1	.0	9.8
Maximum		2.4	1.8	1.8	2.7	2.3	2.6	2.3	.0	14.9
Minimum		.0	1.6	.9	1.6	1.5	1.5	1.1	.0	9.5
Mean		1.0	1.7	1.5	1.8	1.7	1.8	1.6	.0	11.1
1938 to 1939	10	1.9	3.8	1.9	3.8	1.9	3.3	1.9	.0	18.5
	5	1.8	3.8	1.8	3.8	1.9	2.8	1.9	.0	17.8
	10	1.8	1.9	2.8	2.2	3.8	1.9	3.8	1.0	19.2
	5	2.8	1.9	3.8	1.9	3.8	3.8	1.9	.0	19.9
	10	1.9	1.1	4.2	1.9	3.8	1.9	2.6	.0	17.4
	10	1.8	3.8	1.9	3.8	1.9	2.9	1.9	.9	18.9
	5	1.9	1.4	2.8	1.9	2.9	1.9	1.9	.0	14.7
	7	1.7	1.8	3.5	1.8	3.5	1.8	.9	.0	15.0
	10	.9	1.1	4.0	2.0	4.0	2.0	3.0	.0	17.0
	10	1.3	4.8	2.8	5.7	2.8	5.7	.0	1.4	24.5
	10	1.0	1.9	3.8	1.9	3.8	1.7	2.8	.0	16.9
	10	.8	2.0	4.2	2.5	4.2	2.0	2.1	.0	17.8
	10	.5	3.5	2.2	4.4	1.8	3.9	2.6	1.2	20.1
	10	.0	2.3	2.4	4.6	2.2	4.6	2.2	1.4	19.7
Maximum		2.8	4.8	4.2	5.7	4.2	5.7	3.8	1.4	24.5
Minimum		.0	1.1	1.8	1.8	1.8	1.7	.0	.0	14.7
Mean		1.4	2.5	3.0	3.0	3.0	2.9	2.1	.4	18.3

Soils are chiefly alluvial, consisting of sandy and fine sandy loams well suited to agriculture and smooth enough to permit irrigation without excessive land preparation. The Hanford series predominates in the vicinity of Hemet while the Moreno soils belong to the Ramona series.

TABLE 28

MEAN MONTHLY AND ANNUAL TEMPERATURE AND RAINFALL, SAN JACINTO, CALIFORNIA, ELEVATION 1,550 FEET

Authority United States Weather Bureau (59)

Month	Temperature	Rainfall[1]	Month	Temperature	Rainfall[1]
	°F	*Inches*		°F.	*Inches*
January	49.2	2.49	July	77.3	0.10
February	52.2	2.58	August	77.1	.18
March	55.0	2.33	September	72.1	.17
April	59.4	1.18	October	64.7	.75
May	64.5	.48	November	57.1	.96
June	71.5	.06	December	51.1	1.93
			Total		13.21
			Mean	62.6	

[1] Mean of a 47-year record ending December, 1939.

Water used in irrigation in the Hemet area is derived from gravity flow in San Jacinto River and from ground water pumped from wells. Gravity flow is delivered to farms by the Lake Hemet Water Company which maintains storage in the San Jacinto Mountains and diverts from the San Jacinto River where the stream debouches upon the valley floor. Ground water is pumped from individual wells or from wells operated by small mutual water companies each irrigating from 150 to 200 acres of orchard land. The Fruitvale Mutual Water Company, at San Jacinto, furnishes water for irrigation of some orchards north of Hemet and a considerable area of alfalfa and truck crop farms to the northwest. In obtaining irrigation data where dual water sources were involved all sources were taken into account; however, because much of the water was pumped, the records were not understood to represent high accuracy, and they probably provide no more than suggestions as to the actual water requirements, since wide variations appear in the quantities from year to year. No connection is established between amounts of water applied and age of trees, crop yields, cultural practices, etc.; and while an effort was made to obtain records which might be considered generally representative of average use, there is no assurance that they do so.

There appears to be no uniform practice in regard to cover-cropping of orchards in the Hemet area. The most common practice appears to permit grass and weeds to grow after the last fall irrigation. Such cover has been observed to be variable, from sparse to average being the most prevalent. Probably more than half the orchards had weeds and grass to some extent. The next most common practice was clean cultivation with probably less than 25 per cent of the groves being in this category. Planted cover crops were the exception, the most common being grain. Usual practice has been to plant a strip of grain between tree rows in one direction only. There was no marked difference in treatment between citrus and deciduous groves. Plowing under appears to be done quite generally in March.

Water deliveries by the Fruitvale Mutual Water Company fall into four classes: winter water, flood water, summer water and additional water. Winter water is delivered between November and April. It is not delivered on schedule but is run on order. Flood water is delivered during winter months and is available only when San Jacinto River is flowing at San Jacinto. Summer water is allotted on a basis of six miners inch days per share per month from May to October at a cost of 11 cents per miners inch day. ($2.78 per acre-foot.) The total amount under this schedule is 17.1 acre-inches per acre for the six-month summer period. Additional water can be purchased during the summer from the company at the rate of 23 cents per miners inch day ($5.80 per acre-foot). Furrow irrigation is the common method of water application.

Irrigated crops in the Hemet area include apricots, olives, walnuts, citrus, alfalfa and alfalfa seed, sugar beets and sugar beet seed, and truck crops. Definite irrigation requirements for this area have not been determined and the only use of water figures available are those obtained from water companies or from individuals for the quantities of water delivered for each farm or crop. In areas where water is scarce and expensive, the amounts of water applied are an approximate measure of the requirement of the crop irrigated, but these values are not always comparable for different farms or different crops because of variations in irrigation practices and management, and differences in soil type, age of trees, etc. Methods of water delivery also affect the use of water, as under set rotation systems water may be delivered at times when it is not needed or may not be available when it is wanted. Under such a system the grower usually feels obligated to use all the water he can get in order that the soil may not become too dry between irrigations.

In the San Jacinto Valley, investigations (72) have proven that for the entire irrigated area the average amounts of water consumed by all crops is slightly in excess of the annual water supply, thus creating a condition resulting in a lowering of the ground-water levels. Although this is true for the entire area there are those who make a practice of under-irrigation as well as others who over-irrigate. In any tabulation of water applied to crops, records resulting from both practices are likely to be included. Under these conditions, determination of average values for a period of years, or for a number of farms growing the same type of crop within the same year, is the only method of arriving at average depth of water use under the practices of various managements, or for a series of years, each having different amounts of rainfall. Such values are more or less approximate but as they are likely to represent current practices where water is not plentiful they appear to be of considerable value in arriving at an average irrigation requirement for the particular crop irrigated. This is the case in the San Jacinto Valley and it applies to the following tabulations of water delivered to various crops both in the Hemet and the Moreno areas.

Depths of Irrigation Water Applied to Citrus, Walnut and Apricot Trees

Table 29 represents monthly depths of water applied to citrus trees on a single 30-acre farm in the vicinity of Hemet, for the eight-year period 1930-37. A wide difference in total depth of application characterized different years, ranging from 52.3 inches in 1936, which was a year of slightly more than average rainfall, to 29.2 inches in 1931 when the rainfall was only slightly less than during 1936. The average depth of water application was 37.2 inches. This value is twice as high as the irrigation requirement of citrus along the coast in Orange County but as the average temperature is greater and the humidity is less in the San Jacinto Basin it may be assumed that some increase is necessary. If the two highest records are omitted the average for the remaining years becomes 33 inches instead of 37 inches. In the report on "Utilization of the Waters of Beaumont Plains and San Jacinto Basin, California" (72) a value of 30 inches of water was adopted as the estimated consumptive use by citrus trees, and while consumptive use differs from irrigation requirement it sometimes is representative of the average depth of water applied in irrigation.

TABLE 29

WATER APPLIED FOR IRRIGATION OF CITRUS NEAR HEMET, SAN JACINTO VALLEY, CALIFORNIA, 1930-37 (72)

Year	Area irrigated	Depth of water applied per acre													Rainfall
		January	February	March	April	May	June	July	August	September	October	November	December	Total	
	Acres	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1930	30	0.0	0.0	0.0	0.0	0.0	7.7	7.8	7.9	2.1	4.1	1.7	0.8	32.1	15.50
1931	30	.0	.0	3.4	4.5	.2	3.8	3.7	5.9	.4	4.1	1.6	1.6	29.2	15.65
1932	30	.0	.0	.0	.0	6.3	1.6	8.3	5.4	5.1	2.2	3.7	.0	32.6	14.27
1933	30	.0	.0	3.9	.0	.4	6.0	5.5	7.9	4.5	5.1	4.4	.0	37.7	8.35
1934	30	4.0	.0	.0	5.7	5.8	7.1	4.2	6.2	6.5	4.1	1.9	.0	45.5	11.82
1935	30	.0	.0	.0	.0	4.0	4.0	6.3	6.6	3.1	4.0	2.0	.0	30.0	10.98
1936	30	.0	.0	2.6	.0	7.8	9.0	10.2	11.5	5.0	6.2	.0	.0	52.3	17.18
1937	30	.0	.0	.0	.0	6.3	6.6	6.6	5.1	6.9	5.7	.5	.0	37.7	16.46
Maximum	30	4.0	.0	3.9	5.7	7.8	9.0	10.2	11.5	6.9	6.2	4.4	1.6	52.3	17.18
Minimum	30	.0	.0	.0	.0	.0	1.6	3.7	5.1	.4	2.2	.0	.0	29.2	8.35
Mean	30	.5	.0	1.2	1.3	3.9	5.7	6.6	7.1	4.2	4.4	2.0	.3	37.2	13.78

In Table 30, showing irrigation of a five-acre walnut grove near Hemet (72) from 1935 to 1938, the average depth of water applied was 34.8 inches. Water was delivered to the trees every month during the summer at an average rate of 6.2 acre-inches per acre. Walnut trees are deeper rooted than citrus and require moisture in the soil to a greater depth. Generally, for mature trees, the soil should be moistened to a depth of 12 feet or more, which accounts for the somewhat heavy monthly irrigations.

Records of irrigation of apricot trees near Hemet together with annual yields for 1939-40, obtained from the County Farm Advisor (50), (51), are included in Table 31 which shows an average depth of water applied to be 30.4 inches for the two-year period. The six best yields averaging 8.75 tons per acre were obtained as the result of applying 27.2 acre-inches of water per acre.

Table 32 shows monthly applications of water in irrigation of 30 acres of citrus trees near Moreno for each of the nine years 1930 to 1938, to average 36.7 acre-inches per acre annually (72). Since this represents the irrigation practice of a single owner it is not necessarily an average irrigation requirement for the entire area, any more than the average total of irrigation applied to a 30-acre citrus grove near Hemet was representative of different orchards and irrigation practices. A value of 30 acre-inches per acre would appear to be closer to the annual irrigation requirement as the practice frequently is toward over-irrigation. Table 33, representing irrigation of a 10-acre citrus grove near Moreno, shows an average delivery of 35.7 acre-inches per acre, but during three years of the period deliveries were in excess of 40 inches; hence it is probable that here also the average requirement did not exceed 30 inches of depth.

In assuming an average irrigation requirement it should be remembered that many irrigators tend toward over-use unless water is too scarce or too expensive to waste in over-irrigation. While crop yields increase with irrigation there is a limit to the increase beyond which further application of water is a wasteful practice. Tabulations of depth of water applied are not representative of the requirement of the crop although they are an indication of general irrigation practices. Usually, though not always, they are in excess of the requirements. On the other hand, depths of water transpired or consumed by transpiration and evaporation, as reported in irrigation experiments, represent a basic use which must be increased in proportion to the water application efficiency.

TABLE 30

WATER APPLIED FOR IRRIGATION OF WALNUT TREES NEAR HEMET, SAN JACINTO VALLEY, CALIFORNIA, 1935-38 (72)

Year	Area irrigated	Depth of water applied per acre										Rainfall
		December	January	February	March	April	May	June	July	August	September	Total	
	Acres	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1935	5	0.0	0.0	0.0	0.0	6.2	6.2	6.2	6.2	0.0	6.2	31.0	10.98
1936	5	.0	.0	.0	6.2	.0	6.2	6.2	6.2	6.2	6.2	37.2	17.18
1937	5	.0	.0	.0	.0	.0	6.2	6.2	6.2	6.2	6.2	31.0	16.46
1938	5	3.1	3.1	.0	.0	.0	6.2	6.2	6.2	9.1	6.2	40.1	16.29
Maximum		3.1	3.1	.0	6.2	6.2	6.2	6.2	6.2	9.1	6.2	40.1	17.18
Minimum		.0	.0	.0	.0	.0	6.2	6.2	6.2	.0	6.2	31.0	10.98
Mean		.8	.8	.0	1.5	1.5	6.2	6.2	6.2	5.4	6.2	34.8	15.23

TABLE 31

WATER APPLIED FOR IRRIGATION OF APRICOT TREES NEAR HEMET, SAN JACINTO VALLEY, CALIFORNIA, 1939-40 (50), (51)

1939			1940		
Depth of water applied per acre	Yield per acre	Yield per acre-inch of water applied	Depth of water applied per acre	Yield per acre	Yield per acre-inch of water applied
Inches	*Tons*	*Tons*	*Inches*	*Tons*	*Tons*
17.9	5.70	0.32	31.0	5.1	0.16
22.9	8.69	.38	42.0	5.0	.12
33.9	4.38	.13	29.3	4.5	.15
22.1	7.25	.33	27.9	9.3	.33
29.4	9.60	.33	33.4	5.5	.16
31.0	6.85	.22	24.7	8.8	.36
38.7	6.70	.17	35.8	5.2	.15
34.5	8.00	.23	49.9	4.9	.10
40.7	5.51	.14	35.3	3.6	.10
23.8	8.09	.34	26.0	2.6	.10
22.3	3.43	.15	26.9	5.0	.19
23.2	3.75	.16	40.3	4.3	.11
38.8	5.72	.15	20.7	3.6	.17
15.4	2.92	.19	23.2	6.9	.30
32.0	8.10	.25			
27.6	2.27	.08			
35.0	4.14	.12			
Maximum.....40.7	9.60	.38	49.9	9.3	.36
Minimum.....15.4	2.27	.08	20.7	2.6	.10
Mean.........[1]28.8	5.94	.22	[2]31.9	5.3	.18

[1] Mean for 17 farms.
[2] Mean for 14 farms.

TABLE 32

WATER APPLIED FOR IRRIGATION OF CITRUS TREES NEAR MORENO, SAN JACINTO VALLEY, RIVERSIDE COUNTY, CALIFORNIA (72)

Year	Area irrigated	Depth of water applied per acre													Rainfall
		January	February	March	April	May	June	July	August	September	October	November	December	Total	
	Acres	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1930	30	0.0	0.0	0.0	3.8	0.0	3.8	3.8	3.8	2.5	7.0	3.2	3.8	31.7	15.56
1931	30	.0	.0	5.7	3.2	3.2	3.8	4.8	4.3	4.3	4.3	4.3	.0	37.9	16.81
1932	30	.0	.0	.0	5.0	3.2	4.4	4.4	4.1	4.1	4.4	4.4	.0	34.0	14.33
1933	30	2.8	.0	.0	5.7	3.8	2.5	4.1	3.8	3.8	3.8	3.2	1.9	35.4	9.90
1934	30	.0	.0	3.2	4.4	3.8	2.3	3.8	5.7	5.0	2.4	.0	.0	30.6	10.60
1935	30	.0	.0	.0	.0	7.0	3.5	5.1	5.5	6.0	5.4	4.4	.0	36.9	10.85
1936	30	4.8	.0	.0	6.0	4.9	4.9	4.9	5.6	4.9	.6	1.9	1.3	39.8	18.46
1937	30	.0	.0	.0	4.4	2.4	5.1	5.1	5.7	5.7	10.7	1.3	4.4	44.8	16.61
1938	30	.0	.0	.0	5.1	5.1	5.1	5.1	5.7	5.7	3.8	[1]3.8	[1].0	39.4	19.10
Maximum		4.8	.0	5.7	6.0	7.0	5.1	5.1	5.7	6.0	10.7	4.4	4.4	44.8	19.10
Minimum		.0	.0	.0	.0	.0	2.3	3.8	3.8	2.5	.6	.0	.0	30.6	9.90
Mean	30	.8	.0	1.0	4.2	3.7	3.9	4.5	4.9	4.7	4.7	3.0	1.3	36.7	14.69

[1] Estimated.

TABLE 33

WATER APPLIED FOR IRRIGATION OF CITRUS TREES NEAR MORENO, SAN JACINTO VALLEY, RIVERSIDE COUNTY, CALIFORNIA (72)

Year	Area irrigated	Depth of water applied per acre													Rainfall
		January	February	March	April	May	June	July	August	September	October	November	December	Total	
	Acres	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1930	10	0.0	0.0	0.0	3.6	0.0	4.3	4.3	4.3	4.8	6.4	0.0	3.6	31.3	15.56
1931	10	.0	.0	5.7	4.3	4.3	4.3	5.0	5.0	5.0	5.0	5.0	.0	43.6	16.81
1932	10	.0	.0	.0	6.7	4.3	4.3	5.0	7.1	8.3	3.6	3.6	3.6	46.5	14.33
1933	10	.0	.0	.0	4.7	4.7	6.0	5.5	3.6	4.7	8.6	4.3	.0	42.1	9.90
1934	10	.0	.0	.0	2.9	1.7	6.7	5.2	3.6	.0	4.8	.0	.0	24.9	10.60
1935	10	.0	.0	.0	.0	4.8	4.5	4.8	4.8	4.6	5.0	3.6	.0	32.1	10.85
1936	10	3.8	.0	.0	4.8	4.8	3.6	4.3	3.6	4.3	4.3	.0	.0	33.5	18.46
1937	10	.0	.0	.0	.0	7.4	4.3	4.3	.0	7.1	4.3	.0	4.3	31.7	16.61
1938	10	.0	.0	.0	.0	5.7	4.3	4.3	6.1	4.3	7.1	3.6	.0	35.4	19.10
Maximum		3.8	.0	5.7	6.7	7.4	6.7	5.5	7.1	8.3	8.6	5.0	4.3	46.5	19.10
Minimum		.0	.0	.0	.0	.0	3.6	4.3	.0	.0	3.6	.0	.0	24.9	9.90
Mean		.4	.0	.6	3.0	4.2	4.8	4.7	4.2	4.8	5.5	2.2	1.3	35.7	14.69

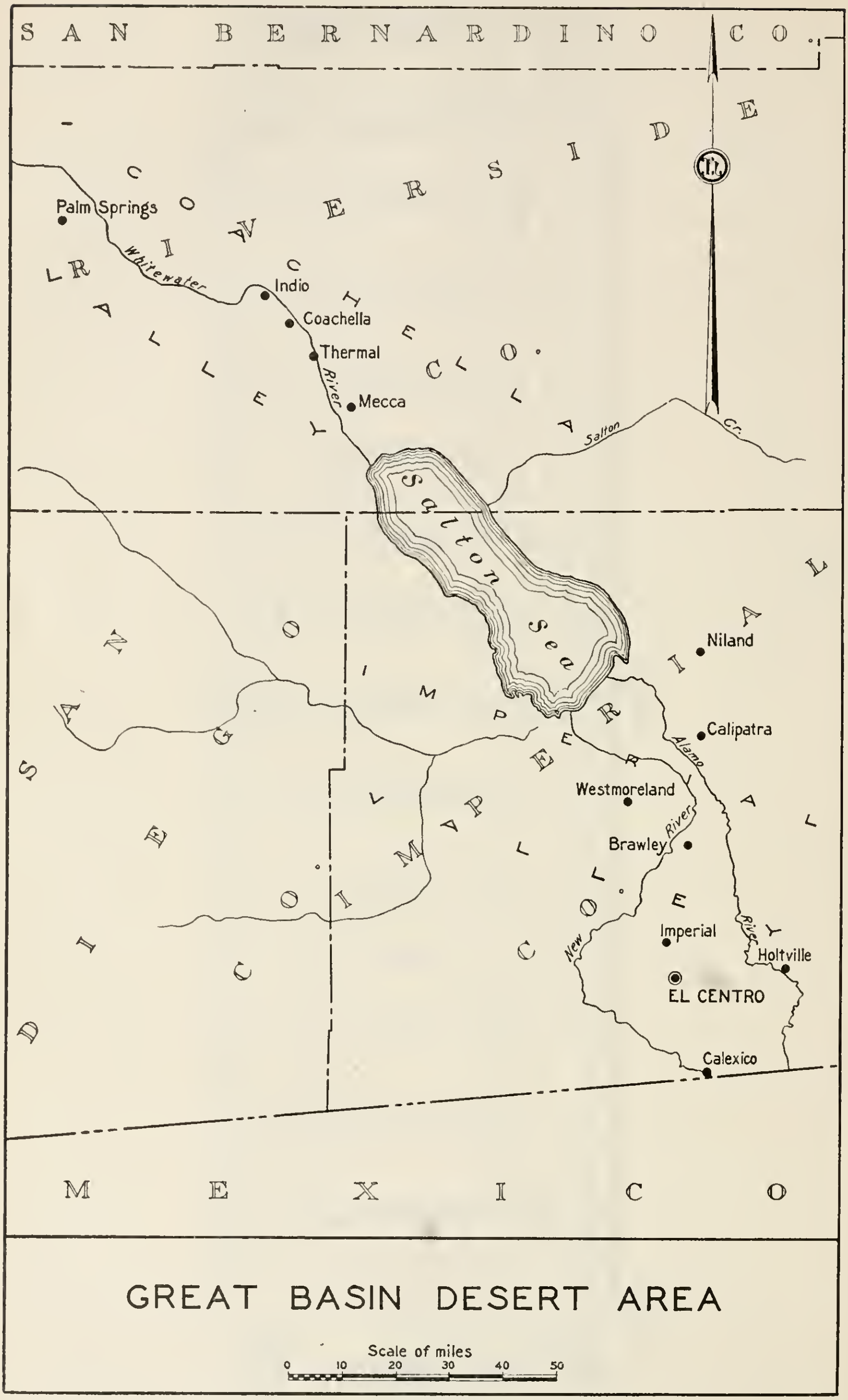
SAN BERNARDINO CO.
RIVERSIDE
MEXICO
Palm Springs
Whitewater
Indio
Coachella
Thermal
River
Mecca
Salton Cr.
Salton Sea
Niland
Calipatra
Alamo
Westmoreland
Brawley
River
New
Imperial
Holtville
River
EL CENTRO
Calexico
GREAT BASIN DESERT AREA
Scale of miles
0 10 20 30 40 50

Fig. 2

GREAT BASIN DESERT AREA

Portions of the Desert area for which some irrigation requirement data are available are the Coachella and the Antelope Valleys.

COACHELLA VALLEY

Coachella Valley (Fig. 2), in Riverside County, is that portion of the desert depression occupied by the valley of the Whitewater drainage. It lies in the northern end of the structural trough of which Salton Sea and Imperial Valley are a part. Indio, the principal town, has an elevation of 15 feet below sea level.

The climate is typically desert with long summers, high temperatures and very low rainfall. Temperatures of 100 degrees are possible in nine out of 12 months and a maximum of 125 degrees has been recorded. Rainfall is negligible and the small amounts that occur during winter months are of no value to crops. The 63-year average at Indio is 3.28 inches. Seasonal extremes in past years have ranged from a minimum of 0.18 to a maximum of 11.50 inches for the season 1939-40. Average monthly temperatures and rainfall are listed in Table 34. Average length of the frost-free period is 302 days between the dates of February 5th and December 4th.

The agricultural soils of the valley are found in four distinct series of which the Coachella and Indio series are the most important on an agricultural basis (36). The Superstition series represents a somewhat older deposit and is mostly located around the edges of the valley as delta cones at the mouths of canyons. Soils of the Woodrow series are low-lying, are highly alkaline and of little agricultural value.

All irrigation, except in a few instances above Point Happy, is from wells. Rainfall on the valley floor is too limited to contribute to the ground water basins, but run-off from adjoining hills and mountains seeps into detrital cones, partly replenishing the groundwater, levels of which are, however, steadily receding. Near Salton Sea are a few flowing wells, but most wells have to be pumped. Hope for additional water is based upon eventual operation of the Coachella Branch of the All-American Canal.

Because of the extreme aridity, crops can not be grown in Coachella Valley without irrigation, but a growing season that extends throughout the year, together with good soil and a water supply, make this a highly productive area. The net acreage cultivated probably is about 13,000 acres, although if double cropping be taken into account, the total cropped acreage is 19,000 acres. Principal crops are vegetables, citrus, dates, cotton and grapes.

Irrigation Requirements of Date Palm Trees

Observations on use of water by irrigation have been made by the California Agricultural Experiment Station cooperating with the Division of Irrigation, Soil Conservation Service. Transpirational use of water by date palms as recorded in the studies is summarized in Table 34 (43).

Depth of moisture used by the trees was determined by soil sampling to depths of eight feet below the dry mulch. Although variations occurred the average root activity was found to be 59 per cent in the upper two feet of soil, 30 per cent in the next two feet and only 2 per cent between the sixth and eighth foot.

The average annual transpirational use of water by all plots was 72.4 acre-inches per acre and the average depth of water applied was 90.7 acre-inches. Cover crops on some plots increased the transpiration use. Transpiration data indicated in Table 34 include only records from plots where the soil moisture in the lower depths of six to eight feet was at or below the moisture equivalent, thus avoiding any data that included drainage loss. By measuring the depths of water applied and determining the soil moisture increase it was found that the average irrigation efficiency was 80 per cent, a high value made possible only by basin flooding.

Assuming that there is no unusual amount of deep percolation below the zone of root activity and with an 80 per cent irrigation efficiency, it may be presumed that the depth of water applied becomes also the water requirement of the crop. Thus a depth of 90 inches applied, including transpiration, evaporation, and a very limited deep percolation, may be assumed to be the average irrigation requirement of dates in the Coachella Valley.

TABLE 34

TEMPERATURE, RAINFALL AND TRANSPIRATION USE OF WATER BY DATE PALMS, COACHELLA VALLEY, CALIFORNIA, 1936-38 (43)

Month	Mean monthly temperature[1]	Mean monthly rainfall[1]	Depth of transpiration use	Adjusted depths of water applied	Month	Mean monthly temperature[1]	Mean monthly rainfall[1]	Depth of transpiration use	Adjusted depths of water applied
	° *F.*	*Inches*	*Inches*	*Inches*		° *F.*	*Inches*	*Inches*	*Inches*
January	53.7	0.61	2.9	3.6	July	93.2	0.07	9.1	11.4
February	59.0	.55	3.4	4.2	August	91.9	.26	10.0	12.5
March	65.1	.32	4.6	5.8	September	85.6	.27	8.6	10.8
April	72.2	.15	6.2	7.8	October	75.0	.28	5.4	6.8
May	79.2	.05	7.9	9.9	November	63.0	.19	3.6	4.5
June	87.6	.02	8.3	10.4	December	55.5	.51	2.4	3.0
Annual totals							3.28	72.4	90.7
Annual mean						73.4			

[1] Temperature and rainfall for Indio, taken from Climatological Data, U. S. Weather Bureau, California Section, 1943.

Irrigation Requirement of Vineyards

Transpiration losses by mature Thompson seedless grapes grown on a plot of Coachella fine sand in the Oasis district of Coachella Valley was determined (43) by soil moisture sampling during 1937-38. Irrigation was by flooding within the plot although the rest of the vineyard was furrow irrigated. Root distribution was found to be 66 per cent in the upper three feet, 29 per cent in the next three feet and five per cent at depths from six to nine feet. Some deep penetration of water was determined but not in unusual amounts.

Table 35 shows monthly depths of transpiration and water applied.

TABLE 35

TRANSPIRATION USE OF WATER BY THOMPSON SEEDLESS GRAPES IN COACHELLA VALLEY, CALIFORNIA, 1937-38 (43)

Month	Depth of transpiration use	Depth of water applied	Month	Depth of transpiration use	Depth of water applied
	Inches	*Inches*		*Inches*	*Inches*
January	0.4	0.5	July	7.8	9.6
February	.5	.6	August	7.4	9.1
March	1.0	1.2	September	4.7	5.8
April	2.3	2.8	October	3.4	4.2
May	5.1	6.3	November	2.0	2.5
June	8.3	10.2	December	.7	.9
			Totals	43.6	53.7

The seasonal depth of transpiration from April 1st to October 30th amounted to 39.0 acre-inches per acre as compared with 48.0 acre-inches of irrigation water applied. On this basis the average irrigation efficiency would be approximately 80 per cent, a high value that appears to have been obtained by use of the basin method of irrigation. Since rainfall is not a factor in supplying crops with water in this area it may be assumed that, in ordinary irrigation practice where deep percolation is negligible and the irrigation efficiencies are 70 per cent or more, the irrigation requirement closely approximates the depth of water applied. On this basis the requirement for grapes for the irrigation period April to October, inclusive, may be assumed to be within the range of 36 to 40 acre-inches per acre. As compared with the requirements of wine grapes in Riverside and San Bernardino Counties, however, these values are high, as in these areas grapes are seldom irrigated unless there is a deficiency in the seasonal rainfall.

IMPERIAL VALLEY

Irrigation of Alfalfa

Imperial Valley (Fig. 2), during its long growing season is subject to high temperatures which are conducive to a high water use for crops. In 1944 alfalfa was grown on 147,000 acres. High ground water exists over much of the area and any estimate of consumptive use of water should consider the possibility of the plant obtaining a portion of its supply from this source. The Imperial Irrigation District data show the average depth of water delivered to 72 farms totaling 7,600 acres of alfalfa during 1941 as 4.01 acre-feet per acre, the production area covering all sections of the valley. The growing season is about 10 months and a high use may be expected.

In 1943 the Agricultural Extension Service made a cost and efficiency analysis (69) of alfalfa in Imperial County in which depths of water applied to seven farms were compared with yield of crop. In Imperial Valley water is cheap and there is not the inducement to economize in irrigation that is usual elsewhere in southern California. Also because of the salts carried by irrigation water and their concentration in the soil solution, it is advisable to over-irrigate in order to prevent their accumulation. These factors tend toward the greater use of water by all crops in the valley.

The alfalfa study showed depths of water applied ranging from 70 to 31 acre-inches per acre annually, as set out in Table 36. The highest yields were from 6.2 to 5.0 tons per acre, produced with 60 acre-inches of water applied as compared with an average of 48 acre-inches per acre as recorded for an area of 7,600 acres by the Imperial Irrigation District.

TABLE 36

IRRIGATION AND YIELD OF ALFALFA GROWN IN IMPERIAL VALLEY, CALIFORNIA, 1943 (69)

Area	Age of stand	Cuttings	Irrigations	Depth of water applied	Cost of water per acre	Yield per acre
Acres	*Years*	*Number*	*Number*	*Inches*	*Dollars*	*Tons*
80	1	5	16	70	4.24	4.3
60	1	7	16	60	3.75	6.2
40	2	5	16	60	3.75	5.8
20	2	5	14	60	3.75	5.0
30	3	5	12	56	3.50	4.9
100	1	5	12	41	2.25	3.8
40	1	4	16	31	1.95	3.5
Maximum.... 100	3	7	16	70	4.24	6.2
Minimum.... 20	1	4	12	31	1.95	3.8
Mean........ 53	1.6	5	15	54	3.31	4.8

From these data and because of high ground water it is evident that no reliable estimate of the irrigation requirement of alfalfa can be made for Imperial Valley.

Irrigation of Flax

Flax in the Imperial Valley is a winter crop sown from October 15th to December 1st and harvested in the spring and early summer. It therefore has a relatively low irrigation requirement as compared with crops grown during the hot summer season. Records provided by the Imperial Irrigation District show the average depth of water delivered to 160 farms covering a total of 16,018 acres of flax during the season 1941-42 was 2.11 feet, as set out in Table 37. All parts of the valley were included and there was little variation in the several divisions.

TABLE 37

AVERAGE DEPTHS OF WATER APPLIED IN IRRIGATION OF FLAX IN IMPERIAL VALLEY, CALIFORNIA, AS REPORTED BY IMPERIAL IRRIGATION DISTRICT, 1941-42

Division	Farms	Net area	Depth of water applied
	Number	*Acres*	*Feet*
Calexico	13	1,621	2.00
Holtville	14	1,382	2.19
El Centro	60	4,629	2.07
Imperial	37	2,677	1.89
Brawley	9	1,869	2.19
Westmoreland	12	1,389	2.38
Calipatria	15	2,451	2.20
Totals	160	16,018	
Mean			2.11

Records obtained by the Agricultural Extension Service of the University of California (54) show an average water application to 16 farms growing flax, over a period of five years, to be 25.2 acre-inches per acre, which is almost the figure obtained by the district for the larger acreage. A total of 73 out of 85 fields were preirrigated before the planting in order to provide moisture for germination. In Imperial Valley rainfall is negligible, averaging 2.7 inches annually over a 30-year period, and preirrigation was generally necessary. Usually five irrigations were applied during the season in addition to the preirrigations. The yields averaged 25.8 bushels per acre of field-run seed of which about two bushels per acre were dockage. Irrigation data for these tests are shown in Table 38.

TABLE 38

DEPTH OF WATER APPLIED, YIELD AND COST OF WATER FOR IRRIGATION OF FLAX, IMPERIAL VALLEY, CALIFORNIA (54)

Year	Farms cooperating	Total area	Average yield of field-run seed	Irrigations after planting	Average depth of water per irrigation	Total depth of water applied	Cost of water per[1] Acres	Cost of water per[1] Ac-ft.	Rainfall at Brawley
	Number	*Acres*	*Bushels*	*Number*	*Inches*	*Inches*	*Dollars*		*Inches*
1935	16	2,743	24.7	4	4.4	22.0	2.61	1.43	3.4
1936	20	3,620	21.8	5	4.2	25.0	2.52	1.21	1.1
1937	17	3,197	24.5	5	4.5	27.0	3.96	1.76	.8
1938	17	2,340	27.5	5	4.5	27.0	2.87	1.28	1.4
1939	15	1,882	30.7	5	4.0	24.5	3.08	1.51	
Totals	85	13,782							
Mean			25.8	5	4.3	25.1	3.01	1.44	[2]2.7

[1] Includes $0.50 per acre-foot plus gate charges of $0.25 per day. Does not include assessments.
[2] Thirty-year average.

ANTELOPE VALLEY

The irrigated portions of Antelope Valley (Fig. 1), in the Mojave Desert comprise about 25,500 acres of alfalfa, 3,500 acres of grain, and 3,000 acres of orchards in the northeastern part of Los Angeles County north of the San Gabriel Mountains. The principal towns are Palmdale and Lancaster. Soils are open and porous on the northern slopes and less permeable toward the center of the valley where they sometimes are impregnated with alkali.

Climate is of the desert variety, with long hot summers, no rain during the irrigation season, an average of seven to 10 inches of rain during winter months, and low humidity. Frost-free period at Mojave averages 264 days between February 27th and November 18th. Frost occurrence, however, is erratic and killing frosts have been recorded early in April and late in September. Such variations are of decided economic importance, as warm spring days force fruit trees into blossom, and sudden changes in temperature accompanied by killing frosts can do much damage. It is said that on December 30, 1895 the temperature fell to six degrees above zero near Lancaster. Mean monthly temperature and rainfall at Palmdale are listed in Table 39.

The valley is a closed basin and the only water supply comes from drainage of the surrounding slopes, most of it sinking beneath the surface within short distances. Some storage is effected on Little Rock Creek for irrigation of the Little Rock Creek Irrigation District and additional water comes from the perennial flow in Rock Creek. most of which sinks into the coarse alluvial deposits near the southern edge of the valley. In the central area water for irrigation derives mostly from pumped wells although there formerly were a few flowing wells. For several years there has been a drop in ground water levels, estimated at four to five feet annually in some areas. Possibility of any considerable recharge, beyond that now being effected, appears unlikely.

TABLE 39

MEAN MONTHLY TEMPERATURE AND RAINFALL AT PALMDALE, ANTELOPE VALLEY, CALIFORNIA, ELEVATION 2,654 FEET

Month	Mean monthly temperature	Mean monthly rainfall	Month	Mean monthly temperature	Mean monthly rainfall
	°F.	*Inches*		°F.	*Inches*
January	44.2	1.70	July	81.7	0.00
February	46.7	2.12	August	80.8	.44
March	52.8	1.95	September	72.9	.32
April	58.5	.52	October	63.3	.43
May	65.7	.17	November	52.8	.20
June	73.2	.04	December	46.1	2.34
Total					10.23
Mean				61.6	

Irrigation of Pear Trees

Little Rock Creek Irrigation District occupies about 2,500 acres at the foot of the northern slope of the San Gabriel Mountains with about 1,100 acres irrigated, including 600 acres of deciduous trees, 270 acres of alfalfa, and 200 acres in vegetables and nursery stock. The water supply for irrigation of this area comes from storage in Little Rock Creek Reservoir and the quantity of water available depends entirely upon the seasonal rainfall. In years of low precipitation there is a deficiency that is overcome to some extent by supplementing storage with a small quantity of pumped water.

Water applied to 26 pear orchards in 1934, a drought year with a total rainfall of six inches, is listed in Table 40 (14). The average irrigations were 17.2 acre-inches per acre from March through October, the maximum for the group being 26.9 inches. The orchards were less thrifty than some observed elsewhere, and showed effects of irrigation deficiency. Reports from the district in 1942 indicate an average duty of water for the entire area including the 270 acres of alfalfa, which has a higher requirement than deciduous trees, of 35.0 acre-inches per acre. Rainfall for this year was 14 inches; hence it may be presumed that no soil deficiency existed at the beginning of the irrigation season and that water was used more lavishly than during years of low rainfall when storage was less than the amount required for full irrigation demands.

Inadequacy of the data prevents any definite estimate of the irrigation requirement for pear orchards in this area, but it may be presumed from experience under similar conditions elsewhere that 17 inches of water applied seasonally is too low and 35 inches is somewhat above normal requirement. It is believed that from 24 to 30 inches applied during the irrigation season in Little Rock Creek Irrigation District will, under good management, produce profitable crops of pears. Variations will depend on differences in soil type, methods of irrigation, and personal farm management.

TABLE 40

WATER APPLIED FOR IRRIGATION OF PEAR TREES, LITTLEROCK CREEK IRRIGATION DISTRICT, ANTELOPE VALLEY, CALIFORNIA, 1934 (14)

Area irrigated	Irrigations	Depth of water applied per acre								
		March	April	May	June	July	Aug.	Sept.	Oct.	Total
Acres	*Number*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
10	5	0.0	3.84	3.94	3.84	3.84	3.84	0.0	0.0	19.2
20	3	0	0	3.84	3.84	3.84	0	0	0	11.5
18	5	0	4.00	4.26	4.00	3.73	0	4.26	0	20.2
10	4	3.84	0	3.84	0	3.84	3.84	0	0	15.4
10	6	0	3.84	1.92	3.84	3.84	3.84	3.84	0	21.1
5	5	3.84	0	3.84	3.84	3.84	3.84	0	0	19.2
9	4	0	4.27	4.27	0	4.27	0	4.27	0	17.1
20	3	0	3.84	0	3.84	0	0	0	3.84	11.5
10	6	3.84	0	3.84	3.84	3.84	3.84	3.84	0	23.0
10	4	0	0	3.84	3.84	3.84	3.84	0	0	15.4
10	5	0	3.84	3.84	3.84	3.84	3.84	0	0	19.2
20	5	0	3.84	3.84	3.84	3.84	0	0	3.84	19.2
17	3	0	3.67	3.95	0	3.95	0	0	0	11.6
10	3	0	1.92	0	1.92	1.92	0	0	0	5.8
10	4	0	0	0	7.68	3.84	0	3.84	0	15.4
4	5	0	3.60	3.60	3.60	3.60	0	3.60	0	18.0
8	5	4.80	0	4.80	4.80	4.80	0	4.80	0	24.0
20	5	0	3.84	3.84	3.84	3.84	0	3.84	0	19.2
10	3	0	0	3.84	3.84	0	3.84	0	0	11.5
10	5	0	3.84	3.84	3.84	3.84	3.84	0	0	19.2
10	5	0	3.84	3.84	3.84	3.84	0	3.84	0	19.2
12	5	3.84	-------	7.68	3.84	3.84	0	0	0	19.2
10	4	0	3.84	3.84	0	3.84	0	3.84	0	15.4
10	7	3.84	3.84	3.84	3.84	3.84	3.84	3.84	0	26.9
10	3	0	3.84	0	3.84	3.84	0	0	0	11.5
10	5	0	3.84	3.84	3.84	3.84	0	0	3.84	19.2
Maximum	7	4.80	4.27	7.68	7.68	4.80	3.84	4.80	3.84	26.9
Minimum	3	0	0	0	0	0	0	0	0	5.8
Mean	4.5	.92	2.44	3.39	3.36	3.51	1.48	1.68	.44	17.2

Irrigation of Alfalfa

Alfalfa is the principal crop of the Antelope Valley which has been called the "milkshed of Los Angeles," and uses more water than any other crop grown in the area. Records obtained from 14 growers by the Agricultural Extension Service, University of California, for 1931, presented in Table 41, show the average depth of water applied to have been 6.05 acre-feet per acre for sand and sandy loam soils, with a minimum of 2.20 and a maximum of 9.62 feet (24). Yields varied from 4.8 to 7.9 tons per acre while yields per acre-foot of water applied varied from 0.50 to 2.68 tons, with 1.16 tons as an average for the farms under observation.

TABLE 41

IRRIGATION WATER APPLIED TO ALFALFA IN ANTELOPE VALLEY, LOS ANGELES COUNTY, CALIFORNIA, 1931 (24)

Acres	Soil type	Depth of water applied	Yield per acre	Yield per acre-foot of water applied
		Feet	*Tons*	*Tons*
72	Rosamond fine sand	5.81	6.65	1.15
45	Hesperia loamy sand	4.40	5.66	1.29
45	Hesperia loamy sand	4.50	7.90	1.75
60	Rosamond sand	7.78	5.79	.75
25	Rosamond sand	9.62	4.80	.50
24	Rosamond fine sandy loam	5.47	7.18	1.30
4		2.20	5.90	2.68
75	Rosamond sand	5.77	5.91	1.02
60	Rosamond sand	6.78	6.43	.95
33	Hesperia sand (heavy)	8.36	5.94	.71
38	Hesperia loamy sand	8.20	7.05	.86
35	Rosamond fine sandy loam	4.60	6.97	1.51
10	Rosamond sand	5.19	4.80	.93
153	Sunrise fine sandy loam	6.03	5.26	.87
	Maximum	9.62	7.90	2.68
	Minimum	2.20	4.80	.50
	Mean	6.05	6.16	1.16

Depths of water applied to alfalfa on the Milaway Ranch near Lancaster during the years 1929 to 1933, inclusive, are presented by months in Table 42. After 1929, which was the first year for this crop, the variations in total water applied were small. The mean value was 6.83 acre-feet per acre which agrees favorably with the average depths of water applied to 14 farms as shown in Table 41.

Values of irrigation requirements for alfalfa have not been determined for this area but may be estimated by comparison with consumptive use by alfalfa in the San Fernando Valley and converted to the irrigation requirement in Antelope Valley through the following procedure as used by Blaney (16):

TABLE 42

WATER APPLIED FOR IRRIGATION OF ALFALFA ON THE MILAWAY RANCH, LANCASTER, ANTELOPE VALLEY, CALIFORNIA, 1929-33, INCLUSIVE (14)

Year	Area irrigated	Irrigations	Depth of water applied										Total
			Feb. 15 to Mar. 15	Mar. 15 to April 15	April 15 to May 15	May 15 to June 15	June 15 to July 15	July 15 to Aug. 15	Aug. 15 to Sept. 15	Sept. 15 to Oct. 15	Oct. 15 to Nov. 15	Nov. 15 to Dec. 15	
	Acres	*Number*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1929	20.5	10	0.29	0.28	0.33	0.68	1.30	1.41	1.71	1.14	0.72	0.14	8.00
1930	34.0	9	.09	.65	.62	.80	1.08	1.09	1.50	.13	0	.70	6.66
1931	34.0	8	0	.90	.75	.87	1.22	1.00	1.05	.70	.01	0	6.50
1932	34.0	8	0	1.33	.31	.74	1.03	1.20	1.06	.36	.01	0	6.04
1933	26.8	11	[1].37	1.02	.55	.81	1.24	1.04	1.01	.80	.07	.01	6.92
Maximum	34.0	11	.29	1.33	.75	.87	1.30	1.41	1.71	1.14	.72	.70	8.00
Minimum	20.5	8	0	.28	.31	.68	1.03	1.00	1.01	.13	0	0	6.04
Mean	29.9	9	.15	.84	.51	.78	1.17	1.15	1.27	.63	.16	.17	6.83

[1] Includes 0.22 acre-foot per acre applied during winter months.

Briefly, the process is to correlate existing consumptive use of water data for alfalfa with monthly temperatures, per cent of daytime hours, precipitation and length of irrigation season. The coefficient thus developed is used to transfer consumptive use data obtained experimentally in the San Fernando Valley to Antelope Valley on a basis of difference in monthly temperatures. Irrigation efficiencies, estimated by making allowances for unavoidable wastes, are then used to compute irrigation requirements. Studies made in the San Fernando Valley and elsewhere indicate there is a definite relation between heat units as expressed by the product of the mean monthly temperature and the monthly percentage of daytime hours, and consumptive use of water; and that for alfalfa the consumptive use is about 85 per cent of the calculated heat units.

Following is Blaney's suggested procedure for estimating the consumptive use and depth of irrigation water required by alfalfa in the Antelope Valley: Neglecting the unmeasured factors, consumptive use varies with the temperature and the daytime hours, and the irrigation requirement is also dependent upon precipitation. In Antelope Valley precipitation is light, and in summer it is of little value to the crop. By multiplying the mean monthly temperature by the monthly per cent of daytime hours of the year there is obtained a monthly consumptive use factor. It is then assumed that the monthly consumptive use varies directly as this factor or, expressed mathematically for the irrigation season, $U = K F$ in which U equals the total consumptive use for any period, K is an empirical coefficient of 0.85 based upon San Fernando Valley and other similar data, and F equals the sum of the monthly consumptive use factors for the period; that is, the sum of the products of the mean monthly temperature and the monthly per cent of daytime hours. Consumptive use is then obtained by multiplying F, the consumptive use factor, by K(0.85) and subtracting rainfall in order to arrive at the monthly or seasonal value of consumptive use.

On this basis it has been estimated that consumptive use by alfalfa grown in Antelope Valley approximates 36.7 acre-inches per acre during the irrigation season from April through October. In order to convert consumptive use into an irrigation requirement it is necessary to divide the consumptive use value by an irrigation efficiency, which in this case has been taken as 70 per cent on the assumption that water is delivered to the fields through pipe systems. Use of this value for the period April to October, inclusive, results in an estimated 52.4 acre-inches of irrigation water required for the production of an acre of alfalfa in the Antelope Valley. (Under improved irrigation practices resulting in higher efficiencies the irrigation requirement could be reduced to 48 inches or less.) When it is considered that average rainfall amounts to about 6.8 inches at Llano, 8.5 inches at Lancaster and 10.2 inches at Palmdale, it may be presumed that in years of greater deficiency a low percentage of soil moisture storage existing in the spring will require early irrigation and a long irrigation season.

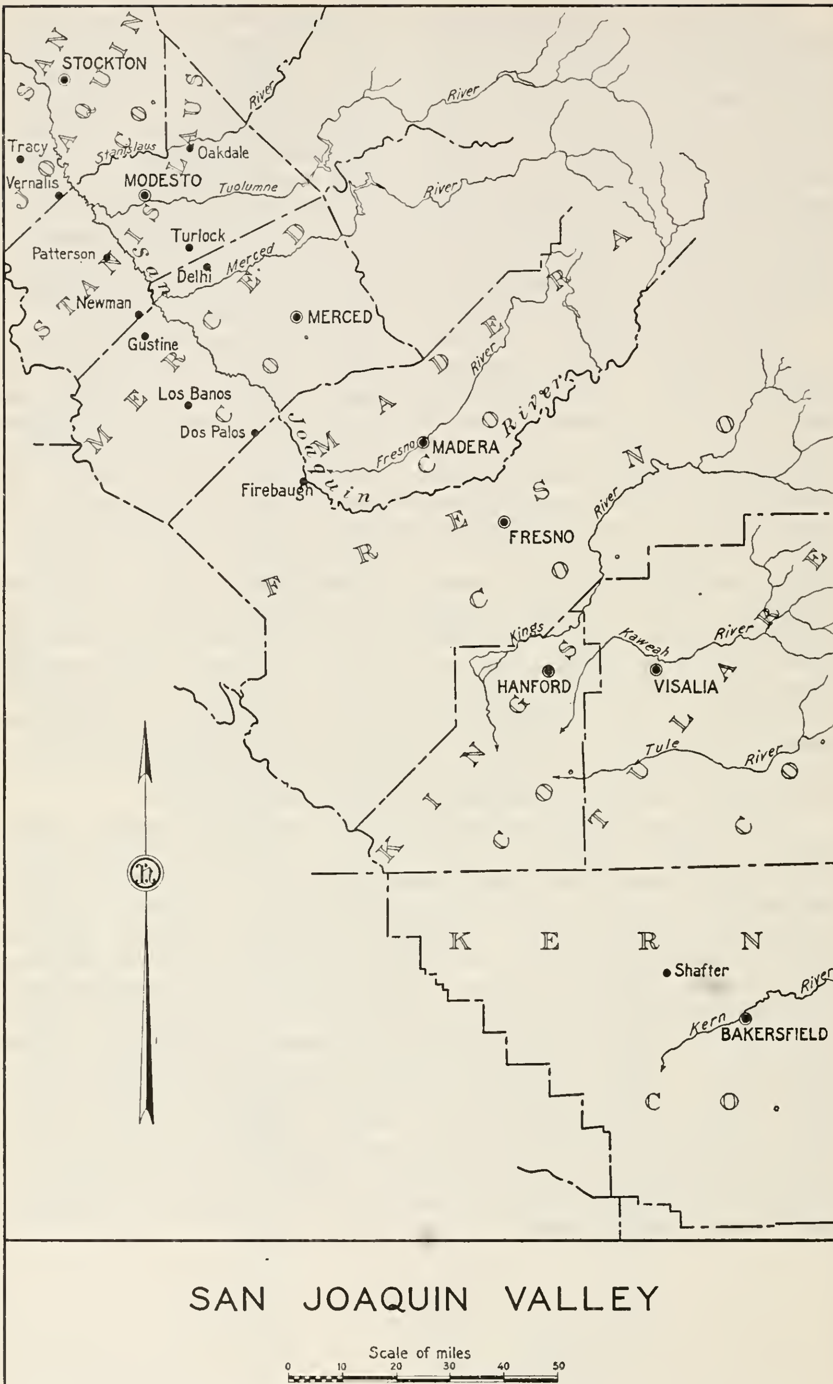
SAN JOAQUIN CO.
STOCKTON
Tracy
Vernalis
STANISLAUS
Stanislaus
Oakdale
MODESTO
Tuolumne
River
Turlock
Patterson
Delhi
Merced
Newman
Gustine
MERCED CO.
MERCED
Los Banos
Dos Palos
MADERA CO.
MADERA
Fresno
River
San Joaquin
Firebaugh
FRESNO CO.
FRESNO
Kings
HANFORD
KINGS CO.
Kaweah
River
VISALIA
TULARE CO.
Tule
KERN CO.
Shafter
Kern
BAKERSFIELD
SAN JOAQUIN VALLEY
Scale of miles
0 10 20 30 40 50

Fig. 3

SAN JOAQUIN VALLEY

Description

The valleys of the San Joaquin and the Sacramento Rivers form the Central Valley of California, approximately 450 miles in length, making a continuous agricultural area that is the largest in the State. The San Joaquin Valley is that portion of the Great Central Valley of California lying between the Sierra Nevada Mountains on the east and the Coast Range on the west, with a northerly boundary along the delta lands of Suisun Bay, and the southerly limit in the Tehachapi Mountains (Fig. 3). It is approximately 250 miles in length and 40 miles wide on the valley floor, but the extreme width, including mountain slopes, approaches 130 miles. The area normally tributary to the San Joaquin River forms the northern and lower portion of the valley but Tulare Basin and the southern portion are separated from it by the low ridge forming the alluvial fan of Kings River. The central portion of the valley, for its entire length, has an elevation less than 500 feet above sea level.

Irrigated crops include citrus, deciduous fruits and nuts, vineyards, alfalfa, potatoes, beans, cotton, truck crops, rice and unclassified crops that cover large acreages. Of the unirrigated crops grain constitutes nearly the entire percentage of dry farmed acreage, but grain (including flax) is also irrigated extensively although its irrigation requirement is light.

The climate of the San Joaquin Valley, as elsewhere in California, is divided into wet and dry seasons, the wet season occurring during the months between November and April. Rainfall in the southern end of the valley averages less than six inches and it increases to seasonal depths of about 11 inches at the northern end. Much of the total often occurs in showers and small storms that are not beneficial to plant growth as the moisture is dissipated by evaporation before it can become available to the roots; hence the effective rainfall, often designated as that in excess of one-half inch, is measurably less than the depths recorded. Precipitation is so small and variable both seasonally and geographically, that only crops of the lowest water requirement can be grown without irrigation.

The seasonal temperatures are warm during the long dry summers and comfortably cool in winter. The growing season for some crops, particularly citrus, is the whole year. Such permanent crops as deciduous fruits, nuts, alfalfa, and vineyards enter a dormant stage during the cooler months, while cotton, rice and some vegetables grow only during the summer and are harvested in the fall of the year. Citrus is sensitive to frost and needs protection during the coldest nights. The frost-free period in the upper valley is 276 days between the average dates of February 22nd and November 25th, but farther north it averages about 300 days.

The water supply for the San Joaquin Valley originates in the streams of the Sierra Nevada Range, very little water being obtained from the Coast Range on the westerly side of the valley. Streams are divided into primary and secondary categories, the primary streams originating at high elevations and obtaining summer supplies from snow melt, while secondary streams head at lower elevations and have less sustained flow. Those tributary to the San Joaquin River after it enters the valley and turns north are listed from south to north beginning with Kings River, which ordinarily is tributary to the San Joaquin River but in flood spills some water into Tulare Basin. Other streams are Fresno, Merced, Tuolumne, Stanislaus, Calaveras, Mokelumne and Cosumnes rivers. From Kings River to the south are the Kaweah, Tule and Kern Rivers. Many smaller streams contribute to the flow of the San Joaquin River; they are of secondary importance individually but together furnish a considerable supply for irrigation.

Return flow, originating from over-irrigation and canal seepage, constitutes a substantial amount of water available for reuse. Underground waters are an important source of supply for irrigation in areas where the stream flow is deficient. Large areas are irrigated wholly by pumping, the entire supply being derived from ground water; or pumped water may supplement gravity water where it is inadequate. According to the Federal census (58), in 1940 there were 23,584 pumped wells in the San Joaquin Valley which were used for the irrigation of crops.

Irrigation Experiments With Cotton at Shafter and at Firebaugh

Production of cotton in the San Joaquin Valley is practiced in most of the valley but its greatest area is in the southern group of counties. Some cotton is still grown in Imperial County, which at one time produced more than any other area of the State, but in recent years the shift has been toward the San Joaquin Valley. According to the agricultural census of 1940 (58) there were 316,000 acres of cotton in the State during 1939.

Experiments with water requirements of cotton were made by the California Agricultural Experiment Station on sandy and fine sandy loam soils at the U. S. Cotton Field Station at Shafter, Kern County (12), from 1927 to 1930, and near Los Banos and Firebaugh, in Merced and Fresno Counties, on heavy soils from 1931 to 1935 (4), the latter studies being carried on in cooperation with the Division of Irrigation of the Soil Conservation Service.

Studies at Shafter (12) were for the purpose of obtaining information of the effects of variable irrigation treatments given to plots of limited areas where operations were under the control of the investigator. Soil moisture measurements were made below the dry surface soil so that determinations were those of transpiration use. Plots were not less than 16 by 90 feet with nine replications for each major treatment. All plots were on Delano sandy loam soil.

Summer temperatures at Shafter exceeded 100 degrees and those in winter months dropped to less than freezing. Mean annual temperature at Bakersfield, about 20 miles from Shafter, is about 65 degrees. The long hot summers are rainless and the average seasonal rainfall, occurring principally between October and April, is only 5.62 inches. Temperature and rainfall data are listed in Table 43. The latest date for killing frosts in the spring is given by the Weather Bureau as April 7th and the earliest in the fall as October 21st. The average period between frosts is listed as 274 days at Bakersfield.

Transpiration use of water by cotton plants grown on plots was determined by soil moisture methods to depths of five feet. All plots were irrigated by flooding, thus insuring good distribution of moisture throughout the soil. All plots were preirrigated. Treatment 1 provided for ample soil moisture, resulted in a transpiration loss of 29.5 acre-inches per acre during the irrigation season, and produced the highest crop yield. Treatment 3, which resulted in a soil moisture deficiency causing wilt at 9 a.m., used but 18.9 inches in irrigation and produced

TABLE 43

TEMPERATURE AND RAINFALL FOR EACH OF THE YEARS 1927 TO 1930 COMPARED WITH THE LONG TERM MEANS, BAKERSFIELD, CALIFORNIA

Month	Temperature					Rainfall				
	1927	1928	1929	1930	Long term mean	1927	1928	1929	1930	Mean 1890 to 1930
	°F.	°F.	°F.	°F.	°F.	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	50	46	43	48	47	0.83	0.29	0.53	1.13	1.04
February	53	54	48	56	53	1.63	.33	.45	.66	.87
March	54	61	56	59	57	1.05	.39	.77	1.01	1.00
April	62	63	58	65	63	.17	.14	.60	.38	.49
May	68	73	71	65	70	.05	1.70	0	1.59	.40
June	77	77	75	79	78	T	0	.37	0	.05
July	84	83	83	85	84	0	0	T	0	.02
August	80	82	85	82	82	0	0	0	0	.01
September	69	76	76	72	74	0	0	.01	.19	.13
October	67	64	69	65	65	1.54	0	T	T	.35
November	55	54	55	56	56	.80	.78	0	1.19	.51
December	48	44	49	43	48	.03	1.00	.01	0	.75
Mean	64	65	64	64	65					
Totals	------	------	------	------	------	6.79	4.63	2.74	6.15	5.62

the lowest yield. Other treatments were intermediate. The results are shown in Table 44, which also shows the total depth of water applied, irrigation efficiency, and methods of irrigation employed in the different irrigation treatments.

The objective in growing cotton on plots near Firebaugh and Los Banos (4), was aimed at determining plant responses to different moisture contents of the soil between the limitations imposed by the moisture equivalent and the permanent wilting percentage. All plots were pre-irrigated but the depths of application were not reported. As distinguished from the Shafter experiments, where the soils were sandy loams, those in the Los Banos studies were clays, clay loams and adobe soils which sometimes cracked badly, and they were fairly uniform in texture to depths of six to 15 feet. Rainfall was somewhat greater than at Shafter although not in sufficient quantity to affect greatly the depth of irrigation water required, nor was there any particular difference in the monthly distribution. Likewise there was little difference in mean temperatures. Rainfall and temperatures for Madera, about 22 miles from Firebaugh, covering the period of investigation, are listed in Table 45.

TABLE 44

DEPTH OF WATER TRANSPIRED BY COTTON, NUMBER OF IRRIGATIONS, DEPTHS OF WATER APPLIED AND YIELDS ON PLOTS UNDERGOING DIFFERENT IRRIGATION TREATMENTS, SHAFTER, CALIFORNIA, 1927-1930 (12)

Treatment	Depth of water transpired								Irrigations	Depth of water applied during growing season	Water accounted for as soil moisture increase	Irrigation efficiency	Average yield of lint cotton 1927-1930
	April	May	June	July	Aug.	Sept.	Oct	Total					
Number	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Number*	*Inches*	*Inches*	*Per cent*	*Lbs.*
1	0.2	1.0	3.2	7.7	8.9	5.5	3.0	29.5	7	32.6	22.6	69.4	1,034
2	.2	1.0	2.2	5.1	5.8	3.9	2.4	20.6	4	18.8	14.2	75.5	766
3	.3	1.1	2.2	4.1	5.3	3.8	2.1	18.9	3	16.6	12.5	75.4	603
4	.2	1.0	3.0	7.6	5.8	3.5	2.3	23.4	5	22.0	15.5	70.5	697
5	.3	1.1	2.3	4.6	6.7	5.4	3.6	24.0	5	26.2	19.0	72.6	630

Treatment 1. Irrigated when the average moisture of the top 5 feet of soil reached approximately 7 per cent or about half way between field capacity and permanent wilting percentage.
Treatment 2. Irrigated when plants wilted at 4 p.m.
Treatment 3. Irrigated when plants wilted at 9 a.m. Early morning wilt indicated definite stress in the plants from la ck of moisture.
Treatment 4. Irrigated as in Treatment 1 until mid-season after which water was not applied until the plants wilted at 9 a.m. This provided ample moisture during the first half of the season and a deficiency in the last half.
Treatment 5. Irrigated during the first half of the season when plants wilted at 9 a.m. as in Treatment 3, after which irrigation was as in Treatment 1. This provided a deficiency during the first half and ample moisture during the last half of the season.

TABLE 45

TEMPERATURES AND RAINFALL AT MADERA, CALIFORNIA

Month	Temperature		Rainfall	
	1931	1932	1931	1932
	°F.	°F.	*Inches*	*Inches*
January	46	43	2.50	1.65
February	58	48	1.22	1.07
March	55	55	.84	.46
April	62	58	.35	.08
May	71	68	.58	.29
June	70	75	.85	0
July	83	78	0	0
August	82	77	.04	0
September	67	76	.16	0
October	63	63	0	0
November	51	56	1.04	.20
December	45	40	4.43	.98
Mean	63	61		
Totals			12.01	4.73

This station is selected because records nearer to the tests are not published. The period between killing frosts varies greatly each year; in a 25-year period it ranged from 152 to 324 days with an average of 236 days. Methods of determining soil moisture percentages in these tests differed from those employed at the Shafter station where dry surface soil was removed before soil moisture sampling and transpiration losses only were determined. In the Firebaugh and Los Banos areas the surface soil was included in the first foot sampled so that both surface evaporation and transpiration were obtained, making the resulting values consumptive use instead of transpiration use. Monthly applications of water for irrigation, depth of water applied and plot yields are shown in Table 46, which also describes the different irrigation treatments producing the best results. Each treatment was replicated several times.

TABLE 46

DEPTHS OF CONSUMPTIVE USE OF WATER BY COTTON GROWN ON PLOTS OF PANOCHE ADOBE SOIL NEAR FIREBAUGH, CALIFORNIA, 1932-33 (4)

Treatment	Depth of consumptive use of water								Depth of water applied	Irrigations	Plot yield of seed cotton
	Year	May	June	July	August	September	October	November	Total		
Number		*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Number*	*Lbs.*
1	1932	0.9	1.2	6.6	7.1	3.6	1.2	0.5	21.1	19.2	5	39.5
1	1932	.2	.3	5.6	7.7	4.3	1.6	.6	20.3	19.2	5	46.5
5	1932	.4	.7	8.4	9.5	3.0	2.5	1.0	25.5	20.8	4	56.0
5	1932	.8	1.1	7.3	7.8	3.6	2.0	1.0	23.6	20.8	4	42.5
10	1932	.8	1.0	3.5	7.6	4.9	3.3	1.5	22.6	15.9	4	61.5
10	1932	.8	1.0	3.8	8.2	4.5	1.6	.8	20.7	15.9	4	53.5
1	1933	0	1.9	5.2	5.9	2.2	1.7	.6	17.5	15.9	3	----------
1	1933	0	1.4	4.1	5.9	2.8	2.2	.7	17.1	15.9	3	----------
5	1933	0	1.6	4.2	6.6	3.7	2.7	.9	19.7	16.6	3	53.0
5	1933	0	2.1	5.1	7.5	2.2	.8	.2	17.9	16.6	3	42.5
10	1933	0	3.3	3.4	6.8	5.2	.5	.1	19.3	19.3	3	50.5

Treatment 1. Irrigated when soil moisture in the upper 6 feet had been reduced to about midpoint between moisture equivalent and permanent wilting percentage.
Treatment 5. Followed the usual practice of neighboring growers. Irrigated in June, July, August and September in 1932 and July, August and September in 1933.
Treatment 10. First irrigation was in July in 1932 and August in 1933 then 3 later irrigations in 1932 and 2 irrigations in 1933.

Irrigation Requirements of Cotton

From Treatment 1, at the Shafter station, the transpiration use of water was 29.5 acre-inches per acre during the irrigation season April to October, inclusive, as a result of applying 32.6 inches of irrigation water. The irrigation efficiency was 69.4 per cent. Since the depth of water applied was sufficient to result in a reasonably high efficiency it may be presumed that the depth applied and the irrigation requirements are approximately equal for cotton grown on sandy loam soil, for the conditions under which the measurements were conducted. This assumption is supported by the authors (12) in the following statement:

> "On the basis of a reasonable efficiency in irrigation (70 to 75 per cent), from 30 to 36 acre-inches per acre of irrigation water will be required during the growing season of the crop, in addition to a pre-season irrigation of 6 to 8 acre-inches per acre. The irrigation requirement during each month in acre-inches per acre will be about as follows: March or April, 6 to 8; June, 4; August, 11; September, 7; and October, 3."

Conclusion of the authors (4), in estimating the irrigation requirements of cotton grown on heavy soils in the San Joaquin Valley are that 24 inches in depth will produce normal yields, this amount being in addition to depths applied in preirrigation:

> "The conclusion is reached that, on the heavy soils of the experiments of 1932 and 1933 * * * cotton plants in San Joaquin Valley will use the equivalent of about 24 inches in depth in producing normal yields of cotton, this use including both surface evaporation and plant transpiration. The experiments do not disclose whether the use would be greater than about 24 inches in depth when cotton is grown on lands of exceptional fertility that might be expected to produce larger plants than were produced in the experiments described. The quantity of water used is, of course, less than it is necessary to apply, since some losses, in addition to surface evaporation, are in practice unavoidable.
>
> "However, the data as to water applied * * * indicate that the application of a depth of 15 to 20 inches of water for heavy soils * * * is ample for cotton in San Joaquin Valley if there has been a preirrigation to a depth of five or six feet of soil. The depth of water it is necessary to apply to wet the soil to five or six feet, prior to seeding, will depend on the depth to which the soil has been wet by the winter rainfall. If these soils are dry to a depth of six feet, the maximum preirrigation required should not be more than a depth of about 14 inches for the heavier soils or about 11 inches for the medium or lighter soils."

If it be assumed that the 24 inches of evaporation and transpiration loss is consumed on a basis of 70 per cent of irrigation efficiency, then the total water necessary to apply to meet the needs of the consumptive use would be about 34 acre-inches per acre, which agrees closely with the investigator's 20 acre-inches of irrigation plus 11 to 14 inches of preirrigation.

Miscellaneous Estimates of Consumptive Use and Depths of Irrigation Water Applied to Cotton in Practice

Numerous records of consumptive use, depths of water applied, and some that are simply estimates of "water used" are available and are tabulated here as having some value, as in most cases they are in general agreement with results obtained by experimentation. These data were previously summarized in a manuscript prepared by the Division of Irrigation (27) in which the approximate depth of water "used" in producing an average crop of cotton in different localities in the San Joaquin Valley, was given as 26 inches during the irrigation season plus a preirrigation of an additional six inches. Althouse (5) also estimated a depth of 26 inches of "consumptive use" for cotton grown in Tulare County.

In 1922 the State Division of Engineering and Irrigation listed "about four irrigations of 0.5 acre-feet per acre" as typical irrigation for cotton without mention of preirrigation (32). In reports by appraisers to the Federal Land Bank the annual "use" of water by cotton in Kern County was variously estimated at 3.25 acre-feet per acre to 42 inches as representing the best practice, also 3.2 acre-feet per acre in the vicinity of Buttonwillow where the soil generally is heavy and it is the practice to irrigate liberally with available gravity supply during the spring and early summer. Presumably this includes preirrigation. The Water Utilization Planning Service, Bureau of Agricultural Economics, mentioned by Ewing (27), set out an assumed "duty of water" for cotton as 2.5 acre-feet per acre (66). An authoritative assertion is the estimate by Meikle and Adams (42) that "net duty" for cotton in the Central Valley is 2.5 acre-feet per acre.

Also, the Chief Engineer of Madera Irrigation District, in a report to the District Engineer of the U. S. Bureau of Reclamation, estimated the consumptive use of cotton within the district to be 2.25 acre-feet per acre. The 1936 survey report of the Corps of Engineers (Appendix VIII) shows the annual "water requirements" of cotton to be 2.5 acre-feet per acre. The annual "use of water" by cotton was estimated by Charles H. Lee as 2.5 acre-feet per acre in Tulare County and 2.75 feet in Kings County.

These several estimates, while not always using the same terms in describing the water use, arrive at a value of approximately 31 acre-inches per acre, which is good agreement with the irrigation requirement values as determined by soil moisture experiments; they, therefore, may be considered as having weight in supporting the experimental studies. It is presumed, however, that in most cases where the estimates are in the vicinity of 24 to 27 acre-inches per acre, preirrigation quantities are not included.

Experimental Treatments in Irrigation of Alfalfa

According to the 1940 census (58) there were grown in San Joaquin Valley 286,000 acres of alfalfa or 42 per cent of all the alfalfa grown in California, but despite this large acreage and the importance of the crop there is little basic information on its irrigation requirement. As far as known the only experimental investigations with alfalfa were carried on from 1922-25 by the California Agricultural Experiment Station (9) in cooperation with the Division of Irrigation, at Delhi, Merced County, which is one of the heavy alfalfa producing counties of the State.

Soils at the Delhi plots were Oakley fine sand for which field capacities varied from six per cent at the surface to 10 or 12 per cent at lower depths, all lying six to nine feet above a practically impervious layer of hardpan. Climate was typical of the San Joaquin Valley, being warm in summer, but with possible periods of frosts in winter, a long dry summer period and rain during winter months. Temperature and rainfall at Turlock, six miles distant, are presented in Table 47.

These experiments were confined to the study of crop yields under irrigation treatments which consisted of applying different depths of water and varying the number of irrigations. From 12 to 60 inches of water was applied in three to 12 irrigations as shown in Table 48, which also reports the yields of hay received from the different treatments. Thus, the experiments were confined to a study of amounts of water applied and determination of the depths of water necessary for the economic production of the crop, rather than determinations of transpiration or consumptive use. It was found, however, that maximum yields were produced with the use of 42 acre-inches of water per acre, that there was little difference in yields resulting from the number of irrigations, and that applications greater than 42 inches resulted in some decrease in rate of yield. In regard to the hardpan layer at a relatively shallow depth for alfalfa, the authors state:

> "No doubt the impervious layer at a depth of about 6 feet prevented the loss of a large part of the water applied in the heavy irrigations, this water being used by the crop in the intervals between irrigations."

This being so, there would be little or no deep percolation from excessive irrigation and little water would be wasted.

Studies showing the distribution of alfalfa roots under the different irrigation treatments disclose less than two per cent of the roots at depths of six feet, 77 to 89 per cent in the upper 30 inches of soil regardless of the irrigation treatments, and 56 per cent in the upper 12 inches. Regardless of heavy irrigations, root activity and use of water appears to have been very light below a depth of three feet. In this study insufficient data were obtained for determination of consumptive use, water application efficiency and irrigation requirement.

Miscellaneous Estimates of Consumptive Use and Depths of Irrigation Water Applied to Alfalfa in Practice

In the compilation by Ewing (27) numerous references are made to consumptive use and depths of water applied to alfalfa, these values being in most cases estimates by individuals having some particular knowledge of the requirements in the area under discussion. They are in no case estimates of irrigation requirements as they are not based on adequate data for arriving at this value; nevertheless, they are useful in consideration of the requirements of the crop, particularly as such estimates cover various portions of the valley. A few of the more important references and their estimates of water applied or consumptive use are here mentioned.

From an examination of available data covering most of the San Joaquin Valley, Etcheverry, Dunlop and Ewing (27) estimate the seasonable "requirements" of water delivered at the farm headgate for irrigation of alfalfa to vary from 2.5 to 3.5 acre-feet per acre, these values being subject to increase or decrease to conform to local conditions and practices. Any value within this range should produce a good crop in this area as witnessed by the Delhi (9) yield of 8.2 tons per acre obtained from irrigations totaling 36 acre-inches.

In an appraiser's report to the Federal Land Bank in 1941, the "net duty" of alfalfa grown in the West Side Irrigation District, surrounding the town of Tracy in San Joaquin County, was estimated to be 3.05 acre-feet per acre as compared with a 14-year "average duty of water delivered to the fields" of 3.42 acre-feet per acre listed in the 1943 annual report of the West Stanislaus Irrigation District (70) some 20 miles farther south. For the Oakdale district the same appraiser also assumed a "duty" of 3.5 acre-feet for alfalfa, and other appraisers estimated the "duty range" for alfalfa in the Patterson-Newman area as two to four acre-feet per acre, the range being according to soil type. For the Gustine-Dos Palos area of western Merced County, the Federal Land Bank estimated a "total seasonal duty" of 36 to 42 acre-inches per acre for irrigation of alfalfa, the variation being due to differences in soil type ranging from sandy loam to clay loam and an increase to 48 acre-inches for sands.

The engineer for the Modesto Irrigation District has estimated the use of water to irrigate alfalfa to maturity as 3.0 acre-feet per acre. Meikle and Adams (42) in a report on the Central Valley Irrigation Project, estimated the "net duty" of alfalfa as 3.0 acre-feet per acre. The Chief Engineer of Madera Irrigation District in a report to the District Engineer of the Bureau of Reclamation estimated the "consumptive use" for alfalfa as 2.5 acre-feet per acre. Consumptive use is usually defined as the depth of water transpired from plant growth and evaporated from the soil and does not include deep percolation losses. In this respect it differs from "duty of water" which indicates depth of water applied to the land and usually is greater than consumptive use, a difference that may explain the conservative value of 2.5 acre-feet per

TABLE 47

TEMPERATURE AND RAINFALL AT TURLOCK, CALIFORNIA

Month	Temperature			Rainfall			
	Mean maximum	Mean minimum (7 year)	Mean (7 year)	1922	1923	1924	1925
	° F.	° F.	° F.	*Inches*	*Inches*	*Inches*	*Inches*
January	51	34	42	2.58	2.00	1.65	1.18
February	60	39	49	3.85	.87	.33	2.03
March	66	39	53	2.42	.10	1.60	1.01
April	72	44	58	.35	3.26	.20	2.81
May	81	47	63	.54	.51	0	1.67
June	90	53	72	.01	T	0	T
July	96	56	76	T	0	T	T
August	91	53	72	0	0	0	0
September	84	51	67	0	.51	0	0
October	73	47	60	.54	.37	1.20	.08
November	70	39	50	2.48	.57	1.02	.70
December	58	35	43	5.02	.70	2.79	1.67
Mean	74	45	59				
Totals				17.79	8.89	8.79	11.15

TABLE 48

IRRIGATION WATER APPLIED AND CROP YIELD OF ALFALFA GROWN ON OAKLEY FINE SAND AT DELHI, CALIFORNIA (9)

Year	Area irrigated	Irrigations	Depth of each irrigation	Total depth of irrigation	Average yield per acre
	Acres	*Number*	*Inches*	*Inches*	*Tons*
1922-24	0.88	3	4	12	5.27
1922-24	.48	3	6	18	5.68
1922-24	.88	4	6	24	6.25
1922-24	1.04	5	6	30	7.21
1922-24	1.04	6	6	36	8.20
1922-24	1.04	6	7	42	8.71
1922-24	1.04	6	8	48	8.42
1922-24	.88	6	10	60	8.24
1922-24	1.07	3	12	36	6.78
1922-24	1.07	6	6	36	7.25
1922-24	1.07	9	4	36	7.52
1922-24	1.07	12	3	36	7.11
1925	4.8	4	6	24	6.63
1925	5.2	6	6	36	7.15
1925	4.6	8	6	48	6.45

acre. A further estimate of the water used by alfalfa is given by the Corps of Engineers in their 1936 survey (Appendix VIII) which lists the "annual water requirements of alfalfa" in the Kings River area as 3.3 acre-feet per acre. It will be noted that these values are somewhat indefinite inasmuch as they usually do not specify the length of period over which water is applied, whether it is intended solely for the irrigation season or for the annual use. While the difference between the irrigation period and the year concerns principally the winter months when transpiration is low, the difference is likely to account, in part, for the difference in estimated water requirements.

"Seasonal duty" of water for alfalfa in Fresno, Tulare, and Kings Counties as estimated by the Federal Land Bank, varies according to soil types as follows:

Fresno and Tulare Counties		Kings County
Acre-feet per acre	*Acre-feet per acre*	*Acre-feet per acre*
Loams and sandy loams 3½ to 4	Loamy sand and sands 5 to 6	Sandy loam 4

In 1933 Chas. H. Lee estimated the "average annual use" of water by alfalfa as 3.3 acre-feet per acre in Tulare County and 3.6 acre-feet in Kings County, in each case during a seven-month irrigation season. Courtlandt Eaton's 1943 report to the Bureau of Reclamation showed a "farm delivery duty" of 4.2 acre-feet per acre for irrigated alfalfa in Tulare County. In 1942 Althouse (5) estimated a "consumptive use" of 2.7 acre-feet per acre for irrigation of alfalfa in the Alpaugh section of Tulare County. This did not include deep percolation. He also estimated the "long mean" consumptive use by alfalfa grown in the Kaweah area at 2.57 acre-feet per acre as compared with an estimated 3.4 acre-feet by Harding (32). In the latter report Harding further estimated the "duty" of alfalfa in the Tule River section as 3.2 acre-feet per acre.

Further estimates by Althouse (5) of "consumptive use" by alfalfa are 2.66 acre-feet per acre in the Tule River area and 2.70 acre-feet in

Deer Creek and the White River areas. Bulletin 6, of the California State Division of Engineering and Irrigation (6) presents "duty" figures for alfalfa as 2.9 acre-feet "net" per acre in the Tule River area, 3.7 acre-feet per acre "gross" in the White River area, and 3.6 acre-feet "gross" in the Deer Creek area. The term "net duty" signifies the quantity of water measured at the point nearest to its entry and spreading out upon the cropped land. Gross duty is the same quantity of water plus conveyance losses incident to its flow from the point of first diversion to its point of entry to the field upon which it is used. The "requirements" for alfalfa for the entire Kern River area, under a regulated water supply, have been estimated by Harding (31) as 3.0 acre-feet per acre. Also, the report of the Kern River Water Storage District for 1928 gave the "water requirement" of alfalfa as 3.25 acre-feet per acre in the district of Kern County and 3.00 acre-feet in the Rosedale and Pioneer area. The usual definition of water requirement includes rainfall in addition to irrigation requirement.

Additional data furnished by the Federal Land Bank include estimates that seven months "use of water" by alfalfa in Kern County is three and one-fourth to four acre-feet per acre, the indicated range having reference to the different soil types, and that "net duty" is 4.12 acre-feet per acre for alfalfa in the Buttonwillow area of Kern County where the soil generally is heavy and it is the practice to irrigate heavily during the early months when gravity flow is available. It is presumed that the terms "use of water" and "net duty" are synonymous. Fortier and Young (29) conclude that alfalfa requires about three acre-feet per acre in the San Joaquin Valley and that as long as sufficient water is available this crop is reasonably certain to occupy a prominent place in crop production.

The foregoing estimates of depths of irrigation water necessary for the production of alfalfa yields in different parts of the San Joaquin Valley are listed under different terms such as "duty of water," "net duty," "gross duty," "farm delivery duty," "requirement" and "annual water requirement," many of which have nearly the same meaning and approximately the same values except as they apply to different soil types in different areas. In summarizing the various estimates there is a noticeable similarity of values which show little variation from the average of 3.3 acre-feet per acre for all values listed, which is but little different from the 42-inch depth of water applied that resulted in a yield of 8.7 tons of hay at Delhi in the experimental study carried out by the Agricultural Experiment Station (9).

Irrigation of Vineyards

According to the census of 1940 (58) there were then in the San Joaquin Valley over 15,000 farms producing table, wine, and raisin grapes, of which two-thirds were the raisin variety. No data on transpiration losses or of consumptive use of water as determined from soil moisture experiments are available and the only records known are a few instances of water applied as reported by the California Extension Service in Kern County (18) and presented in Table 49 which shows a comparison of water applied with yield of Thompson seedless grapes. Of this group of 11 vineyards the highest yield occurred from 36 to 43 inches of water applied, which agrees with the annual transpiration loss by grapes in the Coachella Valley as shown in Table 35. The tabulation is arranged in descending order of depths of water applied and yields are of similar order. Ewing's summary (27) of seasonal estimated requirements for grapes varies somewhat according to soils and locality, increasing from 1.5 acre-feet per acre in the northern portion of the valley to 2.0 acre-feet in the southern portion, these values being the average depths of water delivered at farm headgates.

TABLE 49

IRRIGATION AND YIELD OF THOMPSON SEEDLESS GRAPES GROWN IN KERN COUNTY, CALIFORNIA, 1930 (18)

Area	Age of vineyard	Irrigations	Depth of water applied	Yield per acre of green weight
Acres	*Years*	*Number*	*Inches*	*Tons*
10.0	9	5	58	5.00
3.0	9	6	56	4.64
13.0	9	6	43	8.63
8.0	8	4	43	7.51
8.0	8	7	41	5.04
14.5	8	3	36	7.50
12.0	10	4	36	5.33
10.0	10	4	33	6.00
4.5	9	6	31	3.00
7.5	13	7	29	3.98
5.5	10	4	18	2.25
Maximum 14.5	13	7	58	8.63
Minimum 3.0	8	3	18	2.25
Mean 8.7	9	5	39	5.35

The Agricultural College of the University of California has had a wide experience with irrigation of various varieties of grapes under different soil and climatic conditions. While its interest was principally with the effect of irrigation on quality of grapes produced, its experiments disclosed that grapes can get along with little water, even on sandy soils, provided winter rainfall is sufficient to wet the soil to the full depth of the root zone. This appears also to be the ordinary practice in portions of Southern California where 15 to 18 inches of rainfall appears to provide sufficient water to produce a crop without irrigation. There appears to be little if any difference in the water requirement for raisin, wine and table grapes, such as there may be reflecting the extent of leaf area, vines with larger areas requiring more irrigation water than smaller vines.

In the San Joaquin Valley, in areas where the annual rainfall is from five to ten inches and does not moisten the soil to the required depth, irrigation is necessary. The depths of water required do not seem to have been determined, but Dr. F. J. Veihmeyer, Division of Irrigation, College of Agriculture, University of California, states in a letter, "I feel that three irrigations totaling 18 acre-inches should be generous for grapes in the San Joaquin, Sacramento and coastal valleys."

Miscellaneous Estimates of Depths of Irrigation Water Applied to Beans in Practice

Beans may be grown almost anywhere in California but not all varieties in all places. Limas do best in coastal areas of the southern portion where the climate is warm and moist, but will not stand the dry heat of interior areas. Limas may be produced with little or no irrigation in the most favorable areas. In areas of sufficient winter rains early planted beans are rarely irrigated but plantings after June 1st require preirrigation to supply moisture for germination of the seed, and subsequent irrigations to supply the plant. Extreme heat precludes the planting of dry beans in the southern San Joaquin Valley; in fact, only two counties, Merced with 7,400 acres and Stanislaus with 38,813 acres, had considerable bean acreages in the census year 1939 (58).

No definite information on the irrigation requirements of dry beans is available but the Federal Land Bank (27) has estimated a ''water duty'' of 1.5 to 2.0 acre-feet per acre for clay loam and clay soils depending on rainfall and 2.0 and 2.5 acre-feet for loam and sandy loam soils depending on preirrigation, these values being applicable to the northern portion of the valley. Annual reports of the West Stanislaus Irrigation District (70) show that the ''average duty of water delivered to the fields'' for beans for a 10-year period was 2.39 acre-feet per acre. The Federal Land Bank, in 1941, estimated a ''net duty'' of 2.10 acre-feet per acre for beans in the West Side Irrigation District on a basis of 88 per cent of the deliveries to beans in the West Stanislaus Irrigation District.

Seasonal ''duty'' for beans in the Gustine-Dos Palos area of western Merced County is estimated by the Federal Land Bank at 10 to 24 acre-inches per acre depending on soil types ranging from silt loam to sand. In the area south of Merced River the Bureau of Agricultural Economics (27) has estimated a ''duty of water'' of 1.3 acre-feet per acre for both baby limas and blackeye beans. The delivered ''duty for beans'' as calculated by the Merced Irrigation District for 1943 amounted to 2.3 acre-feet per acre. Few beans are grown in Kern County but the estimated use set out in California State Bulletin 9 (31) shows a value of 1.5 acre-feet per acre of ''applied use of water'' for the entire Kern River area.

Based on the various estimated values shown, Ewing and his associates (27) estimated the seasonal requirement for irrigation of beans as 18 to 21 acre-inches of water delivered at farm head-gates.

Irrigation of Sugar Beets

Production of irrigated sugar beets in California, during the census year 1939 (58) amounted to 143,000 acres of which only 4,400 acres were grown in the San Joaquin Valley, making it one of the minor crops of the area. Early planting insures well-established growth before warm weather arrives, but preirrigation is necessary if the soil is dry at the time of planting. The moisture requirements call for a sufficient supply for germination and to carry through the thinning period, a maximum supply until two or three weeks before harvest and a gradually diminishing supply during the last few weeks to permit proper ripening.

Beet roots extend to five or six feet into the ground and under proper moisture conditions may occupy a volume of 125 to 150 cubic feet of soil. Furrow irrigation generally is recommended and frequent irrigations are necessary to prevent wilting. A medium amount of water is required to bring the plant to maturity—as much as 20 to 24 acre-inches per acre including rainfall and irrigation, has been recommended (45).

While definite information on the irrigation requirements of sugar beets in the San Joaquin Valley is lacking, the Federal Land Bank has recommended a "water duty" of 24 to 27 acre-inches per acre on clay loam and clay and 24 to 33 acre-inches on loam and sandy loam in the northern end of the valley (27). The West Stanislaus Irrigation District reports (70) depths of irrigation water applied to sugar beets ranging from 22 acre-inches in 1937 to 33 inches in 1941. Ewing and his associates (27), after an analysis of existing data recommended seasonal requirements for irrigation water delivered at farm headgates for sugar beets as ranging from 21 acre-inches per acre to 27 acre-inches, subject to increase or decrease to conform to local peculiarities affecting irrigation.

Experimental Irrigation of Young Peach Trees Near Delhi, California

Irrigation of deciduous fruits is necessary throughout California but in the San Joaquin Valley only a single effort has been made to determine the amounts of irrigation water which, when properly applied, will produce the best yield of high quality fruit. A few records of depths of water delivered to orchards are available but the amounts so delivered must necessarily be in excess of those actually used because of percolation beyond the depth of root activity and by waste at the end of the tree rows. The most economical use is difficult of determination.

Irrigation experiments with young peach trees grown near Delhi were made by the University of California (33) during a period of six years, beginning in 1923, when the orchard was two years old. The soil was Oakley fine sand overlying a layer of hardpan at depths of from four to six feet. The trees were first watered from tanks, which was possible because of their small size, but later were irrigated by furrows on each side of the tree row. No attempt was made to determine irrigation requirements as the "experiment was designed to obtain information on the relative effects of different soil moisture conditions, rather than to determine the water requirements of peach trees." All plots followed the general plan of wetting the entire soil mass to a depth of six feet, or to the underlying compacted area, to its field capacity at each irrigation.

The outline of the different irrigation treatments follows:

Treatment A. Plots were irrigated frequently and the soil moisture did not go below the permanent wilting percentage. This treatment contained the high moisture percentage plots.

Treatment B. Plots in this treatment were irrigated according to general practice in the community. Water was applied at rather long intervals and moisture above the compacted layer was reduced to the permanent wilting percentage or below.

Treatment C. These plots, irrigated infrequently, received less water than would be considered practical commercially. Trees were in a permanent wilted condition for long periods during the growing season. The severity of the treatment was reflected in size of trees and crops.

Treatment D. Plots were irrigated as in Treatment A, until the fruit began to turn yellow. They were supplied with available moisture during the first part of the season. After harvest, plots received either no more water or only one irrigation.

Treatment E. This was practically the same as Treatment C until harvest, after which available moisture was supplied to the plots.

Treatment F. This was the same as Treatment A except that plots were irrigated once during the dormant season.

Treatment G. Plots were irrigated as in Treatment C except for an irrigation once during the dormant season.

Treatment H. Plots received only one irrigation before harvest, permitting soil moisture depletion below the permanent wilting percentage several weeks before fruit began to ripen. Water was added a few days before picking began.

Treatments A and F received the greatest number of irrigations, and the greatest depth of applied water, and they produced the largest yields. For these trees moisture was always available in the soil in quantities sufficient for the best growth. Treatments C, E, and G received the least water and produced the lowest yields. Under these treatments trees were under stress and in a wilted condition for long periods. Other treatments were between the highest and the lowest irrigations. The results of the experiments are shown in Table 50. Depths of water applied and yield of fruit increased as trees grew and came into production and the records of highest use and best yield occurred during the last year of the experiment. Table 50, although not representing consumptive use or irrigation requirements, indicates that best results were obtained through maintaining an ample supply of moisture in the soil at all times.

TABLE 50

DEPTH OF WATER APPLIED TO YOUNG[1] PEACH TREES DURING THE IRRIGATION SEASON, NUMBER OF IRRIGATIONS APPLIED, AND YIELD OF PEACHES PER TREE NEAR DELHI, CALIFORNIA, 1923-28 (33)

Average Depth of Water Applied (Inches)

Treatments	1923	1924	1925	1926	1927	1928
A and F	7.8	26.6	27.8	15.7	31.9	24.5
B	3.6	12.2	13.6	11.6	21.9	17.9
D	2.8	15.6	20.0	16.3	22.8	24.5
C, G, and E	3.3	9.9	11.3	11.3	10.2	12.9

Number of Irrigations Received by Plots

Treatments	1923	1924	1925	1926	1927	1928
A and F	3-4	5-6	6-7	4-5	10	6
B	2	2-3	3	4	5	4
D	2	2-3	4	4	5	5
C, G, and E	2	2-3	2-3	3	2-4	3

Yield of Peaches in Pounds Per Tree

Treatments	1923	1924	1925	1926	1927	1928
A and F	----------	----------	71.2	216.3	263.1	394.6
B	----------	----------	88.2	186.9	224.9	370.4
D	----------	----------	44.0	200.9	194.2	371.7
C, G, and E	----------	----------	80.2	187.2	167.9	299.6

[1] Trees 2 years old in 1923.

Estimates of Duty of Water by Peach Trees

A few estimates of water use or depth of water delivered to farm headgates for use on peach or other deciduous orchards have been made by Federal Land Bank appraisers and others for various localities. They differ in quantity according to the customary methods of irrigation for the area, depth of rainfall available for crop use, and presence or absence of ground water approaching the area of root activity.

For the Patterson-Newman area a Federal Land Bank appraiser has estimated a ''duty range'' from two to three acre-feet per acre for peaches and apricots ''exclusive of rainfall where land is not affected by subirrigation.'' These values agree reasonably well with depths of water applied for irrigation of young peaches in the Delhi experiments (33). On the same basis he estimates the ''duty of water'' in Stanislaus County east of the San Joaquin River as two and one-half to three and one-half acre-feet per acre for peaches and two to three acre-feet for apricots, the duty varying according to soil texture. For the area south of the Merced River the Bureau of Agricultural Economics (27) has assumed a ''duty'' of 2.0 acre-feet per acre for apricots and peaches and 1.5 acre-feet for figs and prunes.

Seasonal ''duty of water'' for peaches and apricots in Merced County, including the Gustine-Dos Palos area, has been estimated for the Federal Land Bank as 30 to 42 acre-inches per acre according to soil types ranging from fine sand to clay loam. However, the average ''duty'' for trees, presumably of the deciduous varieties, has been calculated by the Merced Irrigation District, from delivery records for 17,587 acres of orchards, as an average of 2.45 acre-feet per acre, which is more nearly in agreement with data obtained from the Delhi experiments. Also, the estimated ''duty of water'' for deciduous orchards in the Madera Irrigation District, as reported by Meikle and Adams (42), is 2.5 acre-feet per acre.

Seasonal ''duty of water'' for peaches in Fresno, Tulare and Kings Counties as estimated by the Federal Land Bank appraisers is two and one-half to three acre-feet per acre for loam and sandy loam soils, three and one-half to four acre-feet for loamy sand and sands, and three acre-feet for sandy loam. A further estimate by Chas. H. Lee is 3.0 acre-feet per acre for a six-month period in Tulare and Kings Counties. Applied use of water for orchards has been estimated by Harding (31) as 2.17 acre-feet per acre. A review of the records shows an absence of experimental data and such information as has been presented is based principally upon records of water applied by water companies or irrigation districts and on estimates of appraisers for the Federal Land Bank. In general, they are in reasonable agreement with each other, the differences resulting principally from variations in soil, climate and irrigation practices.

Irrigation of Pastures

Since 1930 there has been a large increase in the number of irrigated pastures in California, the estimated acreage amounting to 200,000 acres according to the agricultural census of 1940 (58). Such pastures usually include a mixture of perennial grasses and legumes although sometimes a legume such as Ladino clover is seeded alone. The shallow rooting habits of many of the grasses permit pasturage on soils that are too shallow for alfalfa or other deep rooted plants. Ladino clover extracts but a small portion of its nutrient supply from depths below the top foot of soil and many of the other grasses can continue growth on the same shallow depth. Because of the small volume of soil involved there is little opportunity for water storage, especially in sandy soils, and frequent irrigations are required to provide sufficient moisture for transpiration needs. This condition leads to a high irrigation requirement. Studies by the Agricultural Extension Service of the University of California (34) indicate that the monthly use of water will amount to four to eight acre-inches per acre during the irrigation season, with an estimated total of approximately 60 acre-inches.

Additional information furnished by Ewing (27) shows an unusual range in depths of water applied in the few instances of record. For instance, the average delivery as reported by El Solyo Ranch, two miles south of Vernalis, Stanislaus County, for two years, was 2.7 acre-feet per acre for dairy pasture, which would appear to be a low figure as compared with other records. According to Meikle and Adams (42) the water needs of Ladino clover at Oakdale and Turlock are as follows:

> "The average gross duty of water for irrigated pasture in Oakdale Irrigation District, is about 5.5 acre-feet per acre, and the net duty from 4.0 to 4.5 acre-feet. The average gross duty for 2,516 acres in Turlock Irrigation District, based on records pertaining partly to 1937 and partly to 1938, as computed by the engineer of the district, was 5.1 acre-feet per acre, and the net duty was 4.60 acre-feet after allowing 10 per cent loss between the District canal and the land."

According to the Engineer of the Modesto Irrigation District, irrigated pastures in that area use 3.00 acre-feet of water per acre. Also, as calculated by the Merced Irrigation District, the average duty of water for permanent pasture in 1943 was 4.37 acre-feet per acre, as compared with an estimated value of 2.93 acre-feet for wild pasture. An irrigated pasture management study for Merced County, conducted by the Agricultural Extension Service, University of California, showed a depth of water applied in 1940 ranging from 21 to 60 inches per acre. In a memorandum addressed to the District Engineer, Bureau of Reclamation, the Chief Engineer of the Madera Irrigation District estimated the "consumptive use of water" by permanent pasture as 3.25 acre-feet per acre.

The Corps of Engineers estimates the "application" of water to pasture as 1.0 acre-feet per acre, presumably for salt grass pasture on river bottom land. Furthermore, and in contrast with the above application, an enterprise efficiency study of irrigated pastures in Tulare County, by the University of California Extension Service in 1940 (71), showed water deliveries to the 12 pastures receiving the least amount of water to be 70 acre-inches per acre; the 11 pastures receiving the highest deliveries to be 84 acre-inches and the average of all pastures to receive 76 acre-inches per acre during the irrigation season.

The soils of the 23 pastures reporting were loams and sandy loams. With a shallow rooting system and a high water requirement it is necessary for successful pasturage that frequent light irrigations be applied to reduce the amount of water lost below the roots. A summary of depths of water applied in this study, listed in Table 51, shows an average of 16 irrigations during the season. On loam soils pasture should be irrigated once a week during the warmer weather and once in 10 days for the heavy soils. Depths of penetration need not exceed one and one-half to two feet.

The evidence at hand presents a considerable range in depths of irrigation applied on irrigated pastures, varying from 1.5 to 7.0 acre-feet per acre for different localities and different soil types. The variety of grasses grown in the pastures also influences the total irrigation, as some grasses require more water than others. Other factors, such as personal management and the availability of a cheap and plentiful water supply, are accountable for a part of the variations.

TABLE 51

DEPTHS OF WATER APPLIED TO IRRIGATED PASTURES ON LOAM AND SANDY LOAM SOILS IN TULARE COUNTY, CALIFORNIA, 1940 (71)

Area	Soil type	Irrigations	Depth of water applied
Acres		*Number*	*Inches*
12.0	Foster loam	61	144
10.0	Hanford loam	16	39
50.0	Foster loam	19	83
4.0	Chino loam	14	120
10.0	Foster loam	15	64
9.0	Cajon fine sandy loam	8	44
4.5	Chino loam	12	56
17.5	Foster and Travor loam	12	60
10.0	San Joaquin loam	22	74
10.0	San Joaquin sandy loam	22	50
20.0	Chino loam	10	44
9.5	San Joaquin loam	21	67
5.0	Chino loam	13	70
10.5	Chino loam	12	59
4.0	Tulare sandy loam	10	53
6.0	Foster fine sandy loam	26	103
27.0	Foster sandy loam	19	----
5.0	Chino loam	15	63
10.0	Foster fine sandy loam	22	69
7.0	Tulare sandy loam	12	63
9.0	Tulare sandy loam	19	113
25.0	Foster sandy loam	21	121
6.0	Fresno fine sandy loam	13	122
Total 281		--	--
Mean ----		18	76

A summary of the estimated seasonal depths of water delivered at farm headgates for various crops in San Joaquin Valley is listed in Table 52, as agreed upon by representatives of the Division of Irrigation, Soil Conservation Service (27), the University of California and U. S. Engineer office, as a result of a compilation of water use by crops grown in San Joaquin Valley. They were based on an average standard of present-day irrigation practice and may be used with a reasonable degree of assurance subject to adjustments required by differences in climate and soils. They contemplate farm deliveries rather than actual requirements and include losses by evaporation from wet soil, percolation below the plant roots, and water wasted in irrigation. In this respect they exceed the irrigation requirement which covers transpiration losses, soil evaporation and a minimum requirement of deep percolation. Because of differences in rainfall, length of growing season, and drainage conditions, separate requirements are listed for Merced and Stanislaus Counties lying west of San Joaquin River and the rest of the San Joaquin Valley. Requirements are higher in localities having well drained soils of very light material such as are found in parts of the eastern side of the valley.

TABLE 52

SUMMARY OF ESTIMATED SEASONAL REQUIREMENTS FOR IRRIGATION WATER DELIVERED AT FARM HEADGATES, SAN JOAQUIN VALLEY, CALIFORNIA (27), (48)[1]

Crop	Stanislaus and Merced counties west of San Joaquin River	Balance of San Joaquin Valley south of Stanislaus River
	Inches	*Inches*
Alfalfa	39	42
Ladino clover	54	54
Cotton	27	30
Corn-sorghums	18	18
Small grains	12	12
Flax	12	(2)
Sudan grass	21	24
Rice	72	72
Beans	18	21
Potatoes	27	30
Sweet potatoes	--	27
Sugar beets	24	27
Tomatoes	18	21
Citrus fruit	--	30
Deciduous fruit	21	24
Walnuts	--	30
Grapes	21	24
Truck crops	24	27
Miscellaneous	24	27

[1] Subject to increase or decrease to conform to local conditions of climate, drainage, and irrigation practices
[2] North of Fresno the unit is 12 inches; South of Fresno, 18 inches.

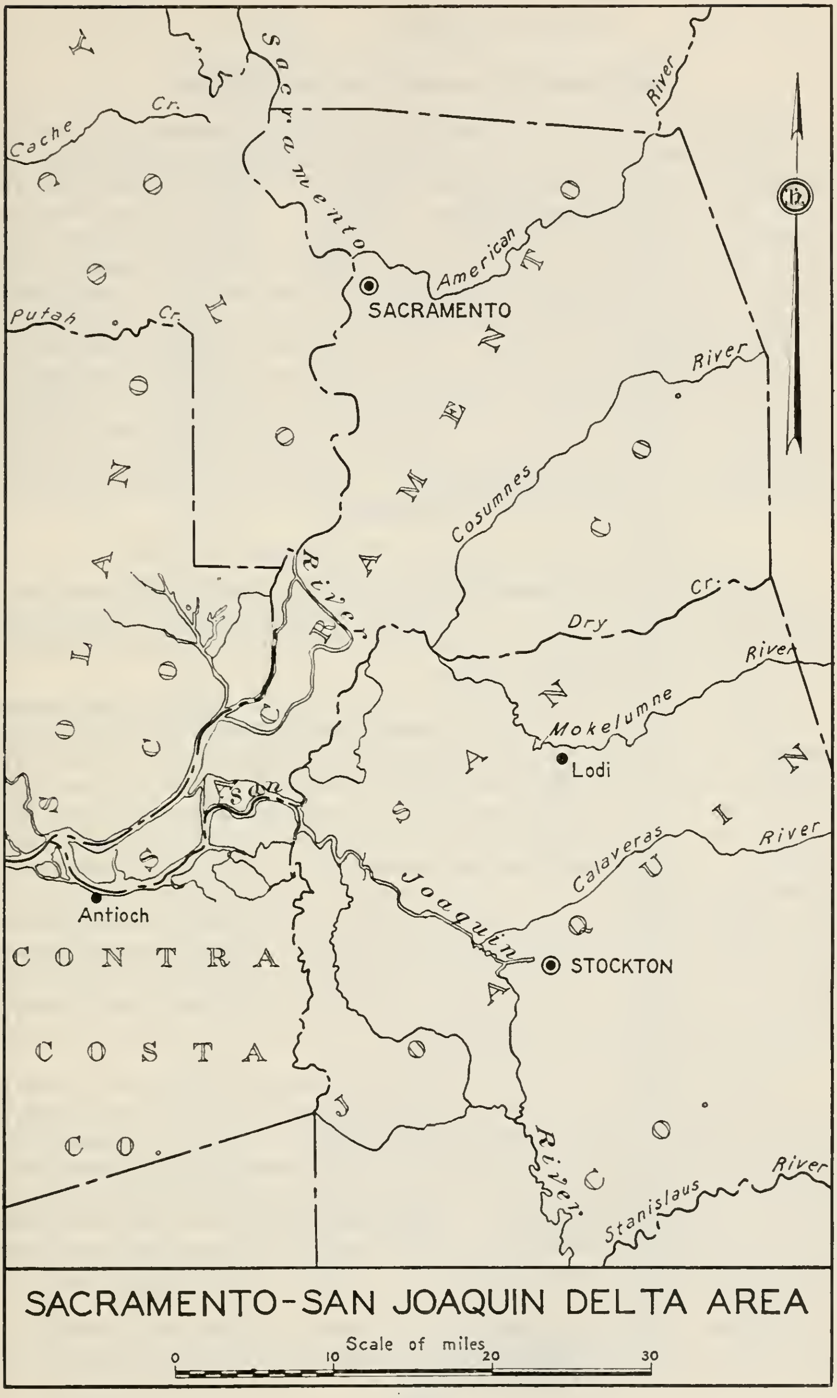
YOLO CO.
SACRAMENTO CO.
SOLANO CO.
CONTRA COSTA CO.
SAN JOAQUIN CO.
Sacramento River
American River
Cache Cr.
Putah Cr.
Cosumnes River
Dry Cr.
Mokelumne River
Calaveras River
San Joaquin River
Stanislaus River
SACRAMENTO
Lodi
Antioch
STOCKTON
SACRAMENTO-SAN JOAQUIN DELTA AREA
Scale of miles
0
10
20
30

Fig. 4

SACRAMENTO-SAN JOAQUIN DELTA

This section includes the low-lying lands contiguous to the confluence of the Sacramento and San Joaquin Rivers, extending westerly to Suisun Bay, and including portions of Sacramento, San Joaquin, Contra Costa, Yolo and Solano Counties. (Fig. 4.) Much of the area lies immediately below sea level and was formerly occupied by tule swamps which have since been drained and protected with river levees. The soils are divided between the sedimentary areas which are principally silt loam and the formerly submerged areas which are of peat formation containing little mineral matter. Both types are unusually productive.

The climate is similar to that in the lower San Joaquin Valley except that summer temperatures are somewhat lower and humidity is higher by reason of being adjacent to Suisun Bay. The mean annual rainfall ranges from a mean minimum of about 10 inches at Tracy to a mean maximum of 18 inches at Sacramento. The frost-free period for different localities varies from 262 to 305 days.

EXPERIMENTAL STUDIES OF CONSUMPTIVE USE

Consumptive use of water data in the delta is based chiefly on experimental studies by Division of Irrigation in cooperation with the State of California Department of Public Works, Division of Water Resources (41), with crops growing in tanks.

Table 52 shows the consumptive use of water for the growing season for a number of important delta crops grown in tanks with either sedimentary or peat soil; also the estimated consumptive use of water by weeds and other non-crop growth before the planting and after harvest. The sum of the two quantities equals the annual consumptive use of the cropped area. For alfalfa, fruit and truck crops, the esitmated consumptive use values are based on experiments in adjacent areas or estimated by comparison with similar crops. Examination of the table shows differences in length and time of the growing season of the various crops. Some, such as asparagus and pasture, have long growing seasons which show use of water throughout the year while others have short seasons: for example, beans, which require irrigation from June through September, and grain or grain hay, either of which is an early crop and needs water from March through June.

In tank experiments the crop grown obtained water from a water table held in the tank at depths previously determined for the experiment. In some cases the water table was manipulated to conform to customary practice in the surrounding fields where a high water table fluctuated during the season. In other tanks it was held at specified depths of two to four feet below the tank surface. Water was added to the tanks from time to time in order to maintain the desired levels, and from these additions the consumptive use was determined. There was no seepage loss from the tanks.

Because of the high water table the growth of weeds was accelerated and depths of water consumed by them adds to the total consumptive use

TABLE 53

UNIT CONSUMPTIVE USE OF WATER BY CROPS IN SACRAMENTO-SAN JOAQUIN DELTA, CALIFORNIA (41), (17)

Crop	Depth of consumptive use												Water consumed before planting and after harvest	Net consumptive use by planted crop
	January	February	March	April	May	June	July	August	September	October	November	December		
	Foot	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Foot*	*Feet*
Alfalfa	*0.06*	*0.08*	0.10	0.30	0.40	0.50	0.65	0.55	0.50	0.20	*0.10*	0.07	0.31	3.20
Asparagus	.05	.05	.05	.05	.08	.14	.40	.68	.55	.42	.12	.10	0	2.69
Beans	*.06*	*.08*	*.08*	*.16*	*.20*	.14	.24	.58	.37	*.09*	*.07*	*.05*	.79	1.33
Sugar beets	*.06*	*.08*	*.08*	*.13*	.32	.51	.61*	.53*	.20*	*.13*	*.10*	*.07*	.52	2.30
Celery	*.04*	*.04*	*.04*	*.08*	*.10*	.10	.10	.20	.25	.30	.20	.05	.30	1.20
Corn	*.04*	*.04*	*.04*	*.08*	*.10*	.24	.85	.84*	.40*	.10	*.10*	*.07*	.47	2.43
Fruit	*.04*	*.04*	*.04*	.18	.32	.50	.57	.40	.23	.07	*.07*	*.05*	.24	2.27
Grain and hay	*.04*	*.04*	.07	.60	.83	.20	*.14*	*.23*	*.21*	*.14*	*.07*	*.05*	.92	1.70
Onions	*.04*	*.04*	.08	.13	.27	.49	.43	.20	*.16*	*.13*	*.10*	*.07*	.54	1.60
Pasture	.08	.10	.20	.25	.25	.25	.25	.25	.20	.15	.10	.08	0	2.16
Potatoes	*.06*	*.08*	*.08*	*.16*	.15	.38	.52	.30	.15	*.09*	*.07*	*.05*	.59	1.50
Seed	*.06*	*.08*	*.08*	.10	.25	.50	.50	.50	.35	.10	*.10*	*.07*	.39	2.30
Truck	*.06*	*.08*	.10	.10	.25	.50	.45	.45	.30	.15	.10	*.07*	.21	2.40

NOTE—Figures in italic type (*.04*) represent consumptive use by weeds and soil evaporation before planting and after harvest. Other figures represent consumptive use by the crop.
"*" Includes estimated additional use by weeds during these months.

of the area. In Table 53 the water used during non-crop months, indicated by italic figures, show consumptive use caused by soil evaporation and use of water by weed growth. During crop periods weeds may be allowed to grow with the crop, thus increasing the consumptive use. These cases are shown in the table by stars (*). A more complete description of the investigation of use of water by crops grown in tanks in the delta area has been presented in the State Division of Water Resources, Bulletin No. 23 (52).

The net consumptive use of water by crops grown in tanks as shown in Table 53 can not be converted into irrigation requirement values for field grown crops because tank conditions differ from actual field conditions in this area in regard to sources of the water supply. In a tank all water received is under control and is replenished by measured amounts. Under open field conditions in much of the delta area a measureable part of the water supply is received from regular irrigation sources, but another part comes from an upward pressure movement of water into the root zone and these amounts are not measureable. The total quantity of water used by the crop should be approximately the same regardless of the source, whether the crop be grown in a tank or in the open field. Consumptive use by tank growth is equivalent to its irrigation requirement because there are no losses by deep percolation or waste such as occur under field conditions, but the irrigation requirement of field growths is less than that of tank growths because a part of consumptive use by field growths is derived from ground-water sources.

Farm Irrigation Deliveries

The average delivery of water to farms in the East Contra Costa Irrigation District through the long period 1922 to 1942 have been tabulated (27) as follows:

Crop	Acre-feet per acre
Alfalfa	1.67
Trees	1.28
Vegetables	1.78
Grain	.80
Trees and vegetables	1.56
Vines[1]	1.02
Trees and alfalfa[2]	1.12
Flax[3]	1.14

[1] Average of 17 years.
[2] Average of 7 years.
[3] One year, 40 acres.

A record of river diversion to fields devoted exclusively to sugar beets in the East Contra Costa Irrigation District, as reported by the Sacramento-San Joaquin Water Supervisor (17), shows a rate of 1.1 acre-feet per acre for a field of 109 acres in 1942. This irrigation district is normally one of low irrigation requirement principally because of high ground water conditions requiring drainage.

Records of 73 pumping plants which served only one type of crop in the Mokelumne area, obtained from unpublished records of the U. S. Geological Survey, are shown in Table 54 for a period of several years.

TABLE 54

DEPTHS OF WATER PUMPED TO IRRIGATED CROPS IN THE MOKELUMNE AREA, OBTAINED BY THE U. S. GEOLOGICAL SURVEY (27)

Crop	Period of record	Average area irrigated	Depth of water applied
	Years	*Acres*	*Inches*
Orchards	1927-33	661	20.9
Vineyards	1927-33	1,993	21.9
Alfalfa	1929-33	144	39.2
Miscellaneous	1928-32	144	22.3

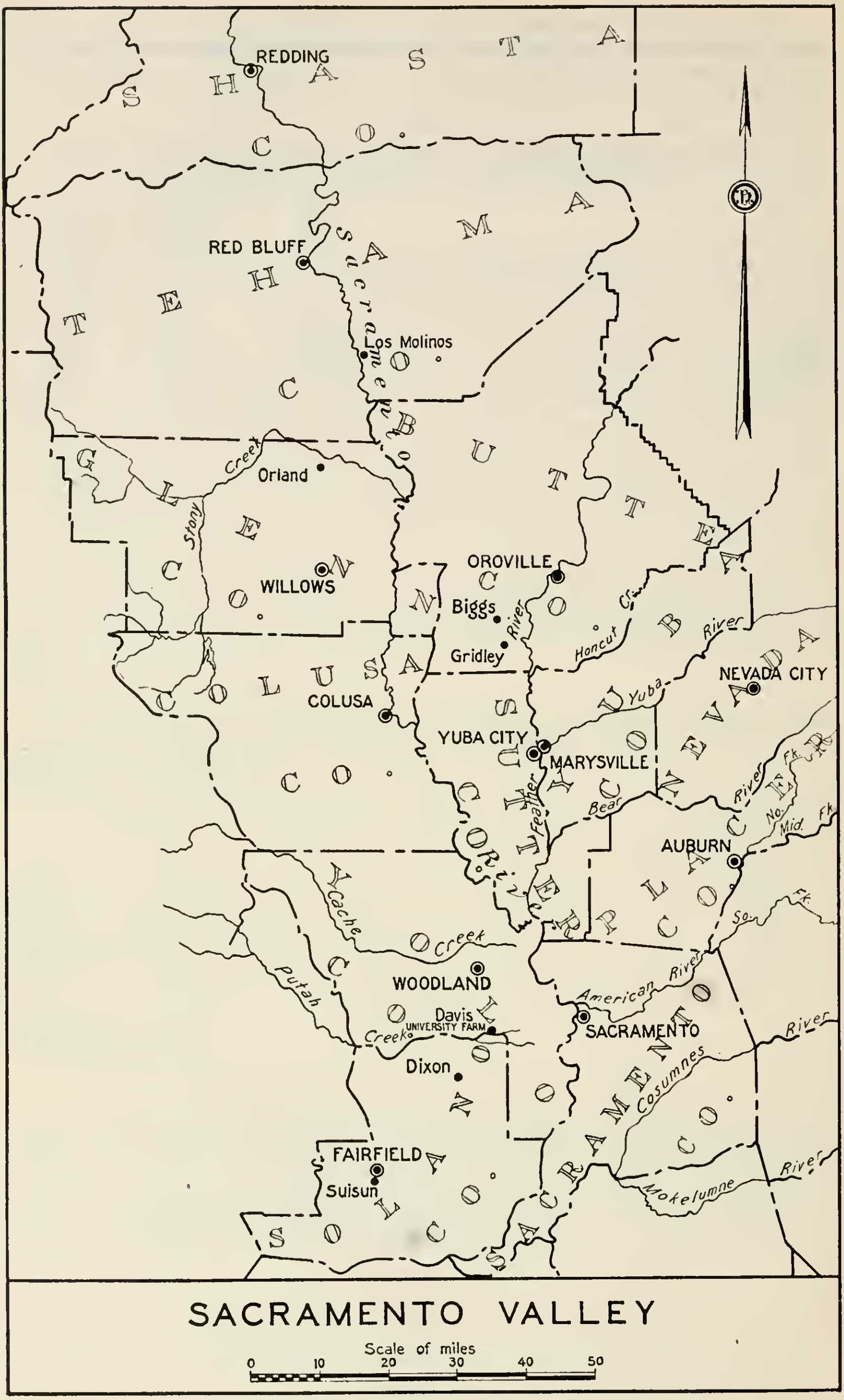
REDDING
RED BLUFF
Los Molinos
Orland
WILLOWS
OROVILLE
Biggs
Gridley
COLUSA
YUBA CITY
MARYSVILLE
NEVADA CITY
AUBURN
WOODLAND
Davis
UNIVERSITY FARM
SACRAMENTO
Dixon
FAIRFIELD
Suisun
SACRAMENTO VALLEY
Scale of miles
0 10 20 30 40 50

Fig. 5

SACRAMENTO VALLEY

The northern part of the Great Central Valley of California, occupying the drainage basin of the Sacramento River System, has available for its many uses the greatest volume of water of any single river system within the State. Only by storage, however, will there be adequate distribution of the total flow necessary for the monthly needs of irrigation, power, salinity control, municipal and industrial uses, flood control and navigation. Shasta Dam permits control of flood wastes and provides a better use of existing supplies. The agricultural portion of the valley extends from Mount Shasta on the north to the Sacramento-San Joaquin Delta on the south in a valley separating the Sierra Nevada and Cascade Range on the east from Coast Range on the west. This is an area about 150 miles long and about 30 miles wide. (Fig.5.)

The mean run-off of the Sacramento River at Red Bluff, approximately at the upper end of the main body of agricultural lands, is about 10,000,000 acre-feet annually. The annual flow has been as high as 22.7 million acre-feet and in years of deficiency as low as 3,000,000 acre-feet, the difference of nearly 20,000,000 acre-feet indicating the necessity of a great storage capacity. The principal tributaries of the Sacramento River are the Pit and McCloud Rivers above Red Bluff, the Feather, Yuba, Bear, and American Rivers entering from the east, and Stony, Cache, and Putah Creeks from the west.

The climate is variable according to altitude and latitude. Records of rainfall available for the City of Sacramento since 1849, show an average of about 18 inches annually with extremes marked by a minimum of seven and a maximum of 35 inches. At Red Bluff the average rainfall is increased to 23 inches and at Nevada City (elevation 2,580 feet), a 60-year record shows an annual precipitation of 53 inches. The long term mean temperature and the annual rainfall at Davis, Calif., for 1934-35 and 38 are presented in Table 55. The frost-free period decreases northward from Sacramento where it averages 306 days between killing frosts, so that at Red Bluff it is but 273 days. The difference may account for selection of crops.

TABLE 55

MEAN MONTHLY TEMPERATURE AND ANNUAL RAINFALL AT DAVIS, CALIFORNIA

Month	Long term mean temperature	Rainfall			Month	Long term mean temperature	Rainfall		
		1934	1935	1938			1934	1935	1938
	°F.	*Inches*	*Inches*	*Inches*		°F.	*Inches*	*Inches*	*Inches*
January	46.5	1.16	4.87	3.49	July	76.2	0	T	0
February	50.9	3.21	.83	8.87	August	74.0	T	T	0
March	55.1	.10	2.88	4.26	September	71.7	T	0	.09
April	59.5	.35	4.40	1.11	October	63.6	.65	1.03	.76
May	65.9	.25	T	.38	November	54.3	2.51	1.05	.60
June	72.7	.44	0	T	December	47.4	2.57	1.51	1.08
Mean						61.5			
Totals							11.24	16.57	20.64

Various classifications have been given the soils of the Sacramento Valley, but of greatest importance are the Class 1 lands north of the delta. These comprise about 1,735,000 acres for which the soil texture, alkali, or topography does not materially limit the feasibility of irrigation. Mountain valleys are in different categories by reason of altitude and climatic differences that increase the depth of precipitation and at the same time shorten the growing season. For such areas the irrigation requirements of crops will be less than for lower elevations on the valley floors.

Practically every crop grown in the State may be found in some degree in the Sacramento Valley. Citrus is grown to a limited extent in the north central portion of the valley. Deciduous fruits, including figs and nuts, are well distributed. The largest peach growing area is in Sutter, Butte and Yuba Counties. Grapes are grown throughout the valley. Rice does well on some of the heavy soils north of Sacramento. Alfalfa is one of the general crops that may be found in most localities and sugar beets, vegetable and truck crops, small grains and beans are grown in several localities.

EXPERIMENTS IN USE OF WATER BY CROPS AT THE UNIVERSITY FARM AT DAVIS

Experiments in the use of water by a number of crops have been conducted at the University Farm at Davis, for many years. Among these crops are watermelons, alfalfa, small grains, corn and milo maize, each of which will be discussed in relation to its consumptive use losses which were obtained as a result of soil moisture studies by the personnel of the station. Each study and its results have been described in publications of the California Agricultural Experiment Station but, because the objective was usually the relation of plant response to different irrigation treatments, quantitive determination of irrigation requirements for individual crops was not usually reported by the investigators. It is presumed that in the process of obtaining records of the consumptive use losses sufficient data were made available to the investigators for calculation of the irrigation requirements for profitable crop production, but in the absence of complete published data no attempt will be made here to arrive at the irrigation requirements for the different crops listed.

Irrigation of Watermelons

Irrigation of watermelons was studied by the California Agricultural Experiment Station at the University Farm, for a three-year period to determine the effects of different irrigation treatments on yields (22). The soil was a fine sandy loam which could be filled to field capacity within the limits of root activity in years in which seasonal rainfall amounted to 16 inches or more. Nevertheless all plots were flooded before being seeded to insure a uniform distribution of soil moisture to the depth desired at the beginning of the season.

Four irrigation treatments were established. Treatment A did not provide an irrigation after germination so that the only water applied was in preirrigation. Treatment B involved irrigation often enough to maintain the soil moisture well above the permanent wilting percentage, the number of irrigations ranging from four applications totaling 13.7 acre-inches per acre to seven applications amounting to only 7.05 acre-inches. Treatment C provided a single irrigation when soil to the depth of root activity reached the wilting point. Depth of water applied ranged from 2.65 acre-inches per acre to 9.13 inches regardless of the depth of rainfall during the previous winter and spring. Treatment D was the same as Treatment B except that there was no irrigation during the blossoming period. This treatment occurred only during the last year of the experiment and provided two irrigations for a total of 7.9 acre-inches applied.

During the first year irrigations were applied by means of furrows spaced nine feet apart, a distance that was insufficient to moisten all the soil between the furrows; but thereafter irrigation was by flooding which permitted a better distribution of the moisture in the soil. The number of irrigations, depth of water applied, and fruit yield per plant are listed in Table 56.

TABLE 56

IRRIGATION APPLIED TO WATERMELONS AND THEIR YIELD AT THE UNIVERSITY FARM, DAVIS, CALIFORNIA (22)

Year	Treatment	Irrigations	Irrigation method	Depth of irrigation	Rainfall January 1 to October 30	Yield per plant
		Number		*Inches*	*Inches*	*Lbs.*
1934	A	0	....	0.0	6.16	70.2
1934	B	7	Furrow	7.05	6.16	69.4
1934	C	1	Furrow	2.65	6.16	58.2
1935	A	0	....	.0	14.01	36.7
1935	B	5	Flooding	18.95	14.01	38.2
1935	C	1	Flooding	9.13	14.01	47.4
1938	A	0	....	.0	18.96	26.1
1938	B	4	Flooding	13.70	18.96	30.4
1938	C	1	Flooding	4.50	18.96	30.4
1938	D	2	Flooding	7.90	18.96	28.2

Yields fluctuated widely with the highest—70 pounds of fruit per plant—occurring in 1934 on soil that had no irrigation other than that prior to seeding. In this year rainfall was below normal, amounting to 6.16 inches between January 1st and October 30th. Nearly the same yield was received from Treatment B in the same year with seven irrigations totaling 7.05 acre-inches per acre. In the following year and with the same Treatment B, five irrigations totaling 18.95 acre-inches, resulted in a yield of 38.2 pounds per plant, a decrease of nearly 50 per cent. This was a year of nearly normal rainfall. The best yields were obtained with application of a small depth of irrigation but the data do not definitely indicate the best amounts to apply. In another paper (38), however, two of the original authors stated that a total of seven to eight acre-inches of irrigation was needed to produce a maximum crop of watermelons on Yolo sandy loam at the University Farm.

Irrigation of Alfalfa

Investigations of the irrigation of alfalfa in the Sacramento Valley were carried on through cooperative studies from 1910 to 1915 by the California Agricultural Experiment Station, the Office of Experiment Stations (including the present Division of Irrigation, Soil Conservation Service), and the State Department of Engineering of California, at the University Farm at Davis, California. In 1913 the scope of the work was increased to include similar studies on a number of representative alfalfa farms of different soil types in several parts of the Valley. Results of the investigations are contained in several publications (1), (2), (8), (9).

Alfalfa is one of the important crops of the Sacramento Valley, as it is in other parts of the State; but in percentage of total area cropped it is less than in some other areas. From the data available it appears that this crop occupies somewhat more than 10 per cent of the entire irrigated acreage of the valley.

The purpose of the investigations was to obtain information on the duty of water in order that alfalfa growers might have a better understanding of the proper number of irrigations, the intervals between them, the depths of water to apply at each irrigation, and the total quantity of irrigation necessary for the production of the best yields. These values differ with variations in soil type and also in different localities, according to several factors of which altitude, precipitation, and temperature are the most important. A summary of the observations at Davis from 1910 to 1925 is presented in Table 57, which shows the relation of different irrigation treatments and total depths of water applied to crop yields. No attempts were made to determine the actual irrigation requirement of the crop.

TABLE 57

IRRIGATION WATER APPLIED, RAINFALL, AND CROP YIELD OF ALFALFA AT THE UNIVERSITY FARM, DAVIS, CALIFORNIA (9)

Year	Area irrigated[1]	Irrigations	Depth of each irrigation	Depth of irrigation	Annual rainfall	Yield per acre
	Acres	*Number*	*Inches*	*Inches*	*Inches*	*Tons*
1910-15	Plots	2	6	12	16.9	5.63
1910-15	Plots	3	6	18	16.9	6.80
1910-15	Plots	4	6	24	16.9	7.92
1910-15	Plots	4	7½	30	16.9	8.98
1910-15	Plots	4	9	36	16.9	9.27
1910-15	Plots	4	12	48	16.9	9.02
1910-15	Plots	4	15	60	16.9	8.42
1918-21	0.61	2	15	30	15.0	8.24
1918-21	.61	3	10	30	15.0	8.41
1918-21	.61	4	7½	30	15.0	7.57
1918-21	.61	6	5	30	15.0	8.72
1918-21	.59	8	3¾	30	15.0	8.79
1918-21	.54	12	2½	30	15.0	9.42
1921-25	.68	2	15	30	14.6	8.33
1921-25	.68	3	10	30	14.6	8.29
1921-25	.68	4	7½	30	14.6	7.36
1921-25	.82	6	5	30	14.6	8.61
1921-25	.77	8	3¾	30	14.6	8.47
1921-25	.71	12	2½	30	14.6	9.20

[1] Soil was Yolo loam.

During the 1910-15 period the total depth of water applied was varied at six-inch intervals from 12 to 60 acre-inches per acre. Application of 36 inches of irrigation water resulted in the highest yield, but the difference in yield between this and that obtained from 30 inches was too small to be significant. For applications greater than 36 inches seasonally there was a decrease in yield; hence it may be assumed that under conditions existing at Davis for this particular period in which the rainfall averaged about 17 inches, 30 inches of irrigation water was the most economical depth. This was obtained by means of four irrigations of seven and one-half inches each.

The reported depths of root zone showed little variation for the different irrigation treatments. Two-thirds or more of the root activity, as evidenced by extraction of moisture from soil, occurred in the upper two feet of soil, while at depths of six feet the average extraction was about two per cent. The soil was fine sandy loam shading into fine sand at about four feet in depth.

It has long been a popular belief that alfalfa is a deeply rooted plant, the roots extending to depths of 20, 40, and even 60 feet. This may occur under favorable conditions with long established stands, but where stands are reseeded every few years and depth of root activity has been determined by soil moisture sampling, the majority of cases indicate that 95 per cent or more of the roots exist in the upper five or six feet of soil (60), (57), (9). This may be due to the fact that irrigation water in the soil is consumed by the plant before it can penetrate to depth, and that beyond the depth of penetration the soil is too dry for root activity. If the soil is moist below the six-foot depth and the upper soil has dried out through lack of irrigation, for a time, at least, greater activity will occur at greater depths.

In further tests at Davis, from 1918 to 1925, variations in the number of irrigations and the depths applied at each irrigation resulted in total applications of 30 acre-inches of water. The number of irrigations varied from two to twelve without changing the total application. The best yields resulted from 12 irrigations of 2.5 acre-inches each, but this increased yield probably would not pay for the extra labor involved in the large number of irrigations. On loam soils in the Sacramento Valley it appears that 30 inches of water applied in three to six irrigations represents good irrigation practice.

In 1913-14 the alfalfa studies by the California Agricultural Experiment Station were extended to a number of other soil types throughout the length of the Sacramento Valley from Woodland to Willows (1), (2), (8). The soils included silt and clay loams, silty clay loam and coarse gravelly loam. Between 40 and 50 representative farms were under observation. While the purpose of the study included measurement and analysis of the amounts of water applied to the crop, in those cases where large amounts of water were applied it became also a study of the underground distribution of the irrigation water and observation of the capacity of the various soils to maintain the moisture necessary for the best crop yields. A summary of the data is given in Table 58, as the complete data are too voluminous for this report.

The table shows great variations in the depth of water applied, ranging from 61.8 acre-inches per acre to 22.0 inches. Where plenty of water was available it was applied wastefully and for these cases the records are not representative of actual irrigation requirements. This appears to be the case for those farms that were under observation at Orland and Los Molinos where an abundance of water was reported available for irrigation. In the Willows area the soil was compact, sticky when wet, and subject to baking when dry. Penetration of irrigation water was difficult and in some cases reached depths of only a foot or so below the surface. Where local drainage was poor, rain water stood in the field, creating some damage to the crops. These conditions are reflected in the low use of water and the low yields tabulated for this area. The best yields appear to have resulted from the application of approximately 30 inches of irrigation water during years when rainfall amounted to about 18 to 20 inches.

TABLE 58

IRRIGATION WATER APPLIED, RAINFALL, AND CROP YIELDS OF ALFALFA GROWN ON DIFFERENT SOIL TYPES WITH DIFFERENT DEPTHS OF IRRIGATION WATER APPLIED, SACRAMENTO VALLEY, CALIFORNIA (1), (2), (8)

Year	Location of tests	Soils	Fields included	Total area	Irriga- tion	Annual rainfall	Yield per acre
			Number	*Acres*	*Inches*	*Inches*	*Tons*
1913	Gridley	Silt loam	14	284	39.7	17.9	6.19
1913-14	Los Molinos	Silt loam	12	130	61.8	20.0	6.01
1913-14	Orland	Coarse, gravelly	7	214	55.9	20.0	6.26
1914	Willows	Silty clay loam	3	28	22.0	22.2	4.82
1913-14	Woodland	Silty loam	12	295	28.0	20.0	6.45
1913	Dixon	Clay loam	6	207	35.3	17.9	6.76

As a result of the studies it was the conclusion of the investigators (8) that the depth of irrigation water required per annum to produce the best yields of alfalfa on medium loam soils in the Sacramento Valley was 30 to 36 acre-inches per acre, depending on rainfall, and that the desirable depth of each irrigation was six to nine inches applied in three to five irrigations.

For gravelly or sandy soils the depth of irrigation required per annum was estimated at 48 to 60 acre-inches per acre applied in two or three irrigations per cutting in depths of three to four inches per irrigation. Where clay or clay loam soils were cropped it appeared that 30 to 36 acre-inches per acre would produce the best yields if applied in two or three irrigations per cutting in amounts of two to four acre-inches at each irrigation. Variations in normal rainfall would advance or retard the date of the first irrigation according to the amount of soil moisture available for the crop in the spring months.

Irrigation of Barley

From 1910 to 1921, inclusive, experiments on irrigation of barley were made on Yolo fine sandy loam soil by the California Agricultural Experiment Station at the University Farm, Davis, California (9). Barley is an early crop, sown in the fall and harvested in late spring so that it obtains the greatest benefit from winter rains. This practice makes irrigation a minor requirement except in years of low rainfall or poor distribution of rains during winter months.

From 1910 to 1916, inclusive, one plot did not receive any irrigation, one was irrigated once and a third plot was irrigated twice, as indicated by crop needs. During the second period of experimentation, 1913 to 1921, one of the plots was without irrigation; of the other two, one was fall irrigated once before seeding and another was summer irrigated, also once before seeding. No apparent difference in yield was noted as a result of summer or fall irrigations. These studies were carried on during periods of both light and heavy rainfall which has a long time seasonal average for this locality of about 17.0 inches. The best yields were obtained from a total moisture supply of about 11 inches of irrigation plus 11.7 inches of rainfall. In Table 59 are shown irrigation data, rainfall and crop yields obtained under the different treatments. During years of high rainfall—22 inches—application of 10.5 acre-inches of irrigation water did not increase the yield.

Irrigation of Wheat

Irrigation of wheat was studied at the University Farm during 1912-1914 with one or two irrigations applied each spring according to crop needs (9). The years 1912 and 1913 were years of deficient rainfall—less than 10 inches—so that one or two irrigations amounting to six to 10 inches were needed to produce the best yields, depending on the rainfall distribution. In 1914, which was a year of high rainfall (28.7 inches), the best yield was obtained without irrigation. For plots where irrigation was applied the yields decreased as the number of irrigations was increased, indicating that irrigation was unnecessary.

Depths of irrigation water applied, rainfall, and yields of grain wheat grown under different irrigation treatments are presented in Table 60 (9).

TABLE 59

COMPARISON OF YIELDS OF BARLEY AFTER YEARS OF LIGHT AND HEAVY RAINFALL AT THE UNIVERSITY FARM, DAVIS, CALIFORNIA, 1910-1921 (9)

Years	Irrigations	Depths of irrigation and seasonal rainfall			Yield per acre[1]
		Irrigation	Rainfall	Total	
	Number	*Inches*	*Inches*	*Inches*	*Bushels*
Seasons of deficient rainfall					
1910, 1912 and 1913	0	0.0	10.07	10.07	17.5
	1	6.7	10.07	16.77	34.1
	2	12.2	10.07	22.27	44.1
1913, 1917, 1918, 1920 and 1921	0	.0	11.69	11.69	16.1
	1-Fall	10.8	11.69	22.49	46.0
	1-Summer	10.8	11.69	22.49	43.8
Seasons of abundant rainfall					
1911, 1914, 1915, and 1916	0	.0	23.20	23.20	31.7
	1	5.2	23.20	28.40	37.1
	2	7.0	23.20	30.20	37.7
1914, 1915, 1916, and 1919	0	.0	22.26	22.26	34.8
	1	10.5	22.26	32.76	32.4
	1	10.5	22.26	32.76	34.2

[1] Weight of barley = 48 lbs. per bushel.

TABLE 60

IRRIGATION WATER APPLIED, RAINFALL, AND CROP YIELDS OF WHEAT GROWN UNDER DIFFERENT IRRIGATION TREATMENTS AT THE UNIVERSITY FARM, DAVIS, CALIFORNIA (9)

Year	Area irrigated[1]	Irrigations	Depths of irrigation and seasonal rainfall			Yield per acre[2]
			Irrigation	Rainfall	Total	
		Number	*Inches*	*Inches*	*Inches*	*Bushels*
1912	Plot	0	0.0	9.5	9.5	9.4
1912	Plot	1	10.0	9.5	19.5	20.2
1912	Plot	2	17.6	9.5	27.1	32.2
1913	Plot	0	.0	8.7	8.7	2.1
1913	Plot	1	2.0	8.7	10.7	9.4
1913	Plot	1	4.0	8.7	12.7	21.9
1913	Plot	2	6.0	8.7	14.7	26.7
1913	Plot	2	8.0	8.7	16.7	27.2
1913	Plot	2	10.0	8.7	18.7	29.9
1913	Plot	2	12.0	8.7	20.7	26.8
1913	Plot	2	15.0	8.7	23.7	20.7
1913	Plot	0	.0	8.7	8.7	22.6
1913	Plot	1	6.8	8.7	15.5	28.8
1913	Plot	2	13.0	8.7	21.7	31.2
1914	Plot	0	.0	28.7	28.7	20.4
1914	Plot	1	4.0	28.7	32.7	15.8
1914	Plot	2	8.0	28.7	36.7	15.2
1914	Plot	3	12.0	28.7	40.7	14.2
1914	Plot	4	16.0	28.7	44.7	13.6
1914	Plot	5	20.0	28.7	48.7	12.9

[1] Yolo fine sandy loam.
[2] Sixty lbs. per bushel.

Irrigation of Oats

Variations in number and depth of irrigation applied to oats grown at the University Farm during two years of rainfall of less than 10 inches also were studied in relation to yields. In three sets of treatments one plot was not irrigated, one was given one irrigation, and a third was given two irrigations, each applied during the spring according to crop needs. Without irrigation the yield ranged from complete failure to 13.6 bushels per acre while one irrigation of 8.1 acre-inches per acre produced 31.7 bushels, one irrigation of 13.2 acre-inches plus 9.5 inches of rainfall produced 45.9 bushels of grain, and two irrigations of 21.8 acre-inches plus 9.5 inches of rain resulted in a yield of 64.2 bushels per acre. These data are shown in Table 61.

TABLE 61

IRRIGATION WATER APPLIED, RAINFALL AND CROP YIELDS OF OATS GROWN UNDER DIFFERENT IRRIGATION TREATMENTS AT THE UNIVERSITY FARM, DAVIS, CALIFORNIA (9)

Year	Area irrigated[1]	Irrigations	Depths of irrigation and seasonal rainfall			Yield per acre[2]
			Irrigation	Rainfall	Total	
		Number	*Inches*	*Inches*	*Inches*	*Bushels*
1912	Plot	0	0.0	9.5	9.5	13.6
1912	Plot	1	13.2	9.5	22.7	45.9
1912	Plot	2	21.8	9.5	31.3	64.2
1913	Plot	0	.0	8.7	8.7	.0
1913	Plot	1	8.1	8.7	16.8	31.7
1913	Plot	2	15.8	8.7	24.5	47.1

[1] Yolo fine sandy loam.
[2] Thirty-two lbs. per bushel.

It was the conclusion of the experimenters (9) that for the Sacramento Valley with normal rainfall normally distributed, the increase in grain yields did not warrant the cost and labor involved in irrigation, and that in years of low rainfall small grains can profitably be produced with irrigation. In 1910, 1912, and 1913, which were years of extreme rainfall deficiency, it was suggested that:

> ''Two irrigations of four to six acre-inches per acre should be sufficient to produce normal yields. Under conditions of partial drought, especially where a deficiency of rainfall occurs in the late winter and early spring (March or April), satisfactory yields may be obtained through one irrigation. In years of heavy rainfall irrigation may produce a decrease in yield. However, if this rainfall should be unequally distributed, with a deficiency during March and April, irrigation water may be applied with advantage. Irrigation of grain land before seeding (either in the summer or in the fall just prior to seeding) produces no increase in yields in years of normal rainfall. In years of deficient rainfall, normal yields will be produced by this method of irrigation. In years of drought the average yield produced by this method was one-third greater than the average yields produced in years of normal rainfall.
>
> ''According to the results obtained in the eight years covered by these experiments, there have been six years of the past 18 years (1909-1926), at the University Farm, Davis, when irrigation would probably have produced no material increase in yields; six years in which the distribution and amount of rainfall was such that one spring irrigation could have been applied with advantage; and six years in which two irrigations would have been required for full production.''.

Irrigation of Corn

A longer study of the irrigation needs of corn was undertaken by the California Agricultural Experiment Station at the University Farm between 1910 and 1922 (9). The number of irrigations varied each year from none to four with depths of water applied ranging from zero to 15.8 acre-inches per acre by means of furrow irrigation. The average seasonal rainfall varied from 10 to 22 inches with an over-all average of 17 inches seasonally. Records of average depths of irrigation water applied, seasonal rainfall and crop yield are listed in Table 62, which is divided into three groups: viz, the dry years, in which rainfall was below normal; the wet years with above normal rainfall, and the average of all years of experimentation. In both the wet and the dry years the best yields were obtained with three irrigations totaling 10.5 acre-inches regardless of the depth of seasonal rainfall. However, the increase in rainfall from the dry to the wet period resulted in a corresponding increase in yield amounting to about 40 per cent.

TABLE 62

SUMMARY OF COMPARISONS OF YIELDS OF CORN GIVEN DIFFERENT IRRIGATION TREATMENTS AT THE UNIVERSITY FARM, DAVIS, CALIFORNIA (9)

Years	Irrigations	Average depths of irrigation and seasonal rainfall			Yield of ensilage per acre
		Irrigation	Rainfall	Total	
	Number	*Inches*	*Inches*	*Inches*	*Tons*
Dry years—1910, 1912, 1913	0	0.0	10.0	10.0	4.04
	1	3.4	10.0	13.4	5.73
	2	6.6	10.0	16.6	6.40
	3	10.5	10.0	20.5	7.36
Wet years—1911, 1914, 1915, 1922	0	.0	22.1	22.1	3.91
	1	3.6	22.1	25.7	6.77
	2	6.8	22.1	28.9	8.96
	3	10.6	22.1	32.7	10.35
	4	15.8	22.1	37.9	9.90
Average of all years—1910-15, 1922	0	.0	17.0	17.0	3.98
	1	3.5	17.0	20.5	6.33
	2	6.7	17.0	23.7	7.86
	3	10.6	17.0	27.6	9.07
	4	14.6	17.0	31.6	8.85

[1] Soil was Yolo fine sandy loam.

Irrigation of Dwarf Milo Maize

Studies of irrigation treatments of dwarf milo maize by the Agricultural Experiment Station at Davis, between 1910 and 1922 (9) indicate the value of additional water applied at the proper intervals in increasing the yield of the crop, the variable factors being the frequency and depth of irrigation. Each variation in the increased number of irrigations and greater depths of water applied produced a greater yield. A summary of data regarding this experiment is shown in Table 63.

TABLE 63

SUMMARY OF IRRIGATION WATER APPLIED, RAINFALL AND CROP YIELDS OF DWARF MILO MAIZE GROWN UNDER DIFFERENT IRRIGATION TREATMENTS AT DAVIS, CALIFORNIA (9)

Years	Irrigations	Average depths of irrigation and seasonal rainfall			Yield per acre[1]
		Irrigation	Rainfall	Total	
	Number	*Inches*	*Inches*	*Inches*	*Lbs.*
1910, 1911, 1913, 1922	0	0.0	15.1	15.1	1,548
1910, 1911, 1913, 1922	1	3.0	15.1	18.1	2,192
1910, 1911, 1913, 1922	2	5.8	15.1	20.9	2,741
1910, 1911, 1913, 1922	3	8.6	15.1	23.7	2,893

[1] Soil was Yolo fine sandy loam.

As a result of the studies with corn ensilage and milo maize the experimenters have concluded (9) that in years of normal rainfall in the Sacramento Valley not more than three irrigations totaling not to exceed 12 acre-inches per acre will produce the best crop. In years of deficient rainfall not more than four irrigations not exceeding 18 acre-inches per acre should be applied. For these crops furrow irrigations will give the best results and four acre-inches per irrigation should be applied for each irrigation. In years when there is insufficient moisture in the soil for germination of the seed a preirrigation will be necessary.

Irrigation of Rice

The growing of rice is adapted to the heavy clay, clay adobe and adobe soils of the Sacramento Valley and according to the agricultural census of 1940 (58) in excess of 90,000 acres was under irrigation there during the previous year. The soil that is the most satisfactory for rice is one that is most impervious to water, so that it will have the least percolation and require the least water for irrigation. Pervious soils permit water to pass through beyond the needs of the plant, thus increasing the danger of creating a drainage problem. It is probable that perviousness of the soil has a greater effect in promoting a high water requirement than all other factors combined.

Irrigation of rice differs materially from irrigation of other crops in that rice is first alternately flooded and drained in order to keep the soil moist for germination of the seed, this period being followed by continued submergence to a depth of about six inches until it becomes necessary to drain the fields so that they may be dried out for harvesting. Rice must have a sufficiently large head of water to permit an initial flooding five to 10 inches deep followed by several shallow floodings to maintain a moisture supply at the soil surface. Heads of two to five cubic feet per second will be necessary depending on the area of the field. Rice fields require drainage ditches around the outside of the field to prevent a rise in the water table that would make the soil too wet for the use of harvesting machinery.

Evaporation from the submerged areas and the growth of water grasses and rice weeds increase the irrigation requirement of the crop. It has been estimated (3) that evaporation disposes of about one-third of the net depth of water required. By net depth is meant the difference between the total depth of water applied to the field for germination and submergence and the depths of water drained from the field following submergence periods. Alkali in the soils of rice fields requires the circulation of water through the area between contour levees, thus increasing the head of water needed although not necessarily the net water requirement.

Cooperative experiments in irrigation of rice in the Sacramento Valley made by the California Agricultural Experiment Station, in various years between 1914 and 1927, determined the best depths of submergence, the time of irrigation and the net depths of water necessary for production of the highest yields on different soil types. On 16 farms totaling 4,395 acres of clay adobe soil the net use of 5.13 acre-feet per acre produced an average of 36 sacks of paddy rice. Eleven farms with a combined acreage of 6,226 acres of clay soil had a net use of 5.39 acre-feet per acre in producing 32 sacks of rice per acre. On the more open loam soil a total of 122 acres required 9.38 acre-feet per acre to produce 43 sacks per acre (3), (46), (23). These data are listed in Table 64.

TABLE 64

SUMMARY, ACCORDING TO SOIL TYPE, OF NET DEPTHS OF IRRIGATION WATER APPLIED AND CROP YIELDS OF RICE GROWN ON HEAVY SOILS IN SACRAMENTO VALLEY, CALIFORNIA (3), (46), (23)

Year	Fields	Area	Soil type	Average net depth of water applied	Average yield per acre
	Number	*Acres*		*Feet*	*Sacks*[1]
1916	2	268	Clay loam and clay	8.12	29
1916-17, 1924	16	4,395	Clay adobe	5.13	36
1916-17, 1924	11	6,226	Clay	5.39	32
1916-17	2	122	Loam	9.38	43

[1] Sacks of rice average 100 pounds in weight.

Results of four years of measurements of the use of water by rice on 40 acres of Stockton clay loam near Biggs, show the average net depth of water applied to be 4.53 acre-feet per acre, producing an average of 46 sacks of paddy rice of approximately 100 pounds per sack. The full irrigation season averaged from the middle to late April to about the first of October. It would appear that a net irrigation requirement of five acre-feet per acre on clay or clay adobe soils would produce 30 to 35 sacks of paddy rice under favorable conditions of growth. More open soils increase the water requirement through percolation losses. Rank growths of water grasses and weeds reduce the yield.

STREAM DIVERSIONS SERVING A SINGLE CROP TYPE FOR IRRIGATION

Table 65 summarizes the monthly average distribution of use of stream diversions and the total average depth of water delivered to about 22,000 acres of various single crops in the Sacramento and San Joaquin Valleys for the years 1935 to 1942 (17). In making this table only those diversions which served a single crop were tabulated. These are gross diversions which include waste, transmission losses, evaporation and possible deep percolation; nevertheless the average depths of water delivered to the crops are not greatly in excess of depths of irrigation determined through experimentation.

It will be observed that the monthly percentage of irrigation applied varies greatly for individual crops, a condition previously discussed in regard to cropping in the Sacramento-San Joaquin Delta. Thus the monthly ratio of use of water by corn in June is about 16 per cent of the seasonal total as compared with 33 per cent for beets in the same month. Eighty-three per cent of the water diverted to hops occurred during June and July while only 49 per cent was diverted to beans during the same period. Such data indicate the peak diversions of water required during the hot summer months.

TABLE 65

MONTHLY AND TOTAL DISTRIBUTION OF WATER DIVERTED FROM STREAMS TO VARIOUS SINGLE CROPS IN PER CENT OF ITS SEASONAL USE IN SACRAMENTO-SAN JOAQUIN VALLEYS, 1935-42 (17)

Crop	Area	Monthly distribution of stream diversion for irrigation								Total depth of water diverted to the crop
		March	April	May	June	July	August	September	October	
	Acres	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Inches*
Alfalfa	3,650	0	2	10	19	27	24	14	4	34.8
Asparagus	1,240	3	1	6	17	28	15	27	3	14.4
Beans	8,170	1	3	10	21	28	29	8	0	24.0
Beets	2,200	1	2	15	33	31	15	3	0	24.0
Corn	1,600	0	2	4	16	42	33	3	0	18.0
Hops	450	0	1	7	34	49	9	0	0	15.6
Orchard	3,220	2	4	8	28	36	15	5	2	26.4
Rice	34,340	0	3	18	21	23	22	11	2	[1]94.8
Truck	1,800	0	2	10	19	29	24	12	4	24.0
Total or average (excluding rice)	22 330	1	3	10	22	30	24	9	1	25.2

[1] Gross diversions including submergence.

WATER PUMPED FROM WELLS FOR IRRIGATION OF A SINGLE CROP TYPE

The gross amount of water pumped from wells for delivery to 15,000 acres of various single crops in the vicinity of Suisun, Dixon, Woodland and Sacramento, as reported by the State Engineer's Office, is presented in Table 66 (17). The average depth of water pumped per acre of cropped land shown in this table is considerably in excess of the acreage diverted from streams as listed in Table 65, although in most cases there is little difference for individual crops. The principal difference lies in irrigation of beets which received 30 inches of irrigation from wells as compared with 24 acre-inches diverted from streams and the addition to the list of Ladino clover using 52.8 acre-inches per acre which from reports on the use of irrigated pastures appears to be a heavy user of water.

TABLE 66

USE OF WATER PUMPED FROM WELLS TO VARIOUS SINGLE CROP TYPES IN THE VICINITY OF SUISUN, DIXON, WOODLAND AND SACRAMENTO, CALIFORNIA (17)

Crop	Wells	Area irrigated	Depth of water delivered by pump
	Number	*Acres*	*Inches*
Alfalfa	114	5,280	36.0
Asparagus	1	51	14.4
Beets	68	6,180	30.0
Berries	6	58	33.6
Grapes	19	543	25.2
Hops	4	188	12.0
Ladino clover	32	1,020	52.8
Orchard	38	1,480	26.4
Tomatoes	6	434	26.4
Totals	288	15,234	
Mean			32.4

ESTIMATES OF IRRIGATION REQUIREMENTS OF CROPS BY VARIOUS AGENCIES

Irrigation requirements of a number of crops grown in the Sacramento Valley, as estimated by the U. S. Bureau of Agricultural Economies, the Bureau of Reclamation, and the State of California, are listed in Table 67 (49). They are based upon the results of various experimental studies by the California Agricultural Experiment Station supplemented by irrigation experience and information from other areas and are considered liberal. They are not necessarily in agreement with the more exact data obtained from consumptive use determinations on small areas for which water was under close control by trained observers, as the data in this tabulation include losses in transit between the farm headgate and the point of application whereas the former did not.

TABLE 67

ESTIMATED WATER REQUIREMENTS PER ACRE AT FARM HEADGATE, SACRAMENTO VALLEY, CALIFORNIA (49)

Crop or other use	Water requirements at farm headgate estimated by		
	Bureau of Agricultural Economics	Bureau of Reclamation[1]	State of California (64)
	Inches	*Inches*	*Inches*
Pasture: Ladino or mixed clover and grasses	54.0	53.9	----
Pasture: Irrigated native	18.0	19.3	15.0
Alfalfa	[2]36.0	36.8	[3]36.0
Sudan grass	15.0	18.6	36.0
Oats and vetch hay	9.0	----	----
Field crops	----	----	21.0
Sorghum—for grain or silage	15.0	12.8	----
Corn or corn silage	15.0	13.1	----
Sugar beets	27.0	25.8	----
Tomatoes	21.0	18.8	----
Peas, winter	9.0	8.0	----
Beans	[4]15.0	13.8	----
Hops	18.0	----	----
Small grains	9.0	----	12.0
Rice	84.0	[5]86.8	72.0
Asparagus	24.0	----	----
Truck crops	21.0	----	24.0
Deciduous fruit	21.0	18.2	21.0
Olives	21.0	----	24.0
Citrus	24.0	----	30.0
Walnuts	24.0	23.8	----
Almonds	15.0	----	----
Grapes	15.0	----	[6]18.0
Pre-irrigation	6.0	----	----
Gun clubs	18.0	----	18.0

[1] Sullivan, A. B. Memorandum Report—Irrigation Requirements of Sacramento Valley Crops. February, 1941. Sacramento Valley Investigations. Bureau Agricultural Economics (unpublished). (55)

[2] Also for deep medium textured soils, 66 inches.

[3] On gravelly soil, 60 inches deep.

[4] For beans doubled cropped after grain hay or peas, 24.0 inches.

[5] Includes 6.0 acre-inches for flooding.

[6] On shallow soil 21.0 inches.

The setting up of such values assumes an average skill in irrigating and they apply to average climatic conditions. Variations in the requirements depend on changes in soil conditions, weather, drainage conditions, and skill and experience of the irrigator in making the most efficient use of the water applied. Under unfavorable conditions it is possible that tabulated requirements may be increased as much as 10 to 25 per cent.

SUMMARY

Irrigation requirements of crops vary with such climatic factors as temperature, rainfall, evaporation, and length of growing season; the quantity and cost of the available irrigation supply; the efficiency of irrigation; with crop characteristics such as rate of growth and rooting habits; and according to soil type. High temperatures, a long growing season and evaporation increase the requirement while low temperatures and effective rainfall decrease it. Expensive water used for irrigation promotes high irrigation efficiencies by deterring overirrigation and other wasteful practices. Both fast-growing and shallow-rooted crops require excess water and mature trees use more water than young trees. Sandy soils need irrigation more frequently than the heavier types. Ground water, close enough to the surface to supply capillary moisture to plant roots, decreases the irrigation requirement and adequate drainage increases it. These are important factors controlling the selection of crops and the depths of irrigation required for their satisfactory production.

Adequate determination of the irrigation requirement, as it has previously been defined, has not been attempted in this report, generally owing to the lack of soil moisture data on which to base satisfactory estimates. Wherever it has been possible, transpiration use or consumptive use has been tabulated as presenting the best evidence available of plant requirements; and where neither of these values is available, depth of water applied in irrigation has been listed as next in value. Where an irrigation requirement value has been listed it usually has been the estimate of the original investigator who is presumed to have had more adequate data on which to base an analysis than has been available to the author of this report. In such cases it is probable that the investigator's estimate is as close a value as may be ascertained and it may be accepted with a reasonable degree of assurance.

The availability of a supply of rainfall stored in the soil within the root zone at the beginning of the growing season is an item in the determination of the irrigation requirement. As long as roots draw on an adequate moisture supply in storage the first irrigation may be delayed, usually until May, and the irrigation season shortened. In California the rainy season occurs during winter months and, if the season is a normal one, the first few feet of soil will be filled with moisture until it is depleted by root action. The quantity of moisture extracted by the plant prior to the irrigation season, when deducted from the seasonal consumptive use, provides a closer approach to the irrigation requirement, but the net seasonal irrigation requirement may not be determined accurately until losses in transmission through farm laterals, by percolation beyond the depth of root activity and by waste, are known. Upon these latter values are based the irrigation efficiency percentage.

Federal and State investigations of the use of water for irrigation of crops in California have been conducted principally in the southern coastal areas, San Joaquin Valley, the delta area, and Sacramento

Valley. In these areas, including also portions of the Mojave Desert in Antelope, Coachella and Imperial Valleys, are found the greatest percentage of irrigated lands in the State. Elsewhere, and particularly along the coast northerly from Los Angeles and in the extreme northeasterly portion including Lassen and Modoc Counties, there is a definite lack of information on irrigation of crops.

In certain districts climate or soil appears to be best suited for production of specific crops although from year to year there may be a shift of crop from one valley to another. Thus, for a time, cotton was one of the principal crops of the Imperial Valley. Later a decline in the production of cotton in Imperial Valley was accompanied by a large increase of its growth in southern San Joaquin Valley. Large acreages of southern California have climate and soil suitable for growing citrus and other subtropical fruits which cannot be grown elsewhere except in a few limited areas not affected by freezing. Alfalfa is one of the principal crops and is grown generally throughout the State. Rice is a product of Imperial, San Joaquin and Sacramento Valleys where it is grown on impermeable soils. Grain is a winter crop often grown on summer fallow rotation without irrigation but in years of rainfall deficiency better yields may be obtained by one or two irrigations.

The irrigation requirements of crops are closely associated with the length of time between planting and maturity and the time of year in which they are produced, although there are other factors of importance. For most crops the principal growing period in which irrigation in California is required is from April through October, although transpiration loss and consumptive use are active for longer periods. Grain, being a winter crop, receives most of its moisture from winter rains. Beans are generally a short season crop, and in coastal areas where climate is cool and moist, may be grown without irrigation although yields may be improved by use of additional water. In the interior valleys beans definitely require irrigation. Alfalfa has a long growing season. Because it grows rapidly following each of its several cuttings, it has a high irrigation requirement that does not differ greatly in the interior valleys. In the southern part of the State the coastal influence is a considerable factor in reducing the water requirements of crops, whereas in the interior valleys the warmer summers increase the requirements. In reports of experimental studies the absence of recorded yields is detrimental to the estimation of the irrigation requirements.

SOUTH PACIFIC BASIN

Citrus, avocados and walnuts are the principal crops in this area for which experimental studies have been conducted to determine the best use of water by irrigation. In northern San Diego County irrigation is characterized by a limited water supply often not exceeding 12 inches during the irrigation season, April to October. In the lower Santa Ana River Valley in Orange County the supply is larger. An irrigation requirement of 18 inches appears to be applicable to both areas. For young citrus trees 12 to 14 years old an irrigation requirement of 12 acre-inches per acre appears to be satisfactory. Mature walnuts require 18 inches seasonally during the summer period. These areas are in the coastal region, where sandy loam soils predominate. A summary of irrigation data applicable to the area appears in Table 68.

TABLE 68

SUMMARY OF IRRIGATION DATA APPLICABLE TO THE SOUTH PACIFIC BASIN, CALIFORNIA

Location	Climatic zone	Crop	Soil	Use of water—depth: Water applied	Use of water—depth: Consumptive use	Use of water—depth: Transpiration use	Period (months inclusive)	Irrigation requirement—depth	Reference: Table No.	Reference: Literature cited
				Inches	*Inches*	*Inches*		*Inches*		*Ref. No.*
Escondido	Intermediate	Citrus	Sandy loam	19.60		13.4	April 1-Oct. 15	18.0	6	11
Fallbrook	Intermediate	Citrus	Sandy loam	11.78		9.2	April 1-Oct. 15	18.0	6	11
Vista	Coastal	Citrus	Sandy loam	11.49		6.3	April 1-Oct. 15	15.0	6	11
Orange County	Coastal	[1]Citrus	Sandy loam			15.5	April -Oct.	18.5	18	10
Orange County	Coastal	[2]Citrus	Sandy loam			10.7	April -Oct.	12.0	18	10
Riverside and San Bernardino counties	Interior	Citrus		26.7		21.3	April -Oct.	[7]24-26	14	44
	Interior	Citrus		29.8		21.4	April -Oct.	[7]24-26	15	44
	Interior	Citrus		40.5		19.2	April -Oct.	[7]25-26	17	44
	Interior	Citrus		46.3		18.8	April -Oct.	[7]24-26	17	44
Orange County	Coastal	Citrus	Sandy loam			[3]21.6	Jan. -Dec.	[7]18-20	19	44
Azusa	Intermediate	Citrus	Fine sandy loam			16.7	April -Oct.	21	21	13
Azusa	Intermediate	Citrus	Fine sandy loam			6.8	Nov. -March	0	21	13
San Fernando Valley	Interior	Citrus	Loam			[4]25.8	April -Oct.	[4,7]30-36	22	15
	Interior	Citrus with cover crop	Loam			9.2	Oct. -April	0	22	15
	Interior	Citrus	Loam			[5]17.1	April -Oct.	[5,7]20-22	22	15
	Interior	Citrus	Loam			6.2	Nov. -March	0	22	15
Hemet	Interior	Citrus	Sandy loam	33.2			April -Oct.		29	72
Moreno	Interior	Citrus	Sandy loam	30.6			April -Oct.		32	72
Vista	Coastal	Avocados	Sandy loam			[6]9.1	April 1-Oct. 15	18	6	11
Vista	Coastal	Avocados	Adobe	16.4			April -Oct.	18	8	63
Vista	Coastal	Avocados	Sandy loam	18.5			April -Oct.	18	9	63
Orange County	Coastal	Walnuts	Sandy loam			25.0	April -Oct.	18	13	10
Orange County	Coastal	Walnuts	Sandy loam	19.3			April -Oct.	18	20	65
Hemet	Interior	Walnuts	Sandy loam	31.7			April -Oct.		30	72
Ontario	Intermediate	Peaches	Sand		29.5	27.3	April -Oct.	[7]31		13
Ontario	Intermediate	Peaches	Sand		4.3		Nov. -March			13
Beaumont	Intermediate	Deciduous fruits	Sandy loam	8.9			April -Oct.	[7]18	27	72
Beaumont	Intermediate	Deciduous fruits	Sandy loam	11.1			April -Oct.	[7]18	27	72
Beaumont	Intermediate	Decisuous fruits	Sandy loam	18.3			April -Oct.	[7]18	27	72
Hemet	Intermediate	Apricots	Sandy loam	30.4				[7]30	31	72
San Fernando Valley	Interior	Alfalfa	Silt loam		37.4		April -Oct.			15
San Fernando Valley	Interior	Alfalfa	Silt loam		10.1		Nov. -March			
Los Angeles County	Coastal	Tomatoes		23.7			April -Nov.		25	30
Escondido-Vista and Fallbrook	Intermediate	Cover crop in citrus orchard	Sandy loam			10.4	Nov. -March	0	7	11

[1] Mature citrus trees.
[2] Young citrus trees—12 to 14 years old.
[3] Annual transpiration loss included 16.4 inches from April to November, plus 5.2 inches, without cover crop, during balance of the year.
[4] Grove with permanent cover crop accounting for high transpiration use.
[5] Grove clean cultivated.
[6] Deficiency in irrigation supply.
[7] Estimated requirements based upon the author's conclusions.

Less definite information exists regarding the requirements of citrus in the upper Santa Ana River Valley in Riverside and San Bernardino Counties, but the interior climate is warmer, humidity is less than along the coast, and the water use is increased. Without more definite information it seems safe to assume an irrigation requirement of 24 to 26 acre-inches per acre for mature citrus trees grown in this area under reasonably good methods of irrigation practice where water is delivered through pipe systems and efforts are made to avoid waste.

Transpiration use of water by peaches grown on sand near Ontario amounted to 27.3 acre-inches per acre during the summer irrigation season and an additional 6.5 acre-inches during the winter months October to April. This land was clean cultivated so that the winter loss was principally because of evaporation from soil after rains. An irrigation requirement of 31 acre-inches per acre has been estimated. Irrigation water applied to deciduous fruits in the Beaumont area at elevations of 2,500 to 3,000 feet depended entirely upon the quantity of water available and in some years the supply was deficient. Trees were in better shape with applications of 18 inches than when nine inches was applied. It may be assumed that 18 inches was the lowest irrigation requirement possible for adequate growth of the trees and satisfactory yields of fruit. In the Hemet area where the average elevation is about 1,000 feet lower than at Beaumont and the water supply is more plentiful, 30 acre-inches per acre was applied to apricots. This appears to be normal practice in the Hemet area.

Consumptive use by alfalfa grown in San Fernando Valley amounted to 37.4 acre-inches per acre between April and October.

Few data exist on the use of water by cover crops grown in citrus groves, but two cases may be cited from soil moisture records. In San Fernando Valley the transpiration use by trees and cover crop from November to March, inclusive, was 9.2 acre-inches per acre and in northern San Diego County the average for five groves was 10.4 inches. This loss does not include soil evaporation which depends upon the amount and distribution of rainfall during the winter months and in Southern California has been determined to be approximately one-half acre-inch per acre (13) after each rain storm.

In general the least irrigation requirement for mature citrus, walnuts and avocados as based upon soil moisture studies in Southern California appears to be about 18 acre-inches per acre between April and October, inclusive, and the most from 24 to 26 acre-inches. Moisture received from rainfall, and irrigation water applied during early spring or late fall, will bring the total water requirement as distinguished from the irrigation requirement to approximately 30 acre-inches per acre annually for the best production.

GREAT BASIN DESERT AREA

Table 69 shows a summary of some irrigation data applicable to the desert area of Southern California. The irrigation requirement of alfalfa in the Antelope Valley is estimated as 52 acre-inches per acre from April to October, inclusive. This estimate is based upon a comparison with consumptive use values for alfalfa grown in San Fernando Valley. From records of the Imperial Irrigation District it is shown that the average depth of water delivered to 7,600 acres of alfalfa has

TABLE 69

SUMMARY OF IRRIGATION DATA APPLICABLE TO THE GREAT BASIN DESERT AREA, CALIFORNIA

Location	Crop	Soil	Use of water—depth			Period (months inclusive)	Yield		Irrigation requirement—depth	Reference	
			Water applied	Consumptive use	Transpiration use		Per acre	Unit		Table No.	Literature cited
			Inches	*Inches*	*Inches*				*Inches*		*Ref. No.*
Antelope Valley	Alfalfa	Loamy sand to sand	72.6				6.2	Tons	[1]52	41	24
Antelope Valley	Alfalfa	Loamy sand to sand	82.0			Mar.-Dec.			[1]52	42	14
Imperial Valley	Alfalfa	Fine sand	54.0			Jan.-Dec.	4.8	Tons		36	69
Coachella Valley	Date palms	Very fine sandy loam	90.7		72.4	Jan.-Dec.			90	34	43
Coachella Valley	Grapes	Fine sand	50.5		41.0	April-Oct.			36-40	35	43
Imperial Valley	Flax		25.3			Nov.-May				37	
Imperial Valley	Flax		25.1			Nov.-May	25.8	Bushels		38	54
Antelope Valley	Pears		17.2			Mar.-Oct.			[1]24-30	40	14

[1] Estimated requirements based on author's conclusions.

been 48 acre-inches per acre, but there is a possibility here that some additional water may have been received from existing high ground water.

Date palms are heavy users of water and it has been shown by experiment (43) that the requirement for the trees is as much as 72 acre-inches per acre for a 12-month year in which 90.7 inches is applied. Coachella Valley is the principal date producing area in the United States.

Flax, grown in Imperial Valley, is a winter crop that is harvested in the spring or early summer and its irrigation requirement is less than that of crops growing during the warmer periods. The average depths of water applied in irrigation of flax grown in Imperial Valley is 25 acre-inches per acre.

Pear trees in Antelope Valley, during years of rainfall deficiency, receive less water for irrigation than is to the best interest of the crop but in years of normal rainfall the water supply appears to be sufficient. It is estimated that 24 to 30 acre-inches per acre is a satisfactory irrigation requirement.

SAN JOAQUIN VALLEY

Lack of experimental studies prevents adequate summarization of the irrigation requirements of many of the crops grown in San Joaquin Valley. Cotton is an exception, as satisfactory information on its requirements is available. Studies by the California Experiment Station indicate an irrigation requirement of 30 to 36 acre-inches per acre on sandy soil at the U. S. Cotton Field Station at Shafter and 34 inches on adobe soil on the west side of the valley, farther north. A summary of irrigation data applicable to the San Joaquin Valley comprises Table 70.

The best yields of alfalfa grown at Delhi were obtained with irrigations amounting to 42 acre-inches per acre, but six inches less water resulted in a decrease of one-half ton per acre. It is estimated that the best irrigation requirement lies between 36 and 42 acre-inches per acre applied during the months April to October. More irrigation results in less yield.

Irrigated pastures are of increasing importance because of their expanding acreage and their large use of water for irrigation. No figures are available for an irrigation requirement but the average depth of water applied to 22 farms in Tulare County amounted to 76 acre-inches per acre. Soils were shallow and the number of irrigations were high.

SACRAMENTO-SAN JOAQUIN DELTA

Consumptive use of water data for the delta region are based mostly on tank and field experiments by the Division of Irrigation, in cooperation with the State Division of Water Resources, on both peat and sedimentary soils. These data have been adopted by the State Engineer for estimating total quantities of water required for irrigation of large areas in the vicinity of the Sacramento and San Joaquin Rivers. On account of high ground water in the delta and its upward recharge it is not possible to estimate the irrigation requirements within a reasonable degree of accuracy, and no attempt is made to do so for this area. Consumptive use varies with the crop and the length of the irrigating season. Alfalfa on sedimentary land in areas where roots do not reach to a water table would require irrigation amounting to 30 to 36 inches in depth.

TABLE 70

SUMMARY OF IRRIGATION DATA APPLICABLE TO THE SAN JOAQUIN VALLEY, CALIFORNIA

Location	Crop	Soil	Use of water—depth			Period (months inclusive)	Yield		Irrigation requirement—depth	Reference	
			Water applied	Consumptive use	Transpiration use		Per acre	Unit		Table No.	Literature cited
			Inches	*Inches*	*Inches*				*Inches*		*Ref. No.*
Shafter	Cotton	Sandy loam	32.6		29.5	April-Oct.	1,034	[1]Lbs.	30-36	44	12
Firebaugh	Cotton	Adobe	20.8	25.5		May-Oct.	1,560	[1]Lbs.	34	46	4
Firebaugh	Cotton	Adobe	19.3	19.3		May-Oct.	1,400	[1]Lbs.	34	46	4
Delhi	Alfalfa	Fine sand	30.0			April-Oct.	7.2	Tons	[2]36-42	48	9
Delhi	Alfalfa	Fine sand	36.0			April-Oct.	8.2	Tons	[2]36-42	48	9
Delhi	Alfalfa	Fine sand	42.0			April-Oct.	8.7	Tons	[2]36-42	48	9
Delhi	Alfalfa	Fine sand	48.0			April-Oct.	8.4	Tons	[2]36-42	48	9
Delhi	Alfalfa	Fine sand	36.0			April-Oct.	7.2	Tons	[2]36-42	48	9
Kern County	Grapes		39.0				5.35	[3]Tons		49	18
Delhi	Peaches	Fine sand	24.5			April-Oct.	395	Lbs./tree		50	33
Tulare County	Pasture	Loams and sandy loams	76.0			April-Oct.				51	71

[1] Yield of seed cotton.
[2] Estimated requirements based on author's conclusions.
[3] Yield measured by green weight.

TABLE 71

SUMMARY OF IRRIGATION DATA APPLICABLE TO THE SACRAMENTO-SAN JOAQUIN DELTA, CALIFORNIA

Location	Crop	Use of water—depth			Period (months inclusive)	Reference	
		Water applied	Consumptive use	Transpiration use		Table No.	Literature cited
		Inches	*Inches*	*Inches*			*Ref. No.*
Delta area	Alfalfa		38.4		Mar. -Oct.	53	41
East Contra Costa Irrigation District	Alfalfa	20.0					27
Mokelumne Area	Alfalfa	39.2				54	27
Delta area	Asparagus		32.3		Jan. -Dec.	53	41
Delta area	Beans		16.0		June -Sept.	53	41
Delta area	Sugar beets		27.6		May -Sept.	53	41
Delta area	Celery		14.4		June -Dec.	53	41
Delta area	Corn		29.2		June -Oct.	53	41
Delta area	Deciduous fruit		27.2		April -Oct.	53	41
East Contra Costa Irrigation District	Deciduous fruit		27.4		April -Oct.		27
Mokelumne area	Deciduous fruit	20.9			April -Oct.	54	27
Delta area	Grain and hay		20.4		Mar. -June	53	41
East Contra Costa Irrigation District	Grain	9.6					27
East Contra Costa Irrigation District	Flax	13.7					27
Delta area	Onions		19.2		Mar. -Aug.	53	41
Delta area	Pasture		25.9		Jan. -Dec.	53	41
Delta area	Potatoes		18.0		May -Sept.	53	41
Delta area	Seed		27.6		April -Oct.	53	41
Delta area	Truck		28.8		Mar. -Nov.	53	41
East Contra Costa Irrigation District	Vineyards	10.8					27
Mokelumne area	Vineyards	21.9				54	27
East Contra Costa Irrigation District	Vegetables	21.4					27

but these conditions are not usually found on the low-lying delta lands. In the Contra Costa Irrigation District where irrigation requirements are noticeably less than elsewhere, possibly because of poor drainage conditions, 20 inches of water is applied for irrigation of alfalfa.

Consumptive use by crops varies from 14.4 acre-inches per acre for celery to 32.3 acre-inches for asparagus which has a longer growing season. Consumptive use for other crops lies between these values as is shown in a summary of irrigation data applicable to the delta area listed in Table 71. The values presented are for the growing season of each separate crop, but consumptive use occurs from the same area before and after the crop is planted and harvested because of the use of water by considerable weed growth that flourishes by reason of moisture supplied by high ground water levels.

SACRAMENTO VALLEY

Irrigation investigations in the Sacramento Valley at the University Farm and elsewhere, under the supervision of the California Agricultural Experiment Station, have included such crops as watermelons, alfalfa, grains, and rice, and were made for the purpose of determining the duty of water and the methods of applying it to obtain maximum returns. Irrigation requirements were obtained only through correlation with maximum yields. On this basis seven to eight inches of irrigation water applied to watermelons produced 69 pounds of fruit per plant, a greater yield than was obtained from other irrigation treatments.

Likewise, maximum yields of alfalfa were obtained with 30 to 36 acre-inches of irrigation water for several soil types in different parts of the Sacramento Valley. These and other values are listed in Table 72. For small grains, as barley, wheat and oats, grown on sandy loam soil, the irrigation requirement is dependent upon the amount and distribution of winter rainfall. In years of normal rainfall, about 17 inches, normally distributed, grains may be grown without irrigation. In years of deficient rainfall normal yields may be obtained by preirrigation and in years of heavy rainfall irrigation may result in a decrease in yield. In drouth years two irrigations of four to six acre-inches per acre should produce satisfactory yields if properly distributed. On the basis of these investigations it may be assumed that the irrigation requirement of grains in the Sacramento Valley varies from zero to 12 acre-inches per acre.

Corn grown for ensilage is a summer crop and needs irrigation regardless of the amount of winter rains, but investigations show that better yield are obtained in years of abundant rainfall. In two studies each applying 10.5 acre-inches of water per acre, the yield was 7.4 tons in a year of deficient rain and 10.4 tons in a year of above normal rainfall. It appears safe to assume that the irrigation requirement is in the neighborhood of 12 acre-inches per acre for the Sacramento Valley.

Rice requires a large amount of water for its production as the fields are flooded during a part of the growing season. Losses occur by evaporation and seepage. Considerably more water is applied to the field than is actually consumed by the crop, as in addition to the actual crop use water is drained from the flooded field prior to harvest. In general, it appears that the best yields are obtained by a net irrigation requirement of about 60 acre-inches per acre.

TABLE 72

SUMMARY OF IRRIGATION DATA APPLICABLE TO THE SACRAMENTO VALLEY, CALIFORNIA

Location	Crop	Soil	Use of water—depth			Yield		Irrigation requirement—depth	Reference	
			Water applied	Consumptive use	Transpiration use	Per acre	Unit		Table No.	Literature cited
			Inches	*Inches*	*Inches*			*Inches*		*Ref. No.*
University Farm	Watermelons	Sandy loam	7.0			69	Lbs./plant	7-8	56	22, 38
University Farm	Alfalfa	Sandy loam	36.0			9.27	Tons	30-36	56	9
University Farm	Alfalfa	Sandy loam	31.9	29.1				30-36	57	9
Gridley	Alfalfa	Silt loam	39.7			6.19	Tons	30-36	58	1, 2, 8
Willows	Alfalfa	Silty clay loam	22.0			4.82	Tons	30-36	58	1, 2, 8
Woodland	Alfalfa	Silt loam	28.0			6.45	Tons	30-36	58	1, 2, 8
Dixon	Alfalfa	Clay loam	35.3			6.76	Tons	30-36	58	1, 2, 8
University Farm	Barley	Fine sandy loam	[1]12.2			44.1	Bushels	[3], [5]0-12	59	9
University Farm	Barley	Fine sandy loam	[1]10.8			46.0	Bushels	[3], [5]0-12	59	9
University Farm	Barley	Fine sandy loam	[2]7.0			37.7	Bushels	[3], [5]0-12	59	9
University Farm	Barley	Fine sandy loam	[2].0			34.8	Bushels	[3], [5]0-12	59	9
University Farm	Wheat	Sandy loam	[1]17.6			32.2	Bushels	[3], [5]0-12	60	9
University Farm	Wheat	Sandy loam	[1]12.0			26.8	Bushels	[3], [5]0-12	60	9
University Farm	Wheat	Sandy loam	[1]13.0			31.2	Bushels	[3], [5]0-12	60	9
University Farm	Wheat	Sandy loam	[2].0			20.4	Bushels	[3], [5]0-12	60	9
University Farm	Oats	Fine sandy loam	21.8			64.2	Bushels	[3], [5]0-12	61	9
University Farm	Oats	Fine sandy loam	15.8			47.1	Bushels	[3], [5]0-12	61	9
University Farm	Corn ensilage	Fine sandy loam	[1]10.5			7.4	Tons	12	62	9
University Farm	Corn ensilage	Fine sandy loam	[2]10.6			10.4	Tons	12	62	9
University Farm	Dwarf milo maize	Fine sandy loam	8.6			28.93	Lbs.	12	63	9
Sacramento Valley	Rice	Clay adobe	61.6			36	[4]Sacks	60	64	3, 46, 23
Sacramento Valley	Rice	Clay	64.7			32	[4]Sacks	60	64	3, 46, 23
Sacramento Valley	Rice	Loam	112.6			43	[4]Sacks	60	64	3, 46, 23
Biggs	Rice	Clay	54.4			46	[4]Sacks	60		3

[1] In year of deficient rainfall.
[2] In year of abundant rainfall.
[3] The irrigation requirements of winter grown grains depends on the winter rains and varies inversely with the rainfall.
[4] Sacks of rice average 100 pounds in weight.
[5] Estimated requirements based upon the author's conclusions.

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DIVISION OF WATER RESOURCES

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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. The Water Project Authority was created by the Central Valley Project Act of 1933.

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Bulletin No. 5—Flow in California Streams, 1923.
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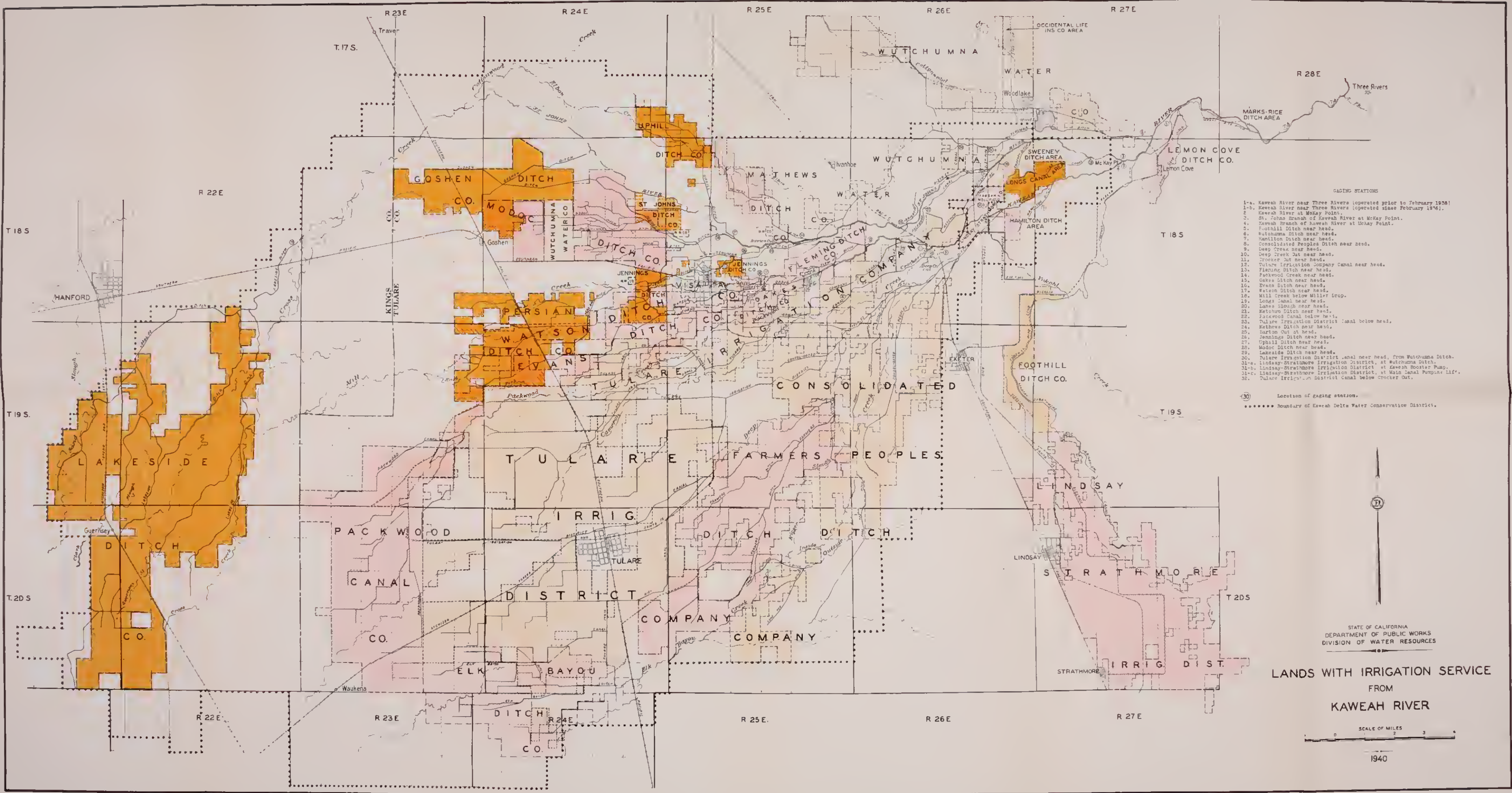

GAGING STATIONS
1-a. Kaweah River near Three Rivers (operated prior to February 1936)
1-b. Kaweah River near Three Rivers (operated since February 1936).
2 Kaweah River at McKay Point.
3. St. Johns Branch of Kaweah River at McKay Point.
4. Kaweah Branch of Kaweah River at McKay Point.
5. Foothill Ditch near head.
6. Wutchumna Ditch near head.
7. Hamilton Ditch near head.
8. Consolidated Peoples Ditch near head.
9. Deep Creek near head.
10. Deep Creek Cut near head.
11. Crocker Cut near head.
12. Tulare Irrigation Company Canal near head.
13. Fleming Ditch near head.
14. Packwood Creek near head.
15. Oakes Ditch near head.
16. Evans Ditch near head.
17. Watson Ditch near head.
18. Mill Creek below Miller Drop.
19. Longs Canal near head.
20. Lanes Slough near head.
21. Ketchum Ditch near head.
22. Packwood Canal below head.
23. Tulare Irrigation District Canal below head.
24. Mathews Ditch near head.
25. Barton Cut at head.
26. Jennings Ditch near head.
27. Uphill Ditch near head.
28. Modoc Ditch near head.
29. Lakeside Ditch near head.
30. Tulare Irrigation District Canal near head, from Wutchumna Ditch.
31-a. Lindsay-Strathmore Irrigation District, at Wutchumna Ditch.
31-b. Lindsay-Strathmore Irrigation District at Kaweah Booster Pump.
31-c. Lindsay-Strathmore Irrigation District, at Main Canal Pumping Lift.
32. Tulare Irrigation District Canal below Crocker Cut.
(30) Location of gaging station.
••••••• Boundary of Kaweah Delta Water Conservation District.
R 22 E
R 23 E
R 24 E
R 25 E
R 26 E
R 27 E
R 28 E
T. 17 S.
T 18 S
T 19 S.
T. 20 S
Traver
Three Rivers
MARKS-RICE DITCH AREA
OCCIDENTAL LIFE INS CO AREA
WUTCHUMNA WATER
Woodlake
CUO
LEMON COVE DITCH CO.
Lemon Cove
SWEENEY DITCH AREA
LONGS CANAL AREA
HAMILTON DITCH AREA
Mc Kay Pt.
UPHILL DITCH CO.
GOSHEN DITCH CO.
MODOC
WUTCHUMNA WATER CO.
ST JOHNS DITCH CO.
Goshen
KINGS
TULARE
HANFORD
Ivanhoe
MATHEWS DITCH CO.
WUTCHUMNA WATER
JENNINGS DITCH CO.
VISALIA
FLEMING DITCH CO.
IRRIGATION COMPANY
PERSIAN DITCH CO.
WATSON DITCH CO.
EVANS
TULARE
CONSOLIDATED
EXETER
FOOTHILL DITCH CO.
LAKESIDE DITCH CO.
Guernsey
TULARE IRRIG DISTRICT
FARMERS DITCH COMPANY
PEOPLES DITCH COMPANY
LINDSAY
Lindsay
STRATHMORE IRRIG DIST.
Strathmore
PACKWOOD CANAL CO.
TULARE
ELK BAYOU DITCH CO.
Waukena
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF WATER RESOURCES
LANDS WITH IRRIGATION SERVICE FROM KAWEAH RIVER
SCALE OF MILES
1940