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DETERMINING WATER REQUIREMENTS *in* IRRIGATED AREAS *from* CLIMATOLOGICAL *and* IRRIGATION DATA

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FOREWORD

Modern irrigation has been practiced in some areas of the West for more than 100 years. During this period the science has advanced remarkably, particularly with respect to structures used in storing, conveying and controlling irrigation waters. Unfortunately, improvement of methods and practices of applying water to the land has not kept pace with the development of irrigation structures. This is especially true in many of the older irrigated sections where farmers do not know how much water is required by the plants to produce a crop, nor how much water is delivered to their farms.

By using information available on water requirements, such as that set forth in this and similar reports, technicians can readily estimate how much water a farmer needs for his crops. Water-measuring devices requiring the application of simple engineering principles can be installed to determine the quantity of water actually delivered to the farm. This knowledge will make possible an evaluation of the losses occurring between the farm headgate and the plant roots. Such losses -- frequently more than 50 percent -- can be materially reduced by improved water conservation practices.

Water requirements of crops -- seasonal, monthly, and even daily -- affect the operation of an irrigation system, the method of application, the cropping pattern, and the farm labor requirement.

The irrigation requirements of an area should be fairly well known before expensive new irrigation projects are developed. The use of available water supplies must be adapted to fit the natural requirements of the land to be irrigated and the crops to be grown.

Data on total water requirement, irrigation requirement, and consumptive use are not merely desirable; they are necessary in the efficient practice of modern irrigation. The method of determining irrigation requirements and consumptive use of water, suggested herein, will help to meet this need.

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DETERMINING WATER REQUIREMENTS IN IRRIGATED AREAS

FROM CLIMATOLOGICAL AND IRRIGATION DATA 1/

By

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INTRODUCTION

In western states it is essential that the water requirements and consumptive use of water be known in irrigation planning for soil conservation and irrigation districts and for individual farms. Conservation of water supplies, as well as of soils is of first importance in the agricultural economy of the West. In basin-wide investigations of water utilization and in water conservation surveys, valley consumptive water requirement is one of the most important factors to be considered. Engineers and other technicians have expressed an urgent need for information on irrigation requirements in connection with farm planning programs for areas where few data are available

A knowledge of consumptive use is necessary in planning farm irrigation system layouts and improving irrigation practices. Irrigation and consumptive water requirement data are used more and more widely by water superintendents as well as State, Federal and other agencies responsible for the planning, construction, operation and maintenance of multiple-purpose projects and by those responsible for guiding and assisting farmers in the solution of their irrigation problems. Some of the larger Federal agencies requiring information on consumptive use and irrigation requirements are the Soil Conservation Service, Bureau of Reclamation, Corps of Engineers, Bureau of Indian Affairs and Federal Power Commission.

In the past, various methods have been used in estimating the irrigation water requirements of new and existing irrigation projects in the West. In the early days of irrigation, little or no effort was made to determine the amount of water needed to irrigate the land It was then necessary to do no more than dig a ditch of such capacity and stability as would carry the desired amount of water to the small farm or group of farms located near the stream The ditch was dug by hand or with light horse-drawn equipment If it was too small, its enlargement was a simple operation

In later years, however, new sources of irrigation water supplies have become limited while the area of irrigable land is still extensive. Larger, longer and more costly diversion, storage, and conveyance structures have been needed. As the cost of water has increased, more careful estimates of water requirements on the projects have

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1/ Prepared under the direction of George D. Clyde, Chief, Division of Irrigation and Water Conservation, Soil Conservation Service, Research, U. S Department of Agriculture.

been in order. Only the land that may be served adequately and economically can now be brought under irrigation. For some of the more recent large projects the construction costs chargeable against irrigation are well above $200 per acre. With costs so high, large errors in estimating the acreage of land suitable for continued irrigation and the amount of water required for it must be avoided. If insufficient water is allowed for maximum production, the project lands will not be able to pay the charges; while if the water supply exceeds the needs of the land, its cost will likewise be exorbitant.

For many years certain types of climatological data, such as temperature and precipitation, have been kept by the United States Weather Bureau. Some progress has been made in correlating climatic data with plant behavior. As pointed out by Hambidge (10), 2/ "A plant will thrive in one region with a certain amount of rainfall and fail miserably in another with the same amount. Rainfall does not tell the story. Further investigation shows why. It is not the amount of rainfall that counts, but the amount of water the plants can get, and this depends on a great many things besides the amount of rainfall. It depends on the nature of the soil, the amount of wind, the sunshine and cloudiness, the humidity of the air, the temperature -- above all, the rate of evaporation and transpiration, which are affected by these other factors."

Thus there is a need to correlate evaporation from water and land surfaces, and transpiration from plants, with the climatological factors and soil conditions. If long-time measurements of all the factors affecting consumptive use were available, an empirical formula taking into account the effect of each factor could probably be developed and applied with accuracy sufficient for average conditions in any area. However, even in the more intensively settled areas, only part of the factors have been measured. In new projects that are still sparsely settled, it is unusual that any factors have been measured except precipitation and temperature, and in many instances records even of these influences are not available.

The purpose of this publication is to outline a method, developed by the authors, of estimating water requirements for irrigated lands where few or no data, except climatological, are available. Actual measurements of consumptive use under each of the various physical and climatic conditions of any large area are time-consuming and expensive. Some rapid method is needed for applying the results of careful studies made in a limited number of areas to other areas and conditions. The method suggested by this report is believed to meet this need.

SUMMARY

Many factors influence the amount of water consumed by plants. The more important natural influences are climate, water supply, soil and topography. The climatic factors that particularly affect consumptive use are precipitation, temperature, humidity, wind movement and growing season. Irrigation practices also influence the amount of water consumed.

2/ Figures in parentheses refer to Literature Cited.

From the results of experimental studies throughout the western United States, an empirical formula has been developed showing the relationship between temperature, length of growing season, monthly percent of annual daytime hours and consumptive use of water. By using this relationship, consumptive use and irrigation water requirements of crops can be quickly estimated for any area where the necessary climatological and irrigation data are available

Briefly, the procedure is to correlate existing consumptive-use data with monthly temperature, monthly percentages of yearly daytime hours precipitation, and growing or irrigation season Coefficients have been developed from existing measured consumptive-use and temperature data and monthly percents of yearly daytime hours Thus, if only monthly temperature records are available and latitude is known the consumptive use can be computed from the formula $U = KF$, where U = consumptive use of water in inches for any period, K = empirical consumptive-use coefficient, and F = sum of the monthly consumptive-use factors for the period (sum of the products of mean monthly temperature and monthly percent of annual daytime hours)

The net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the effective precipitation from the consumptive-use requirement for the irrigation season This net requirement of irrigation water divided by the irrigation efficiency indicates the seasonal irrigation requirement of the crop Further refinements can be made as desired or needed by taking into account irrigation practices, soil characteristics topography, and water supplies. The irrigation efficiency may be determined from field studies or estimated by making allowances for certain wastes such as ditch seepage, deep percolation, and surface runoff. The procedure may include the development of a water-use curve for each crop, upon which farm irrigation schedules may be drawn or the irrigation needs of a proposed project estimated

DEFINITION OF TERMS

Some of the terms used in this report are defined as follows:

Irrigation requirement: The quantity of water, exclusive of precipitation, that is required for crop production It includes surface evaporation and other economically unavoidable wastes It is usually expressed as depth in inches or feet for given time

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, 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 or inches

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

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; 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. This moisture percentage usually is reached within two to four days after an ordinary irrigation, the time interval depending on the soil type.

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

PREVIOUS INVESTIGATIONS

The effect of sunshine and heat in stimulating transpiration was studied as early as 1691. Measurements of transpiration of various kinds of plants indicate a close correlation between transpiration and evaporation from free-water surfaces, air temperature, solar radiation and wet-bulb depression readings.

Many formulas have been developed in the past for determining evaporation from meteorological data. Formulas for estimating consumptive use are not so numerous. A few methods for determining consumptive use, based on climatic factors, have been found to give reasonably accurate results. For many years irrigation engineers have used temperature data in estimating valley consumptive use in arid and semiarid areas of the West. Hedke, as reported by Blaney *et al* (4), developed the effective-heat method on the Rio Grande. By this method, consumptive use is estimated from a study of the heat units available to the crops of a particular valley. It assumes a linear relation between the amount of water consumed and the quantity of available heat. From studies by the Bureau of Reclamation, conducted intermittently from 1937 to 1940 by Lowry and Johnson (15), a similar method was suggested which has been widely used by the Bureau in making its estimates of valley consumptive use. This method also assumes a direct relationship between temperatures and consumptive use. It assumes a linear relation between consumptive use and accumulated daily maximum temperatures above 32° F. during the growing season. In 1947, G. H. Hargreaves, also of the Bureau of Reclamation, suggested a method of calculating consumptive use for the Central Valley of California. This method was based on local records of evaporation, temperature and humidity. 3/

Division of Irrigation Studies

At various times during the past 46 years, the Division of Irrigation and Water Conservation and its predecessor, in cooperation with state agricultural experiment stations and other agencies, have measured evapo-transpiration of different agricultural crops in many sections of the western United States (4) (9). Usually evaporation,

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3/ Hargreaves, G. H. A Suggested Method of Standardizing Irrigation Requirement Data for Central Valley Crops. U. S. Dept. of the Interior, Bur. of Reclamation, Sacramento, Calif. 35 pp., illus. 1947. (Mimeographed) temperature, humidity, precipitation and wind movement were recorded at the same time. Thus, data are available in many areas for correlating consumptive-use measurements with temperature and other climatological observations

In 1931 the practicability of using the evaporation pan and temperature records as an index for estimating evapo-transpiration losses from moist areas was demonstrated by the Division of Irrigation in southern California (7); similar use of such data was made in 1936 in the Joint Upper Rio Grande Investigation (4) Studies in 1931-44 in northern Idaho indicated a relationship between evaporation, temperature and consumptive use 4/

Measurements of use of water by alfalfa in San Fernando Valley, California in 1939-40 showed a direct relationship between evapo-transpiration, evaporation from a water surface, and temperature. 5/

Studies of use of water by crops, at Scottsbluff, Nebraska, from 1932 to 1936, can be correlated with temperatures and evaporation 6/

Studies conducted by the Division of Irrigation in 1939-41, in connection with the Joint Pecos River Investigation of the National Resources Planning Board indicated that data on evaporation, evapo-transpiration, mean monthly temperature, monthly percent of daytime hours, growing season, monthly precipitation, and efficiency of irrigation could be used to estimate irrigation requirements (5). Later, empirical formulas were developed from the Pecos River studies for estimating unit annual values of evaporation from free-water surfaces and consumptive use by native vegetation having access to a plentiful supply of ground water (6) This method gives consideration to temperature daytime hours, and humidity records, and is applicable to areas where there is ample water to take care of evaporation and transpiration It was also shown how the formulas might be used in estimating consumptive use by irrigated crops having access to an ample water supply In 1945 the authors of this paper simplified the Pecos formulas by eliminating the humidity factor. 7/

4/ Criddle, Wayne D and Marr, James C. Consumptive Use of Water Studies in Idaho U S. Dept of Agr., Soil Conserv. Serv., Div of Irrigation Boise Idaho 46 pp., illus 1945 (Mimeographed)

5/ Blaney, Harry F. and Stockwell, Homer J. Progress Reports on Cooperative Research Studies on Water Utilization, San Fernando Valley, Calif 1940-41. (Unpublished Typewritten)

6/ Bowen, Leslie Uses and Efficiencies of Water by Some Farm Crops under Irrigation in Western Nebraska U. S. Dept. of Agr., Soil Conserv Serv., Div. of Irrigation Scottsbluff, Nebr. 1937. (Typewritten)

7/ Blaney, Harry F and Criddle, Wayne D A Method of Estimating Water Requirements in Irrigated Areas from Climatological Data U. S. Dept. of Agr., Soil Conserv Serv , Div. of Irrigation. 17 pp. Revised 1947 (Mimeographed)

Methods

Various methods have been used to determine the amount of water consumed by agricultural crops and native (or "natural") vegetation. Regardless of the method used, numerous problems are encountered. The source of water used by plant life, whether precipitation alone, irrigation plus rainfall, or ground water plus precipitation, is a factor influencing the selection of a method. Heretofore, the principal approaches used in determining consumptive use have been tank experiments, studies of soil moisture, and observations of ground-water fluctuations; and, for large areas, the inflow-outflow, effective-heat, and integration methods. 8/ One of the more common methods of determining the use of water by individual crops or other plants is to grow them in tanks and measure the quantity of water necessary to maintain the growth satisfactorily. Although tanks as large as 10 feet in diameter have been used, the tanks in most consumptive-use studies are about 2 to 3 feet in diameter and 4 to 6 feet deep. Double tanks have frequently been used by the Division of Irrigation. The inner tank is not watertight but holds the column of soil, usually undisturbed, in place (8). The outer tank, which is 2 or 3 inches wider in diameter and several inches longer, is watertight. The outer or larger tank is set in the ground flush with the land surface. This type of installation is shown in figure 1. Other investigators have used tanks of various sizes.

Another method used in determining the consumptive use of individual crops employs soil-moisture depletion studies. In those areas not affected by high ground water, the change in the moisture content of the soil within the root zone of the crop is measured from soil samples taken periodically. Samples are taken in 1-foot increments to depths of 3 to 10 feet depending upon the crop and root zone. Figure 2 shows a set of soil sampling equipment developed in southern California by the Division of Irrigation (8), consisting of a compressed-air unit, soil tube and soil-tube jack. For shallow depths either a soil tube or auger may be used.

Consumptive Use by Various Crops

Even after a hundred years of modern irrigation in western United States there are many crops for which consumptive-use rates under any condition are still unknown. The more common crops, including alfalfa, cotton, small grains and others, have been studied carefully under varying conditions by a number of investigators. The information in this report about those crops is believed to be fairly accurate. With respect to certain minor crops, many years of study of the behavior of the crops under different site conditions will be necessary before the rates of consumptive use can be definitely determined. Table 15, appendix, gives the consumptive use of water by 17 crops as reported by various investigators throughout the West. A tabulation based on this information is given in table 1. The variation in the total and seasonal use of water as determined by Bowen 9/ is illustrated in figure 3.

8/ Blaney, Harry F. Field Methods of Determining Consumptive Use of Water. U. S. Dept. of Agr., Div. of Irrigation. (Printed in Proceeding of IV National Congress of Cuban Engineers, 1938.) 16 pp. Revised 1942. (Mimeographed)

9/ See footnote 6, page 5.

Figure 1. Evapo-transpiration tanks at Kootenai Experiment Station, Bonners Ferry, Idaho. Alfalfa has been harvested from several tanks.

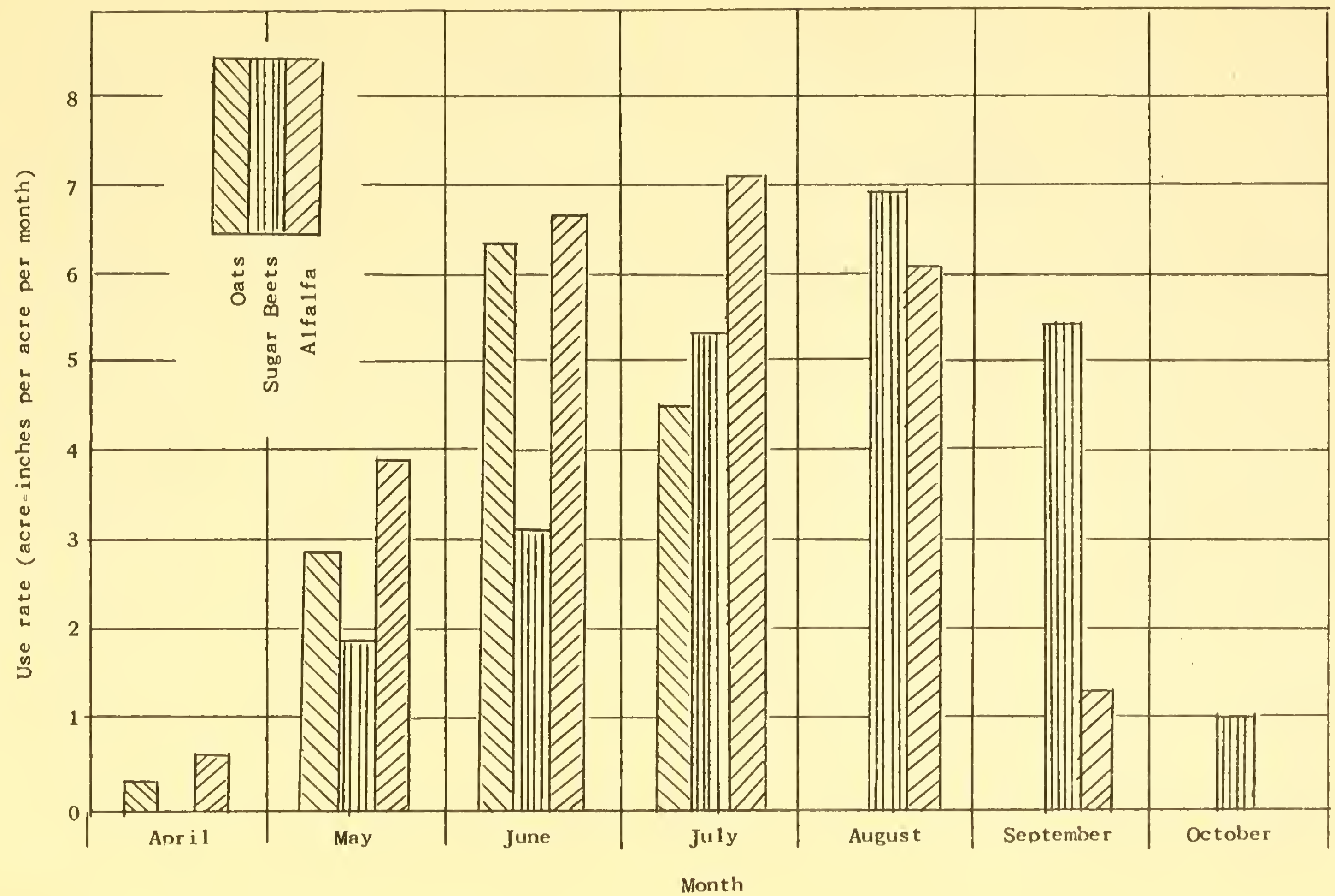
Figure 2.- Soil-sampling equipment, consisting of a soil tube, hand hammer, light air-hammer, soil-tube jack and compressor unit.

Table 1.--Seasonal consumptive use of water for different crops measured by state and federal agencies in the western United States

Crop	Range of consumptive use per season			
	Low		High	
	Depth	Location	Depth	Location
	Inches		Inches	
Alfalfa	21.6	Gooding, Idaho	52.5	Mesa, Ariz.
Beans	12.8	Davis, Calif.	18.0	Davis, Calif.
Corn	19.4	Vernal, Utah	29.3	Bonners Ferry, Idaho
Cotton	23.6	Los Banos, Calif.	31.0	Mesa, Ariz.
Flax	--	--	34.0	Mesa, Ariz.
Grains (small)	12.0	Davis, Calif.	18.0	Prosser, Wash.
Grain (sorghum)	--	--	21.4	Mesa, Ariz.
Orchard				
Oranges	18.1	Azusa, Calif.	32.4	Mesa, Ariz.
Grapefruit	--	--	40.2	Mesa, Ariz.
Deciduous	19.5	Albuquerque, N. Mex.	28.4	Ontario, Calif.
Walnuts	26.3	Tustin, Calif.	27.4	Tustin, Calif.
Pasture	19.0	Redmond, Ore.	25.0	Vernal, Utah
Potatoes	15.0	Logan, Utah	23.0	Prosser, Wash.
Soy Beans	--	--	22.3	Mesa, Ariz.
Sugar Beets	22.8	Spanish Fork, Utah	26.3	Davis, Calif.
Tomatoes	17.0	Mercedes, Tex.	22.8	Davis, Calif.
Truck	21.4	Stockton, Calif.	24.6	Stockton, Calif

Figure 3 Monthly consumptive use of water by oats, sugar beets and alfalfa at Scottsbluff Experiment Station, Scottsbluff, Nebraska

1932 - 1936



INFLUENCE OF VARIOUS FACTORS ON WATER USE

Many factors operate singly or in combination to influence the amounts of water consumed by plants. Their effects are not necessarily constant but may differ with locality and fluctuate from year to year. Some involve the human factor, others are related to the natural influences of the environment.

The more important of the natural influences are climate, water supply, soils and topography. The climatic factors that particularly effect consumptive use are precipitation, temperature, humidity, wind movement and growing season

Precipitation

The amount and rate of precipitation may have a pronounced effect on the amount of water consumptively used during any summer. Under certain conditions, precipitation may be a series of frequent, light showers during the hot summer. Such showers may add little or nothing to the soil moisture for use by the plants through transpiration. The precipitation may be largely lost by evaporation directly from the surface of the plant foliage and the land surface. Some of the precipitation of heavy storms may be lost by surface runoff. Other storms may be of such intensity and amount that a large percentage of their precipitation will enter the soil and become available for plant transpiration. Such a condition may materially reduce the amount of irrigation water needed and the consumptive use.

Temperature

The rate of consumptive use of water by crops in any particular locality is probably affected more by temperature than by any other factor. Abnormally low temperatures may retard plant growth and unusually high temperatures may produce dormancy. Consumptive use may vary widely even in years of equal accumulated temperatures because of deviations from the normal seasonal distribution, since transpiration is influenced not only by temperature but also by the area of leaf surface and the physiologic needs of the plant, both of which are related to stage of maturity.

Humidity

Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity. If the average relative humidity percentage is low during the growing season, a greater use of water by vegetation may be expected

Wind movement

Evaporation of water from land and plant surfaces takes place much more rapidly when there is moving air than under calm air conditions. Hot dry winds and other unusual wind conditions during the growing period will affect the amount of water consumptively used.

Growing season

The growing season, which is tied rather closely to temperature, has a major effect on the seasonal use of water by plants. It is frequently considered to be the period between killing frosts, but for many annual crops it is shorter than the frost-free period, as such crops are usually planted after frosts are past and mature before they recur. For most perennial crops, growth starts as soon as the maximum temperature stays well above the freezing point for an extended period of days, and continues throughout the season in spite of later freezes. Sometimes growth persists even after the first so-called killing frost. In the spring, and to less extent in the fall daily minimum temperatures may fluctuate one or two degrees above and below 32° F for several days before remaining definitely above or below the freezing point. The hardier crops survive these fluctuations and continue to grow unharmed during a few hours of sub-freezing temperature. In fact, many hardy crops, especially grasses may mature even though summer temperatures repeatedly drop below freezing.

Although the growing season may be used as a guide for computing consumptive use, actual data on dates of planting and harvesting of the crops and average annual dates of the first and last irrigation are important in determining the consumptive irrigation requirements of the crops.

Latitude

Although latitude may hardly be called a climatic factor, it does have considerable influence on the rate of consumptive use of water by various plants. Because of the earth's movement and axial inclination, the hours of daylight during the summer are much greater in the northern latitudes than at the equator. This longer day may allow plant transpiration to continue for a longer period each day and to produce an effect similar to that of lengthening the growing season.

Available irrigation water supply

All the above-mentioned climatic factors influence the amount of water that will be consumed in a given area. However, other factors can also cause important differences in the consumptive use. Unless water is available from some source, precipitation, natural ground water, or irrigation, there can be no consumptive use. In the arid and semiarid West where the major source is irrigation, both the quantity and seasonal distribution of the available supply will usually affect consumptive use. Where water is plentiful there is a tendency for farmers to over-irrigate in both frequency and depth of application. If the soil surface is frequently wet and the resulting evaporation is high, the consumptive use will likewise increase. Also, under more optimum soil moisture conditions, particularly with alfalfa, the yields may be higher than average and more water will consequently be used.

It is believed by some investigators that besides the quantity and seasonal distribution of the water supply, the quality of the water also has an appreciable effect on the consumptive use. Whether or not plants require more or less water if the supply is highly saline may be debatable. However, if it is necessary to apply additional water to the land to move the salts down through the soil, more water will probably be lost by evaporation from the soil surface, and such loss will be chargeable against the consumptive requirement of the crop.

Soil fertility

If a soil is made more fertile through the application of manure or by some other means, the yields may be expected to increase with an accompanying increase in water used. However, as indicated by Scofield as the result of tank investigations at the Umatilla Field Station in Oregon, an increase in fertility of the soil causes a decrease in the amount of water consumed per unit of crop yield. 10/

Plant pests and diseases

Where plant pests and diseases seriously affect the natural growth of the plants, it is reasonable to assume that transpiration will correspondingly decrease. It is recognized that some damage to crops is caused every year by pests and diseases. While ordinarily the losses may not vary greatly from year to year, in those years when they are unusually severe, consumptive use may be lowered materially.

IRRIGATION EFFICIENCIES

Although a knowledge of consumptive use is important in the case of a large irrigation project, and especially a river system as a whole, it may not be as important to the individual farm as the efficiency with which the water is distributed and applied, especially on a long shoestring project. Irrigation authorities have estimated that in some areas less than one-fourth of the water diverted from the source actually becomes available for use by the plant. This, for example, means that in order to supply 25 inches depth of water per acre to alfalfa for actual consumptive use, at least 100 acre-inches (8-1/3 acre-feet) would have to be diverted from the river or other source. Of the unused 75 percent, a large part is usually made up of transmission and distribution losses in canals, laterals and farm ditches. Application losses -- evaporation, deep percolation and surface runoff -- account for the remainder. Such losses indicate a need for improvement in the use of available water resources.

Irrigation efficiency is the percentage of irrigation water that is available for consumptive use by crops. When the water delivered is measured at the farm headgate it is called "farm" irrigation efficiency; when measured at the field or plot it may be designated as "field" irrigation efficiency. Research workers have considered efficiency of irrigation (water-application efficiency) as the percentage of water that can be accounted for as the increase of soil moisture in the soil occupied by the principal rooting system of the crop, and they have assumed that the amount of water stored by the irrigator in the soil is available for transpiration or consumptive use. Irrigation efficiency determinations have been made by the Division of Irrigation in cooperation with agricultural experiment stations and other agencies in western States, particularly California (2), New Mexico (5), and Utah (14).

If the farm is small and the farm laterals relatively short; if they are lined; or if the water is delivered to the field by pipelines, farm transmission losses may become negligible and field-irrigation efficiency may be approximately the same as the farm-irrigation efficiency Skill in the handling of the water by the irrigator, proper land preparation, and adequate farm irrigation structures may greatly increase the efficiency, with a corresponding decrease in the total amount of water that must be delivered to the land for crop production.

10/ Scofield, C. S. Water Input and Crop Yield, Experiment No. 6, Umatilla Field Station.. Bur. of Plant Industry, Soils, and Agr. Engin., U. S. Dept. of Agr. 6 pp. 1942. (Typewritten)

Methods of determining irrigation efficiency have been described in other reports (5), (14). Briefly, to determine the field-irrigation efficiency it is essential to know the moisture content of the soil before and after irrigation, as well as the quantity of water delivered to the field or plot. Additional information on irrigation efficiencies is needed for various site conditions throughout the irrigated country.

Effect of soils

Probably the factor having the greatest effect on irrigation efficiency, aside from the irrigator himself, is the soil on the farm and that through which the canals and ditches run. This is particularly true on older projects where farm irrigation systems were not necessarily laid out according to soil characteristics. In general, there is considerable loss of water by deep percolation in the lighter soils. On the heavier soils, much water is frequently lost through surface runoff. Typical irrigation efficiencies for several different soil conditions are shown in table 2.

Table 2.--Typical water-application losses and irrigation efficiencies for different soil conditions

	General soil type		
	Open porous	Medium loam	Heavy clay
	Percent	Percent	Percent
Farm-lateral loss	15	10	5
Surface-runoff loss	15	15	30
Deep percolation loss	35	15	5
Field-irrigation efficiency	50	70	65
Farm-irrigation efficiency	35	60	60

Effect of crops

In general, it is possible to get higher efficiency of irrigation with close-growing crops than with those grown in rows. Also, application efficiencies of irrigation for deep-rooted crops are usually higher than for shallow-rooted crops. In large fields of shallow-rooted crops, a substantial part of the water applied may be lost because the upper end of the field becomes over-soaked and the water sinks below the root zone before the lower end has received enough water.

In a similar manner, the age of the crop likewise affects irrigation efficiency, especially with row crops while the plants are young. The root zone of young plants is extremely shallow, and much water is usually lost through deep percolation or surface runoff before enough water moves horizontally from the furrow to the young plant roots. As the plants develop and the root system grows, this loss can be reduced appreciably.

Effect of methods of irrigation

The method of irrigation has considerable effect on the efficiency of application Under some conditions, the highest application efficiency can be attained by the use of sprinklers. Border irrigation is conducive to relatively high efficiency in the use of the water for situations to which this method is adapted Wild flooding is probably the least efficient of all methods and is usually not justified where the cost of water is high It frequently results in excessive waste of water without a compensating uniformity of crop production, and is likely to create serious drainage problems.

Thus many natural factors enter into obtaining high application efficiency. They should be carefully considered when basic consumptive-use data and irrigation efficiency figures are used to determine total irrigation-water requirements.

High efficiencies essential

Efficient water application not only conserves the productivity of soils but also helps to keep the water under control These are major goals in irrigation agriculture In the interest of the individual irrigator and the public, therefore, high irrigation efficiencies should be the rule Lower efficiencies may be tolerated in particular areas where deeply percolating water will not waterlog productive soil and will soon be recovered as return flow, or in areas where water is applied for leaching purposes to decrease the accumulation of harmful salts in surface soils. Efficient water application on the higher lands delays the time when drainage of adjacent lower lands may be required.

METHOD OF ESTIMATING WATER REQUIREMENTS

In working out farm planning programs for areas for which few or no measurements of water requirements are available, it is usually necessary to estimate consumptive use and irrigation requirements of crops from climatological and irrigation data

The procedure is to correlate existing consumptive use data for different crops with monthly temperature, percent of daytime hours, precipitation, frost-free (growing) period, or irrigation season. The coefficients so developed are used to transpose the consumptive-use data for a given area to other areas for which only climatological data are available The net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the effective precipitation from the consumptive water requirement during the growing or irrigation season. This net requirement, divided by the irrigation efficiency, indicates the seasonal irrigation requirement of the crop

Consumptive Use of Water

As previously indicated, consumptive use of water is affected by numerous independent and related variables; and of the climatic factors affecting plant growth, temperature and precipitation undoubtedly have the greatest influence. Furthermore, records of temperature and precipitation are far more universally available throughout the western States than are data for other factors The actual hours of sunshine also play an important part in the rate at which plants grow and consume water, but sunshine records are not generally available. The theoretical daytime hours for each day are available for all the latitudes (16) and may be used in place of the actual data. Although it is recognized that these may be misleading in areas where heavy fog or stormy weather exists during a large part of the year, temperatures tend to correct for such a condition. Humidity records, if available, may also be used as a correction (5).

Consumptive-use formula

Disregarding the unmeasured factors, consumptive use varies with the temperature, daytime hours, and available moisture (precipitation, irrigation water or natural ground water). By multiplying the mean monthly temperature (t) by the monthly percent of daytime hours of the year (p), there is obtained a monthly consumptive-use factor (f) It is assumed that the consumptive use varies directly as this factor when an ample water supply is available. Expressed mathematically, $U = KF =$ sum of kf where

$U =$ Consumptive use of crop (or evapo-transpiration) in inches for any period

$F =$ Sum of the monthly consumptive-use factors for the period (sum of the products of mean monthly temperature and monthly percent of daytime hours of the year).

$K =$ Empirical consumptive-use coefficient (irrigation season or growing period)

$t =$ Mean monthly temperature, in degrees Fahrenheit.

$p =$ Monthly percent of daytime hours of the year.

$f = \frac{t \times p}{100} =$ monthly consumptive-use factor.

$k =$ Monthly consumptive-use coefficient.

$u = kf =$ monthly consumptive use in inches.

The consumptive-use factor (F) for any period may be computed for areas for which monthly temperature records are available. Then by knowing the consumptive-use coefficient (K) for a particular crop in some locality, an estimate of the use by the same crop in some other area may be made by application of the formula $U = KF$ Table 14, appendix, assembles the results of calculated normal monthly consumptive-use factors (f) and average monthly precipitation (r) for various areas in the western States, from which the seasonal factor (F) can be determined for any period. The monthly percent (p) of daytime hours of the year for various latitudes is shown in figure 4 and table 16, appendix.

Coefficient (K)

Table 15, appendix, gives a summary of consumptive-use values (U) for the important crops in various localities of the West as determined by investigations, and the calculated consumptive-use factor (F) and the crop coefficients (K) for the areas studied. These data have been correlated with temperature and the growing season, and

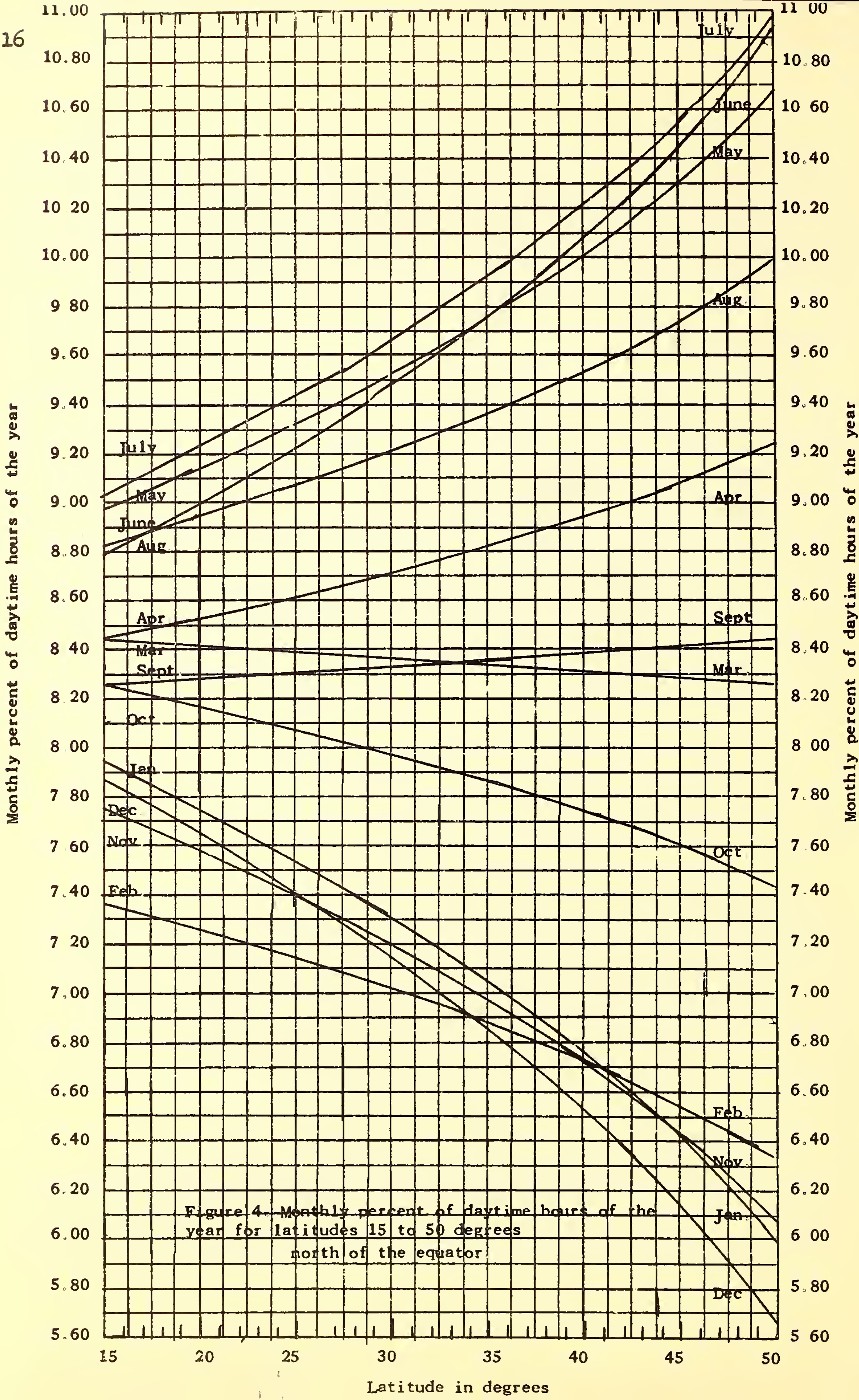


Figure 4. Monthly percent of daytime hours of the year for latitudes 15 to 50 degrees north of the equator

the consumptive-use coefficient (K) has been computed by the formula $K = \frac{U}{F}$. The computed coefficients varied somewhat because of the diverse conditions (such as soils, water supply and methods) under which the studies were conducted. These coefficients were adjusted, where necessary, after the data were analyzed. The resulting coefficients, believed to be suitable for normal conditions, are presented in table 3 Further studies may verify or modify these coefficients In areas where additional data are available, the farm planner or technician can compute consumptive-use coefficients to fit local conditions.

Assumptions

In order to apply the results of a study in one area to some other area for which sufficient basic data are not available, it is usually necessary to make certain minor assumptions. If sufficient basic information is available, the actual data should, of course, be used; but rarely are all the data known in sufficient detail for reliable use. In other words, the more data available, the more accurate are the estimates or assumptions Where the necessary information is lacking, the following assumptions must be made in applying the consumptive-use formula between areas:

1. Seasonal consumptive use (U) of water varies directly with the consumptive-use factor (F)
2. Sufficient water is applied at the proper time to maintain good growing conditions
3. The length of growing season, to a large extent, determines or is an index of the production and consumptive use of continuously growing crops such as alfalfa and pasture
4. The fertility and producing power of the soils are similar
5. The growing periods for orchard and native or "natural" vegetation are the same as the frost-free periods.

Irrigation Requirements

A major use of basic consumptive-use data is in estimating the water requirement of existing or proposed irrigation projects and in determining the amount of water required for crop production on individual farms The amount of water required for irrigation is dependent not only on consumptive use but also on the irrigation efficiency, usable summer precipitation, soil moisture contributed by winter rains and ground-water contribution. In some areas it is necessary to pre-irrigate before a crop is planted. In other areas there may be sufficient moisture from precipitation to start plant growth or it may be necessary to irrigate the first time shortly after planting

Consumptive use of any crop may be estimated from the local consumptive-use factor for the growing or irrigation season and the coefficient for the crop, with allowance for abnormal conditions As indicated by studies at Scottsbluff, Nebr (figure 3), the use of water varies for different crops, not only in total amount but also in seasonal distribution. 11/

11/ See footnote 6, page 5

Table 3.--Consumptive-use coefficients (K) for irrigated crops in western States.

Crop	Length of growing season or period	Consumptive-use coefficient 1/ (K)
Alfalfa	Between frosts	0.80 to 0.85
Beans	3 months	.60 to .70
Corn	4 months	.75 to .85
Cotton	7 months	.60 to .65
Flax	7 to 8 months	.80
Grains, small	3 months	.75 to .85
Grain sorghums	4 to 5 months	.70
Orchard, citrus	7 months	.50 to .65
Orchard, walnuts	Between frosts	.70
Orchard, deciduous	Between frosts	.60 to .70
Pasture, grass	Between frosts	.75
Pasture, Ladino clover	Between frosts	.80 to .85
Potatoes	3½ months	.65 to .75
Rice	3 to 5 months	1.00 to 1.20
Sugar beets	6 months	.65 to .75
Tomatoes	4 months	.70
Truck - small	3 months	.60

1/ The lower values of K are for coastal areas, the higher values for areas with an arid climate.

Similar graphs might be drawn showing the variation in use by the same crop in different locations. Particularly with the perennials, use varies widely, depending upon the climatic conditions.

Usable precipitation

The amount of growing-season precipitation that is usable by plants is difficult to determine. Undoubtedly, not all the water from a rainstorm of a particular size will enter the soil. In some areas, practically all summer precipitation may be lost by evaporation from the foliage and land surface. However, in many such areas, the total summer precipitation is a relatively small amount of the consumptive requirements of the crops. The showers, although adding little or nothing to the soil moisture for use by the plants, are commonly accompanied by some cloudy weather, during which evapotranspiration is slowed down. Thus, they may be of some value. Unless detailed information is available on the character of the storms and the surface runoff that occurs from each, the authors recommend that in arid and semiarid areas the total amount of summer precipitation be regarded as "effective precipitation" helpful in reducing the requirement for irrigation water. In humid areas a portion of the summer precipitation may be lost for crop use by surface runoff.

Winter soil-moisture carry-over contribution

As with precipitation, the contribution to the seasonal water requirement from carry-over soil moisture is difficult to determine. In most areas, winter precipitation is sufficient to bring the soil in the root zone of the plants up to field capacity. Where water supplies, particularly late-season supplies are short, the soil moisture in the fall is usually well below field capacity and possibly down to the wilting point. For crops having a 6-foot root zone, the amount of water that the root zone would hold between wilting point and field capacity could be 2 inches per foot of soil, or 12 inches in a 6-foot root zone, for clay loam soil. This amount is a major part of the water requirement for even alfalfa in many areas. However, in areas where irrigation water is plentiful, it is not unusual to find the soil moisture content nearly as high at the end of the season as at the beginning, making the contribution from this source negligible or zero. The quantity of moisture carried over in the soil tends to offset any deficiency in the estimated irrigation water requirements that might result from treating all summer precipitation as effective precipitation.

Ground-water contribution

In areas of high natural ground-water, the irrigation requirement may be materially less than if ground water were not available. If the high ground water is the result of irrigation, the demand by the crops on the irrigation supply is not decreased. In such a case, part of the irrigation is by underground methods.

Recent studies in San Fernando Valley, Calif. indicate a consumptive use of water by alfalfa of 37 inches during the irrigation season. In the areas of high water-table, only 24 inches of surface-irrigation water is required to produce a good yield of alfalfa. 12/

12/ See footnote 5, page 5

Irrigation efficiencies

Thus it may be seen that the consumptive requirement of irrigation water is dependent not only on the amount of water consumed by the crops but also on the amount supplied by precipitation, winter soil-moisture carry-over and natural ground-water contribution After each of these factors is given consideration, the net amount of irrigation water that must be supplied for consumptive use of the crop can be determined However, this is not the amount of irrigation water required for a farm or even a field, since the water cannot be applied without some loss, regardless of the method used Generally, not more than 60 percent of the water delivered at the upper end of the farm is made available for the consumptive use of the crops. The balance is either lost in conveyance to the field, on the field itself through deep percolation, or through surface runoff from the field. Irrigation efficiencies must therefore be taken into account in estimating the irrigation water requirement of the crop A range of efficiencies for several site conditions is given in table 2.

APPLICATION OF METHOD TO SPECIFIC AREAS

The amounts of water required to irrigate an individual crop, a single farm, or an entire irrigation project may be estimated by the procedure described in this report

Montrose, Colorado Area

The method and analysis of data are illustrated in tables 4, 5, and 6. Table 4 shows the calculations necessary to determine the monthly consumptive-use factors (f) from percent of daytime hours (p) and monthly temperatures (t) at Montrose, Colorado

In some farm-planning programs it is necessary to estimate irrigation requirements of each crop at the point of water delivery to the field. This may be accomplished by dividing consumptive use minus precipitation by field irrigation efficiency, as shown in table 5. For example, the irrigation water required to satisfy the consumptive use of alfalfa is (26.4 - 4.7) or 21.7 inches. Assuming a field-irrigation efficiency of 70 percent, then $\frac{21.7}{0.70} = 31.0$ inches, the amount of irrigation water that would be required at the field for the season May 6 to October 10. This is equivalent to 1.81 acre-feet per acre By making an allowance for conveyance-loss from the farm headgate to the field, the amount of water that should be delivered to the farm headgate to irrigate the alfalfa adequately may be estimated

The irrigation water required to satisfy consumptive use by each crop growing or to be grown on a farm is obtained by subtracting the effective rainfall from consumptive water requirements during the growing or irrigation season This net consumptive requirement (consumptive use minus precipitation) of the crop when divided by the farm-irrigation efficiency, gives the seasonal amount of water required at the farm headgate for each acre of the crop. The summation of the headgate requirements for each crop, times its acreage, gives the total amount of water that must be delivered to the farm headgate for satisfactory crop production. To this total must be added the amount of water needed for incidental farm operations. The method employed is shown in table 6

Table 4. - Example of observed monthly temperatures and precipitation and calculated consumptive-use factors, Montrose area, Colorado

Month	Mean temperature (t)	Percent daytime hours (p)	Consumptive-use factor (f)	Average precipitation (r)	Growing season and crop: Alfalfa - grass, hay and orchard 5/6 - 10/6 (f)	(r)	Corn and annuals 5/6 - 9/6 (f)	(r)	Grain and beans 5/6 - 8/6 (f)	(r)
	°F.			Inches		Inches		Inches		Inches
Jan.	24.6	6.84	1.68	0.55						
Feb.	31.7	6.78	2.15	.47						
Mar.	39.8	8.34	3.32	.76						
Apr.	48.4	8.92	4.32	1.00						
May	57.3	9.94	5.70	1.05	4.60	0.85	4.60	0.85	4.60	0.85
June	66.5	9.98	6.64	.47	6.64	.47	6.64	.47	6.64	.47
July	72.2	10.13	7.31	.79	7.31	.79	7.31	.79	7.31	.79
Aug.	69.8	9.49	6.62	1.31	6.62	1.31	6.62	1.31	1.28	.21
Sept.	62.0	8.38	5.20	1.11	5.20	1.11	1.04	.22		
Oct.	50.0	7.78	3.89	.96	.75	.19				
Nov.	37.6	6.80	2.56	.60						
Dec.	26.8	6.62	1.77	.69						
Total		100.00	51.16	9.76	31.12	4.72	26.21	3.64	19.83	2.32

Table 5. - Example of computations of seasonal consumptive use and irrigation requirements for crops in the Montrose area, Colorado

Culture	Growing Season	Consumptive-use factor (F)	Consumptive-use coefficient (K)	Consumptive-use (U)	U minus R	Field irrigation efficiency (E)	Irrigation requirement (I)
				Inches	Inches	Percent	Inches
Alfalfa	5/6 - 10/6	31.12	0.85	26.45	21.73	70	31.0
Grass hay	5/6 - 10/6	31.12	.75	23.34	18.62	60	31.0
Corn	5/6 - 9/6	26.21	.75	19.66	16.02	65	24.6
Small grain	5/6 - 8/6	19.83	.75	14.87	12.55	65	19.3
Orchards	5/6 - 10/6	31.12	.65	20.23	15.51	70	22.2
Seeped land	5/6 - 10/6	31.12	.80	24.90	20.18	--	--
Dense natural vegetation	5/6 - 10/6	31.12	1.20	37.34	32.62	--	--

U = KF = Consumptive use for growing or irrigation season.

K = Empirical consumptive-use coefficient determined experimentally. (See table 3)

F = Sum of monthly consumptive-use factors, (f), for the growing or irrigation season.

R = Sum of monthly precipitation for growing or irrigation season

$I = \frac{U - R}{E}$ = Irrigation requirement at head of the field

Table 6. - Illustration of the method used to compute the normal amount of irrigation water required at headgate at a typical farm - Montrose, Colorado

Classification	Area	Irrigation required for consumptive use 1/	Farm irrigation efficiency 2/	Water required at farm headgate: Unit 3/	Water required at farm headgate: Total
	Acres	Acre-feet per acre	Percent	Acre-feet per acre	Acre-feet
Irrigated					
Alfalfa	35	1.81	60	3.02	105.7
Grass hay	20	1.55	50	3.10	62.0
Corn	10	1.33	55	2.42	24.2
Orchard	10	1.29	60	2.15	21.5
Miscellaneous					
Roads	3	0	--	--	0
Dense natural vegetation	1	2.72	--	2.72	2.7
Seeped lands 4/	1	1.68	--	1.68	1.7
Total water delivery required at farm headgate for normal season					217.8

1/ Consumptive use (U) minus precipitation (R) for growing season. (See table 5).

2/ Assumed reasonable for this area. (See table 2).

3/ Amount of water to be delivered at the farm headgate, in acre-feet per acre, to satisfy crop requirements.

4/ Vegetation along ditch banks and on low land.

The application of the above procedure to other specific areas having different climatic and crop conditions is illustrated in the following examples.

Coastal Area in Southern California

Irrigation is the most essential item in the production of citrus fruits in southern California, since the rainfall in that area is insufficient for the growth of the crop Normally, rainfall occurs from November to April, inclusive, and provides moisture for winter use. Rainfall distribution in some years, however, may be such as to make winter irrigation necessary. Water is usually delivered to the farm headgate by concrete-lined canals or concrete pipe There is practically no conveyance loss from the farm headgate through the underground pipe distribution system to the field to be irrigated. Thus the farm-irrigation efficiency is usually about the same as the field-irrigation efficiency Table 7 illustrates the procedure for computing the monthly irrigation requirements of a mature orange grove in Orange County. The total irrigation requirement for the period April 1 to October 31 is estimated at 23.6 inches In some years sufficient moisture is stored in the soil from winter rains so that irrigation is not necessary in April. In wet years and in areas of high rainfall, 18 inches of irrigation water may be sufficient to meet the needs of the crop

Table 7. - Computed normal monthly consumptive use and irrigation requirements of an orange grove, Santa Ana, California

Month	Mean temperature (t)	Daytime hours (p)	Consumptive-use factor (f)	Average rainfall (r)	Consumptive use (u)	Consumptive use minus rainfall (u-r)	Irrigation requirement 1/ (i)
	°F.	Percent		Inches	Inches	Inches	Inches
Apr	59.9	8.79	5.27	0.98	2 63	1 65	2.1
May	63.5	9.71	6.17	.38	3.08	2.70	3 4
June	67 1	9.69	6.50	.04	3 25	3.21	4 0
July	71.4	9.37	7.05	.01	3.52	3.51	4 4
Aug	71.9	9.33	6.71	.05	3 35	3 30	4 1
Sept.	69.5	8 36	5 81	22	2.90	2 68	3 3
Oct.	64 7	7.90	5.11	71	2 55	1.84	2 3
Total	--	--	--	2.39	21 28	18.89	23.6

1/ Based on irrigation efficiency of 80 percent under good irrigation practice in Orange County Usually in normal and wet years 2 to 4 inches of moisture is available as carry-over from winter rains Under such conditions this moisture should be deducted from irrigation requirements.

$u = kf = 0.50\ f$ = monthly consumptive use by orange trees

$k = 0.50$ = monthly consumptive-use coefficient for orange trees

$i = \frac{u-r}{0.80}$ = monthly irrigation requirement

Salt River Valley, Arizona

The climate of the Salt River Valley is characterized by high maximum and mean temperatures, long hot summers, short mild winters, low annual rainfall and low humidity. Research studies have been made by Harris (11, 12) on use of water by cotton, citrus, and other crops in this valley. The irrigation requirements of cotton and citrus in the vicinity of Phoenix are typical of the irrigation needs of these crops in hot interior valleys of the West.

The monthly consumptive-use factors and the average rainfall for Phoenix may be obtained from table 14, appendix. Table 8 shows the results of the computations for monthly irrigation requirements of grapefruit. Actual measurements of use of water in this vicinity indicate that the monthly consumptive-use factor (k) ranges from 0.55 in March to 0.75 in August.

Similar calculations may be made for the normal seasonal water requirements of cotton areas. For example, the sum of the monthly consumptive-use factors for the growing season of cotton (April 1 to October 31) is 50.93. The effective rainfall for this period is 3.6 inches (rainfall during May and June considered ineffective). Measurements indicate that the normal consumptive-use coefficient for cotton in this area is 0.63. Then, $U = KF = 0.63 \times 50.93 = 32.1$ inches; and assuming a field irrigation efficiency of 70 percent, the irrigation requirement $= \frac{32.1 - 3.6}{0.70} = \frac{28.5}{0.70} = 40.7$ inches.

Table 8. - Computed normal monthly consumptive use and irrigation requirements for grapefruit in the vicinity of Phoenix, Salt River Valley, Arizona

Month	Consumptive Use Factor (f)	Consumptive Use Coefficient (k)	Consumptive use (u)	Average Rainfall (r)	Consumptive use minus rainfall (u-r)	Irrigation requirement 1/ (i)
			Inches	Inches	Inches	Inches
January	3.64	0.55	2.00	0.80	1.20	1.8
February	3.82	.55	2.10	.77	1.33	2.0
March	5.07	.55	2.79	.68	2.11	3.1
April	5.89	.65	3.83	.40	3.43	5.1
May	7.28	.65	4.73	.12 2/	4.73	7.1
June	8.17	.70	5.72	.07 2/	5.72	8.5
July	8.85	.70	6.20	1.07	5.13	7.7
August	8.25	.75	6.19	.95	5.24	7.8
September	6.91	.75	5.18	.75	4.43	6.6
October	5.58	.70	3.91	.47	3.44	5.1
November	4.20	.65	2.73	.70	2.03	3.0
December	3.62	.60	2.17	1.00	1.17	1.7
Annual	--	--	47.55	7.59	39.96	59.5

1/ Based on a field-irrigation efficiency of 67 percent. The frequency of irrigation (12) and the amount of water per irrigation will vary according to weather, soil and other conditions (see recommendations (13) by Hobart and Harris).

2/ Rainfall so small it is considered ineffective and not included.

High Valley Areas, Elk River, Colorado

In high valley areas such as the Upper Colorado River Basin, the frost-free period is relatively short and a large portion of the irrigated land is used for grass hay and pasture. The Elk River area, Colorado, is taken to illustrate the method of estimating the amount of water required by grass hay.

Monthly temperature and precipitation records have been kept for many years at Steamboat Springs. The normal monthly consumptive-use factor (temperature multiplied by percent of daytime hours) and average monthly precipitation for Steamboat Springs may be obtained from table 14, appendix. Consumptive-use coefficients are shown in table 3. A tabulation of factors and computed monthly consumptive use and irrigation requirement of grass hay in this area is shown in table 9. It is assumed that all precipitation falling during the irrigation season is consumptively used. The wild flooding method of irrigation is common in the high valley areas. Under this system of water distribution, irrigation efficiencies are low. Assuming a field-irrigation efficiency of 40 percent, the seasonal amount of water required to irrigate grass hay would be 17.2 inches (acre-inches per acre) delivered at the upper end of the field. With a farm irrigation efficiency of 25 percent, 27.4 inches or 2.22 acre-feet would be required at the farm headgate to irrigate each acre of grass hay in the farm during the period May 10 to August 15. Thus, 100 acres of grass-hay land would need about 222 acre-feet of water delivered at the farm headgate during the irrigation season in normal years.

Table 9. - Computed normal monthly consumptive use and irrigation requirements for grass hay in the Elk River Area, Colorado

Month	Consumptive use Factor (f)	Consumptive use Coefficient (k)	Consumptive use (u)	Precipitation (r)	Consumptive use minus precipitation (u - r)	Irrigation requirement at head of field 1/ (i)
			(Inches)	(Inches)	(Inches)	(Inches)
May	4.84 2/	--	--	2.23 2/	--	--
10-31	3.23	0.60	1.94	1.51	0.43	1.1
June	5.60 2/	--	--	1.38 2/	--	--
1-27	5.04	.60	3.02	1.24	--	--
28-30	0.56	.75	0.42	0.14	--	--
1-30	--	--	3.44	1.38	2.06	5.2
July	6.32 2/	.75	4.74	1.58 2/	3.16	7.9
August	5.68 2/	--	--	1.76 2/	--	--
1-15	2.75	.75	2.06	.85	1.21	3.0
Total irrigation requirement at head of field						17.2

k = 0.60 for pre-frost-free period May 10 to June 27.
k = 0.75 for normal frost-free period June 28 - August 15 (See table 3).
u = kf = consumptive use

1/ $i = \frac{\text{consumptive use minus precipitation}}{\text{field irrigation efficiency}} = \frac{u - r}{0.40}$ = irrigation requirement.

2/ Monthly data obtained from table 14, appendix.

Twin Falls Area, Idaho

In certain areas of relatively short frost-free periods the water requirements of the crop in midsummer are high. Table 10 shows the monthly consumptive use by alfalfa and the monthly irrigation requirement of such an area at Twin Falls, Idaho.

Table 10. - Computed normal monthly consumptive use and irrigation requirements for alfalfa in Twin Falls area, Idaho.

Month	Consumptive-use factor	Consumptive use 1/	Rainfall	Consumptive use minus rainfall	Irrigation water requirement 2/
		Inches	Inches	Inches	Inches
May 15-31 3/	2.88	2.4	0.5	1.9	3.5
June	6.53	5.6	.8	4.8	8.7
July	7.57	6.4	.3	6.1	11.1
August	6.67	5.7	.2	5.5	10.0
September	5.00	4.3	.4	3.9	7.1
Total		24.4	2.2	22.2	40.4

1/ Consumptive-use coefficient K = 0.85
2/ Based on 55 percent farm-irrigation efficiency
3/ Assumed to be one-half of amount for the full month

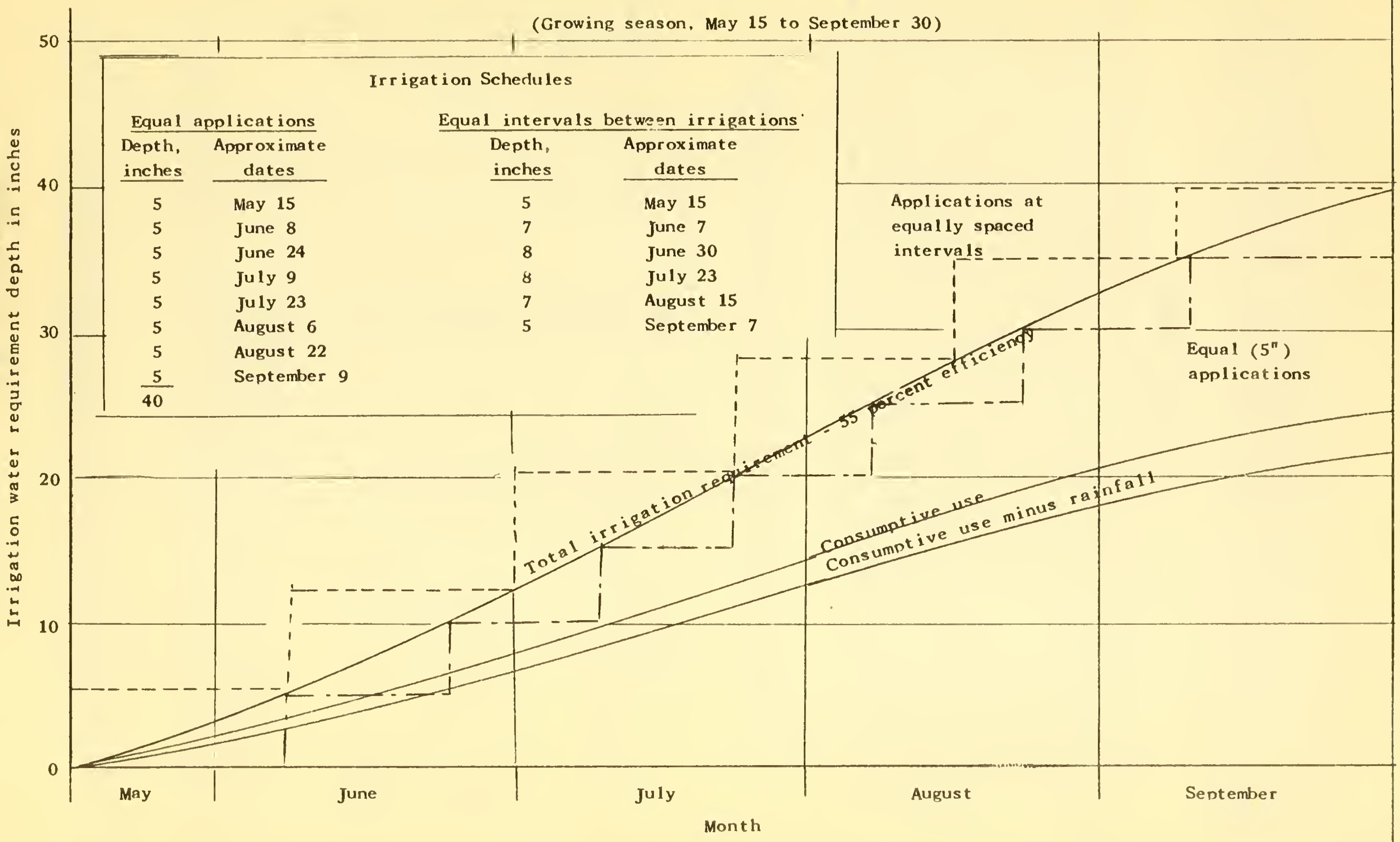
Assuming that all the precipitation falling during the growing period, May 15 to October 1, is consumptively used, the amount of irrigation water needed in the root zone to satisfy the consumptive requirement is computed as: consumptive use minus rainfall = 24.4 - 2.2 = 22.2 inches (which does not include losses on account of farm laterals, deep percolation and surface runoff). With a farm-irrigation efficiency of 55 percent, the total irrigation requirement for alfalfa for the period May 15 to October 1 in the Twin Falls area would be $\frac{22.2}{0.55} = 40.4$ inches.

Figure 5 shows the accumulated irrigation requirement and consumptive-use curves for alfalfa in the Twin Falls area for average temperature and rainfall conditions. Similar curves may be prepared for years of minimum and maximum rainfall.

Also shown in figure 5 is a method of estimating the amount of irrigation water required at each irrigation under average conditions and a rotation system of delivery. Under this system, the depth of water applied may vary with each irrigation, heavier applications being required during the middle of the summer than at either its beginning or end. This method is indicated by the dotted steps on the upper side of the total irrigation requirement line. The stepped dot-and-dash lines on the under side show how

Figure 5. - Irrigation water requirement of alfalfa
Twin Falls Area, Idaho

(Growing season, May 15 to September 30)



Irrigation Schedules

Equal applications

Depth, inches	Approximate dates
5	May 15
5	June 8
5	June 24
5	July 9
5	July 23
5	August 6
5	August 22
5	September 9
40	

Equal intervals between irrigations

Depth, inches	Approximate dates
5	May 15
7	June 7
8	June 30
8	July 23
7	August 15
5	September 7

U.S.D.A. - S.C.S.

approximate dates for equal applications of water might be determined. A similar schedule could be worked out for any combination of depth of application and period between irrigations. The quantities of water scheduled for application at any one time should not be great enough to cause an excess of water over the water-holding capacity of the soil in the root zone.

Altus Area, Oklahoma

Grain, cotton and alfalfa are grown without irrigation in many areas of the Midwest and Southwest. However, in dry years the yields frequently are low. Yields for most crops, particularly alfalfa, will often be increased by supplemental irrigations. One such area is the Altus Reclamation Project, Oklahoma where a study was made in 1945. 13/

At that time the annual precipitation at Altus ranged from about 14 to 48 inches. The mean annual precipitation was 26.47 inches, of which 20.59 inches fell during the period April to October, inclusive. Table 11 illustrates the procedure used in estimating the normal water requirement and distribution of irrigation water for alfalfa at the field, in connection with the farm-planning program in the Altus District in 1945. With a field-irrigation efficiency of 75 percent, the total irrigation requirement for alfalfa hay at the head of the field would be $\frac{19.8}{0.75} = 26.4$ inches in years of average

Table 11. - Computed normal monthly consumptive use and irrigation requirements for alfalfa in Altus area, Oklahoma

Month	Consumptive use factor 1/ (f)	Consumptive use 2/ (u)	Average rainfall 1/ (r)	Consumptive use minus rainfall (u - r)	Irrigation requirement 3/ (i)
		Inches	Inches	Inches	Inches
April	5.43	4.62	2.88	1.74	2.32
May	6.82	5.80	3.66	2.14	2.85
June	7.75	6.59	3.58	3.01	4.01
July	8.29	7.05	2.52	4.53	6.04
August	7.76	6.60	2.49	4.11	5.48
September	6.48	5.51	2.48	3.03	4.04
October	4.98	4.23	2.98	1.25	1.66
Total		40.40	20.59	19.81	26.40

1/ Based on Weather Bureau records available in 1945.
2/ $u = kf = 0.85f =$ monthly consumptive use by alfalfa.
3/ Based on a field-irrigation efficiency of 75 percent. (Farm-lateral losses are not included.)

13/ Blaney, Harry F. Irrigation in the Altus Area, Oklahoma. U. S. Dept. of Agr., Soil Conservation Service. 1945. (Unpublished, typed report) rainfall. With a farm-irrigation efficiency of 65 percent, 30 inches of irrigation water would be required at the farm headgate During periods of high-intensity rainfall, some water may be lost for crop use by surface runoff. This would increase the irrigation requirements. Thus if 10 percent of the precipitation in the Altus area during the irrigation season were lost as surface runoff about 3 inches additional irrigation water would be required Careful preparation of the land would prevent excessive runoff

Analyses of records in Arizona California and New Mexico indicate that seasonal consumptive use of water for cotton is about 62 percent of the calculated heat units (F) Thus a coefficient (K) of 0.62 is used in calculating the consumptive use for cotton. The sum (F) of the monthly consumptive-use factors (f) shown in table 11 for the period April to August inclusive is 42.53. When the consumptive use for this period is computed by the formula $U = KF$ the use equals $0.62 \times 42.53 = 26.4$ inches Assuming that all the rainfall during the period (April to August, inclusive) is consumptively used and that neither soil moisture nor ground water contributed to the consumptive requirement of the crop, then the amount of irrigation water needed in the root zone in a normal year is computed as: Total consumptive use minus rainfall $= 26.4 - 17.6 = 8.8$ inches of water to be made available for crop use With a farm-irrigation efficiency of 60 percent, the total irrigation requirement for cotton at the farm headgate would be $\frac{8.8}{0.60} = 14.7$ inches for years of average rainfall Any rainfall lost as surface runoff during the growing season should be replaced by increasing the irrigation requirement For example, if the runoff during the period was 2 inches, then 18 inches of irrigation water would be required.

Kearney Area, Nebraska

In the Kearney area of Nebraska, the mean annual precipitation is nearly 21 inches, more than two-thirds of which occurs during the frost-free period of May 1 to October 6 Although this amount of rainfall may normally produce a satisfactory crop of small grain, it is not usually adequate for crops such as sugar beets and alfalfa

In column 2, table 12 is given the monthly consumptive-use factor for this area, from which is computed the monthly consumptive use (column 3) The average monthly rainfall for the growing season is shown in column 4. From the monthly consumptive use is subtracted the monthly rainfall to determine the consumptive irrigation requirement (column 5). 14/ The irrigation requirement (column 6) was determined by assuming that 65 percent of the water applied to the field would be available for consumptive use by the crop. The remaining 35 percent of the water applied would probably be surface runoff or deep percolation

South Atlantic Coastal Area

In recent years, irrigation to supplement rainfall has increased along the Atlantic Coast Much of the irrigation is done by the sprinkler method and estimates of monthly peak rates of water delivery are needed in designing the sprinkler system In irrigated

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14/ This assumes that all or nearly all of the precipitation is effective in reducing the irrigation requirement. If heavy runoff from precipitation occurs from the field, this assumed amount may be too high.

Table 12. - Computed normal consumptive use and irrigation requirements for sugar beets in Kearney Area, Nebraska

1	2	3	4	5	6
Month	Consumptive use factor 1/ (f)	Consumptive use 2/ (u)	Average rainfall 1/	Consumptive use minus rainfall (u - r)	Irrigation requirement 3/
May	6.09	4.26	3.83	0.43	0.66
June	7.16	5.01	3.89	1.12	1.72
July	7.89	5.52	3.53	1.99	3.06
August	7.19	5.03	2.63	2.40	3.69
September	5.53	3.87	2.40	1.47	2.26
October 1-6 4/	0.80	0.56	0.30	0.26	0.40
Total	34.66	24.25	16.58	7.67	11.79

1/ Based on Weather Bureau records available in 1948.
2/ $u = kf = 0.70f$ = monthly consumptive use by sugar beets.
3/ Based on a field-irrigation efficiency of 65 percent (farm lateral losses not included).
4/ The average frost-free growing season at Kearney, Nebraska is from May 1 till October 6.

areas, monthly and seasonal distribution of precipitation is a factor. Precipitation records for typical years should be analyzed by storms for each month during the growing season in estimating irrigation requirements. Also, surface runoff should be considered when the rainfall rate per hour is greater than the infiltration capacity of the soil. Owing to the high humidity in the eastern coastal area, consumptive-use coefficients established in the semiarid areas should be reduced. Research is needed to develop the relation of monthly temperature to monthly consumptive use, so that such coefficients may be determined. Meanwhile, tentative coefficients may be used for humid areas.

For instance, the normal mean monthly precipitation records at Charleston, S.C. indicate that there is sufficient rainfall to produce some crops during the growing season, while others will require supplemental irrigation in the summer months. In dry years there is a definite need for the irrigation of most crops during the summer. Table 13 illustrates the method of making tentative estimates of monthly consumptive use and irrigation requirement for grass pasture based on an analysis of temperature, evaporation and precipitation records for a dry year at Charleston. On the assumption that surface runoff may be disregarded, the irrigation requirement from March 1 to September 30 is computed as 21.4 inches. If all the rainfall for June--5.49 inches--occurred in one storm early in the month, perhaps only 75 percent of it would be effective, in which event 1.2 inches of irrigation water would be required in June assuming an irrigation efficiency of 70 percent. The monthly consumptive-use coefficients (k) shown in table 13 need verification by research or by further analysis of existing temperature, humidity, evaporation, and infiltration data before being accepted for general use

Table 13. - Computed monthly consumptive use and irrigation requirement for grass pasture, Charleston, S. C., for dry year 1925

Month	Mean monthly temperature (t)	Monthly percent of daytime hours (p)	Monthly consumptive-use factor 1/ (f)	Monthly consumptive-use coefficient (k)	Monthly precipitation (r)	Monthly consumptive use 2/ (u)	Consumptive use minus rainfall (u-r)	Irrigation requirement 3/ (i)
	°F.	Percent			Inches	Inches	Inches	Inches
March	59.2	8.36	4.95	0.60	1.28	2.97	1.69	2.4
April	66.8	8.77	5.86	.60	1.89	3.51	1.62	2.3
May	71.0	9.67	6.86	.65	1.96	4.46	2.50	3.6
June	79.8	9.63	7.68	.65	5.49	4.99	--	--
July	82.8	9.83	8.14	.70	2.38	5.70	3.32	4.7
August	81.2	9.31	7.56	.70	1.62	5.29	3.67	5.2
September	77.0	8.34	6.42	.65	1.94	4.17	2.23	3.2
October	68.8	7.91	5.44	.60	3.08	3.26	0.18	--
Season 3/1 - 10/1					Total	34.35		21.4

1/ $f = \frac{t \times p}{100}$

2/ $u = kf$

3/ Based on field-irrigation efficiency of 70 percent

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APPENDIX

Table 14. - Normal monthly consumptive-use factors and average monthly precipitation for various locations in western United States.

Table 15. - Records of consumptive use of water by irrigated crops and calculated consumptive-use factors and crop coefficients.

Table 16. - Daytime hour percentages for each month of the year for latitudes 24° to 50° north.

Table 14. - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States

Month	Arizona				California			
	Phoenix		Yuma		Bakersfield		El Centro	
	f	r	f	r	f	r	f	r
January	3.64	0.80	3.90	0.45	3.33	1.10	3.88	0.28
February	3.82	.77	4.07	.41	3.58	1.01	4.00	.61
March	5.07	.68	5.36	.34	4.74	1.06	5.37	.29
April	5.89	.40	6.10	.10	5.55	0.52	6.17	.10
May	7.28	.12	7.36	.04	6.87	.36	7.58	0
June	8.17	.07	8.16	.02	7.51	.07	8.20	.01
July	8.85	1.07	8.91	.18	8.38	.01	9.07	.09
August	8.25	0.95	8.41	.50	7.69	.01	8.56	.27
September	6.91	.75	6.98	.31	6.20	.13	7.19	.50
October	5.58	.47	5.81	.26	5.13	.37	5.95	.24
November	4.20	.70	4.42	.29	3.68	.46	4.44	.10
December	3.62	1.00	3.87	.53	3.33	.86	3.93	.74
Total	71.28	7.78	73.35	3.47	65.84	5.96	74.34	3.23
Frost-free period	2/5 - 12/6		1/12 - 12/26		2/21 - 11/25		1/29 - 12/9	

Month	California							
	Escondido		Merced		Red Bluff		Sacramento	
	f	r	f	r	f	r	f	r
January	3.70	2.68	3.16	2.30	3.06	4.55	3.13	3.72
February	3.70	4.64	3.38	1.91	3.35	3.87	3.39	3.09
March	4.72	2.80	4.45	1.87	4.53	3.04	4.52	2.57
April	5.26	1.55	5.27	1.01	5.33	1.67	5.18	1.51
May	6.20	0.27	6.57	0.48	6.70	1.06	6.30	0.77
June	6.49	.11	7.35	.11	7.58	0.45	6.93	.15
July	7.22	.02	8.08	.01	8.34	.05	7.42	0
August	6.93	.23	7.39	.02	7.61	.04	6.92	0
September	5.95	.35	6.06	.18	6.14	.62	5.81	.38
October	5.14	1.16	4.95	.49	4.98	1.34	4.89	.92
November	4.06	1.14	3.67	1.17	3.60	2.74	3.64	1.88
December	3.73	4.67	3.14	1.80	3.02	4.40	3.06	3.03
Total	63.10	19.62	63.47	11.35	64.24	23.73	61.19	18.02
Frost-free period	3/9 - 11/25		3/9 - 11/20		3/5 - 12/5		2/6 - 12/10	

f = Monthly consumptive-use factor = mean monthly temperature multiplied by monthly percent of daytime hours.

r = Average monthly precipitation in inches

NOTE: Mean monthly temperatures and average monthly precipitation are from climatological data, annual summaries for 1948, U. S. Weather Bureau. Frost-free periods are from 1941 Yearbook of Agriculture

Table 14. (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States

Month	California				Colorado			
	San Fernando		Santa Ana		Durango		Fort Collins	
	f	r	f	r	f	r	f	r
January	3.81	3.29	3.77	2.27	1.68	1.61	1.76	0.42
February	3.73	3.57	3.78	3.25	2.01	1.60	1.89	.57
March	4.77	2.94	4.77	2.57	3.07	1.79	3.02	1.01
April	5.29	1.23	5.27	0.98	3.95	1.59	4.10	2.05
May	6.25	0.45	6.17	.38	5.13	1.14	5.49	2.79
June	6.61	.09	6.50	.04	5.96	0.87	6.45	1.56
July	7.30	.02	7.05	.01	6.65	2.08	7.11	1.61
August	6.86	.02	6.71	.05	6.14	2.19	6.50	1.36
September	6.15	.19	5.81	.22	4.84	2.02	4.98	1.30
October	5.14	.66	5.11	.71	3.71	1.86	3.73	1.13
November	4.33	1.12	4.15	.91	2.48	1.24	2.42	0.48
December	3.80	2.95	3.80	3.01	1.76	1.71	1.81	.45
Total	64.04	16.53	62.89	14.40	47.38	19.70	49.26	14.73
Frost-free period	2/27 - 12/11		2/7 - 12/7		6/1 - 9/26		5/7 - 9/29	

Month	Colorado							
	Grand Junction 1/		Lamar		Montrose 1/		Pueblo	
	f	r	f	r	f	r	f	r
January	1.72	0.62	2.11	0.31	1.68	0.55	1.97	0.31
February	2.29	.60	2.38	.52	2.15	.47	2.18	.49
March	3.57	.82	3.64	.82	3.32	.76	3.40	.59
April	4.67	.80	4.76	1.63	4.32	1.00	4.40	1.31
May	6.20	.72	6.27	2.25	5.70	1.05	5.85	1.60
June	7.22	.43	7.30	2.14	6.64	0.47	6.84	1.36
July	7.98	.75	7.94	2.48	7.31	.79	7.51	1.94
August	7.19	1.19	7.31	1.98	6.62	1.31	6.89	1.82
September	5.60	1.03	5.76	1.22	5.20	1.11	5.42	0.75
October	4.22	0.86	4.34	1.00	3.89	0.96	3.99	.66
November	2.71	.57	2.83	0.51	2.56	.60	2.61	.36
December	1.92	.68	2.09	.57	1.77	.69	2.07	.50
Total	55.29	9.07	56.73	15.43	51.16	9.76	53.13	11.69
Frost-free period	4/13 - 10/25		4/27 - 10/11		5/6 - 10/6		4/21 - 10/15	

f = Monthly consumptive-use factor = monthly temperature multiplied by monthly percent of daytime hours.

r = Average monthly precipitation, inches.

1/ Average 1914 - 1945.

Table 14 (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States

Month	Colorado		Idaho					
	Steamboat Springs 1/		American Falls		Boise		Burley	
	f	r	f	r	f	r	f	r
January	0.93	2.31	1.57	1.40	1.82	1.73	1.71	0.94
February	1.25	2.43	1.81	1.13	2.22	1.48	2.06	.95
March	2.18	2.39	2.97	1.28	3.44	1.35	3.24	.72
April	3.42	2.27	4.10	1.32	4.44	1.18	4.26	1.15
May	4.84	2.23	5.50	1.49	5.74	1.43	5.71	0.90
June	5.60	1.38	6.32	1.02	6.68	0.92	6.30	.79
July	6.32	1.58	7.30	0.63	7.58	.24	7.61	.33
August	5.68	1.76	6.62	.56	6.87	.19	6.98	.48
September	4.37	1.78	4.91	.71	5.15	.53	5.07	.51
October	3.22	1.99	3.64	1.16	3.83	1.24	3.84	.82
November	1.93	1.69	2.29	1.16	2.58	1.28	2.45	.88
December	1.10	2.26	1.68	1.10	1.90	1.57	1.86	.92
Total	40.84	24.07	48.71	12.96	52.25	13.14	51.09	9.39
Frost-free period	6/27 - 8/25		5/26 - 9/16		4/23 - 10/17		5/16 - 9/23	

Month	Idaho							
	Grace		Idaho Falls		Lewiston		Twin Falls	
	f	r	f	r	f	r	f	r
January	1.30	1.20	1.26	1.31	2.09	1.41	1.77	0.89
February	1.57	1.10	1.55	0.97	2.42	1.22	2.16	.84
March	2.58	1.12	2.79	1.08	3.77	1.22	3.35	.85
April	3.79	1.38	4.05	0.94	4.84	1.12	4.39	1.07
May	5.15	1.61	5.45	1.24	6.25	1.49	5.75	0.94
June	6.03	1.29	6.26	1.21	7.12	1.46	6.53	.79
July	6.99	0.98	7.19	0.62	8.13	0.48	7.57	.30
August	6.28	.95	6.45	.59	8.01	.48	6.67	.23
September	4.72	1.07	4.79	.82	5.40	.90	5.00	.43
October	3.52	1.28	3.60	.98	4.02	1.23	3.93	.74
November	2.13	1.17	2.18	.79	2.64	1.47	2.48	1.05
December	1.45	1.07	1.45	1.06	2.12	1.47	1.84	0.75
Total	45.51	14.22	47.02	11.61	56.81	13.92	51.44	8.88
Frost-free period	5/29 - 9/15		5/15 - 9/19		4/5 - 10/26		5/18 - 9/26	

f = Monthly consumptive-use factor = mean monthly temperature multiplied by monthly percent of daytime hours

r = Average monthly precipitation

1/ Average 1914 - 1945

Table 14. (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States.

Month	Kansas							
	Garden City		Lawrence		Topeka		Wichita	
	f	r	f	r	f	r	f	r
January	2.12	0.35	2.04	1.09	2.00	0.91	2.21	0.71
February	2.32	.86	2.21	1.34	2.17	1.30	2.39	1.24
March	3.65	1.02	3.70	2.16	3.64	1.98	3.80	1.63
April	4.81	2.05	4.92	3.14	4.88	2.90	4.98	2.96
May	6.32	2.58	6.45	2.20	6.44	4.42	6.45	4.66
June	7.30	2.95	7.40	4.67	7.44	4.00	7.45	4.58
July	7.97	2.54	8.04	3.75	8.10	3.41	8.10	2.89
August	7.37	2.24	7.37	3.70	7.43	4.21	7.53	3.13
September	5.83	1.91	5.85	4.44	5.87	4.10	5.99	3.33
October	4.41	1.25	4.53	2.86	4.52	2.56	4.65	2.45
November	2.93	0.76	3.03	2.20	3.00	1.76	3.13	1.77
December	2.17	.50	2.17	1.17	2.15	1.03	2.32	1.02
Total	57.20	19.01	57.71	35.40	57.64	32.58	59.00	30.37
Frost-free period	4/25 - 10/16		4/10 - 10/22		4/8 - 10/20		4/10 - 10/27	

Month	Montana							
	Agricultural College		Hamilton		Kalispell		Missoula	
	f	r	f	r	f	r	f	r
January	1.30	0.87	1.60	0.79	1.26	1.57	1.16	0.85
February	1.48	.81	1.87	.75	1.49	1.14	1.54	.80
March	2.50	1.21	3.15	.69	2.72	0.95	2.77	.82
April	3.76	1.69	4.27	.87	4.01	.80	4.01	.90
May	5.16	3.06	5.62	1.47	5.42	1.46	5.46	1.75
June	6.03	2.89	6.40	1.75	6.19	2.06	6.34	2.00
July	6.87	1.28	7.22	0.76	6.92	1.10	7.17	0.80
August	6.21	1.09	6.47	.66	6.30	0.87	6.32	.75
September	4.53	1.67	4.79	1.00	4.52	1.24	4.51	1.25
October	3.35	1.42	3.48	0.91	3.26	1.06	3.26	0.95
November	2.03	1.00	2.27	.81	2.01	1.35	1.98	.90
December	1.41	0.98	1.66	.71	1.45	1.45	1.27	.95
Total	44.63	18.03	48.80	11.17	44.55	15.05	45.79	12.72
Frost-free period	5/24 - 9/16		5/16 - 9/23		5/5 - 10/1		5/18 - 9/23	

f = Monthly consumptive-use factor = mean monthly temperature multiplied by monthly percent of daytime hours

r = Average monthly precipitation

Table 14 (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States.

Month	Nebraska							
	Kearney		McCook		North Platte		Scottsbluff	
	f	r	f	r	f	r	f	r
January	1.66	0.48	1.85	0.41	1.53	0.39	1.72	0.41
February	1.84	.67	2.11	.67	1.78	.55	1.88	.52
March	3.13	1.05	3.34	.95	3.05	.86	3.02	.88
April	4.51	2.57	4.59	2.12	4.36	2.06	4.20	2.10
May	6.09	3.83	6.14	2.89	5.92	2.78	5.71	2.72
June	7.16	3.89	7.17	3.31	6.85	3.22	6.79	2.63
July	7.89	3.53	7.97	2.88	7.51	2.74	7.58	1.73
August	7.19	2.63	7.25	2.50	6.79	2.39	6.87	1.42
September	5.53	2.40	5.56	1.77	5.21	1.35	5.19	1.30
October	4.13	1.56	4.20	1.12	3.84	1.07	3.83	0.95
November	2.56	0.82	2.64	0.66	2.44	0.47	2.45	.48
December	1.79	.61	1.91	.60	1.72	.53	1.81	.52
Total	53.48	20.92	54.73	19.88	51.00	18.41	51.05	15.56
Frost-free period	5/1 - 10/6		5/3 - 10/6		4/29 - 10/6		5/11 - 9/26	

Month	New Mexico							
	Albuquerque		Carlsbad		State College		Tucumcari	
	f	r	f	r	f	r	f	r
January	2.40	0.46	3.18	0.34	2.96	0.32	2.68	0.30
February	2.69	.32	3.37	.39	3.12	.43	2.83	.46
March	3.85	.47	4.64	.55	4.29	.32	4.05	.71
April	4.87	.81	5.56	.80	5.15	.22	5.02	1.40
May	6.23	1.25	6.89	1.19	6.29	.30	6.29	2.39
June	7.09	0.94	7.61	1.63	7.29	.55	7.35	1.97
July	7.65	1.22	7.93	2.15	7.72	1.73	7.83	2.31
August	6.98	1.62	7.55	1.80	7.17	1.73	7.26	2.72
September	5.65	1.58	6.15	1.91	5.94	1.35	5.92	1.55
October	4.46	0.83	5.04	1.41	4.77	0.70	4.66	1.40
November	3.01	.52	3.70	0.53	3.45	.54	3.26	0.74
December	2.54	.61	3.06	.58	2.85	.49	2.61	.63
Total	57.39	10.63	64.68	13.28	61.00	8.68	59.76	16.58
Frost-free period	4/13 - 10/28		3/29 - 11/4		4/6 - 10/31		4/16 - 10/27	

f = Monthly consumptive-use factor equals mean monthly temperature multiplied by monthly percent of daytime hours

r = Average monthly precipitation

Table 14. (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States.

Month	Nevada							
	Caliente		Carson City		Alamo		Yerington	
	f	r	f	r	f	r	f	r
January	2.21	0.93	2.20	2.12	2.54	0.73	2.06	0.62
February	2.53	1.12	2.40	1.77	2.74	.80	2.46	.60
March	3.79	0.88	3.45	1.30	3.92	.88	3.56	.43
April	4.57	.64	4.25	0.69	4.88	.77	4.40	.42
May	5.94	.40	5.49	.52	6.26	.47	5.65	.48
June	6.71	.27	6.23	.33	7.10	.21	6.37	.41
July	7.59	.72	7.04	.17	7.96	.71	7.17	.17
August	6.98	.87	6.42	.18	7.23	.91	6.63	.24
September	5.45	.51	5.00	.26	5.70	.27	5.09	.27
October	4.13	.56	3.87	.58	4.52	.59	3.95	.33
November	2.86	.48	2.69	1.26	3.25	.33	2.67	.36
December	2.29	.67	2.24	1.74	2.66	.63	2.11	.52
Total	55.05	8.05	51.28	10.92	58.76	7.30	52.12	4.85
Frost-free period	5/2 - 10/6		5/25 - 9/19		4/29 - 10/13		5/23 - 9/18	

Month	Oklahoma				Oregon			
	Altus		Oklahoma City		Baker		Bend	
	f	r	f	r	f	r	f	r
January	2.74	0.76	2.56	1.19	1.60	1.39	1.97	1.72
February	3.09	.84	2.72	1.14	1.90	1.27	2.25	1.51
March	4.43	1.54	4.18	1.98	3.12	1.10	3.23	1.10
April	5.49	2.78	5.29	3.29	4.10	1.09	4.04	0.79
May	6.86	3.50	6.62	4.88	5.33	1.55	5.21	1.14
June	7.78	3.18	7.45	3.67	6.11	1.34	6.08	1.00
July	8.33	1.84	8.03	2.86	6.92	0.58	6.82	0.50
August	7.82	2.49	7.48	2.89	6.26	.49	6.14	.31
September	6.34	2.83	6.09	3.05	4.72	.49	4.67	.64
October	5.07	3.21	4.83	2.86	3.55	.91	3.66	.68
November	3.65	1.24	3.39	1.87	2.32	1.05	2.54	1.65
December	2.88	1.28	2.68	1.50	1.68	1.70	1.98	1.70
Total	64.48	25.49	61.32	31.18	47.64	12.96	48.59	12.74
Frost-free period	3/28 - 11/9		3/28 - 11/7		5/12 - 10/3		6/8 - 9/7	

f = Monthly consumptive use factor = mean monthly temperature multiplied by monthly percent of daytime hours.

r = Average monthly precipitation.

Table 14. (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States

Month	Oregon							
	Burns		Hood River		La Grande		Medford	
	f	r	f	r	f	r	f	r
January	1.60	1.55	2.09	5.18	1.93	2.14	2.50	2.31
February	1.89	1.23	2.40	3.98	2.18	1.90	2.81	2.08
March	3.01	0.93	3.61	3.24	3.36	2.05	3.90	1.50
April	4.00	.73	4.57	1.69	4.36	1.71	4.69	1.33
May	5.21	.76	5.83	1.10	5.67	1.93	5.91	1.10
June	6.05	.95	6.47	0.77	6.45	1.53	6.74	0.76
July	6.97	.44	7.15	.18	7.41	0.59	7.54	.30
August	6.25	.25	6.50	.26	6.71	.63	6.85	.17
September	4.68	.87	5.04	1.18	5.01	1.12	5.33	.65
October	3.52	.62	3.92	0.99	3.80	1.57	4.12	1.41
November	2.30	1.30	2.65	5.32	2.57	2.12	2.90	2.34
December	1.64	1.37	2.15	6.23	2.02	2.06	2.42	2.88
Total	47.12	11.00	52.38	31.30	51.47	19.35	55.71	16.83
Frost-free period	5/24. - 9/18		4/20 - 10/20		4/26 - 10/3		5/6 - 10/4	

Month	Texas					
	Amarillo		Fort Stockton		Lubbock	
	f	r	f	r	f	r
January	2.33	0.51	3.45	0.47	2.85	0.49
February	2.48	.73	3.61	.53	3.09	.58
March	3.78	.71	4.87	.55	4.28	.90
April	4.75	1.83	5.74	.76	5.25	1.42
May	6.07	2.79	7.08	1.56	6.57	2.54
June	6.98	2.84	7.69	1.75	7.37	2.47
July	7.54	2.84	7.94	1.89	7.80	2.13
August	6.98	3.08	7.47	2.07	7.28	1.98
September	5.67	2.30	6.25	2.72	5.95	2.90
October	4.39	1.66	5.25	1.37	4.83	2.29
November	2.87	0.92	3.93	0.72	3.47	0.66
December	2.43	.80	3.39	.52	2.84	.79
Total	56.27	21.01	66.67	15.11	61.58	19.15
Frost-free period	4/11 - 11/2		4/1 - 11/3		4/12 - 11/3	

f = Monthly consumptive-use factor = mean monthly temperature multiplied by monthly percent of daytime hours.

r = Average monthly precipitation.

Table 14 (cont) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States

Month	Texas						Utah	
	Plainview		San Antonio		Wichita Falls		Cedar City	
	f	r	f	r	f	r	f	r
January	2 89	0.50	3.83	1.46	3.05	1.12	2 10	0.92
February	2.99	.65	3.89	1.75	3.30	1.37	2.31	1.10
March	4.26	.75	5.26	1.84	4.68	1.84	3.38	1.38
April	5.22	1.78	6.02	3.19	5.71	2.64	4.29	1.19
May	6.60	2.72	7.15	3.20	7.03	1.62	5.64	0.84
June	7.37	3.02	7.67	2.46	7.92	3.49	6.64	.43
July	7.76	3.11	8.09	2.17	8.46	2.33	7.43	1.38
August	7.27	3.17	7.69	2.42	8.01	2.17	6.76	1.31
September	5.97	2.43	6.59	3.05	6.52	2.82	5.31	0.95
October	4.82	1.99	5.63	2.23	5.33	2.85	4.04	1.34
November	3.51	1.01	4.35	1.90	3.80	1.74	2.76	1.01
December	2.84	0.76	3.85	1.61	3.11	1.54	2.11	0.94
Total	61.50	21.29	70.02	27.28	66.92	28.53	52.77	12.79
Frost-free period	4/11 - 11/1		2/24 - 12/3		3/22 - 11/4		5/9 - 10/6	

Month	Utah							
	Logan		Ogden		Provo		Salt Lake City	
	f	r	f	r	f	r	f	r
January	1.59	1.55	1.88	1.76	1.78	1.54	1.96	1.31
February	1.86	1.51	2.18	1.77	2.16	1.62	2.26	1.57
March	3.05	1.92	3.39	1.90	3.37	1.59	3.47	1.98
April	4.28	1.91	4.60	1.82	4.35	1.43	4.45	2.05
May	5.63	1.96	6.02	1.73	5.68	1.49	5.77	1.92
June	6.53	0.97	7.01	0.92	6.51	0.73	6.83	0.80
July	7.53	.57	7.95	.46	7.40	.63	7.77	.51
August	6.86	.69	7.19	.76	6.70	.82	7.13	.85
September	5.19	1.19	5.39	.98	5.10	.92	5.40	.98
October	3.87	1.60	4.01	.55	3.87	1.36	4.06	1.44
November	2.46	1.30	2.62	1.36	2.61	1.18	2.75	1.35
December	1.69	1.27	1.98	1.76	1.88	1.43	2.06	1.43
Total	50.54	16.44	54.22	16.77	51.41	14.74	53.91	16.13
Frost-free period	5/7 - 10/11		5/6 - 10/8		5/24 - 9/25		4/13 - 10/22	

f = Monthly consumptive-use factor = mean monthly temperature multiplied by monthly percent of daytime hours.

r = Average monthly precipitation.

Table 14. (cont.) - Normal monthly consumptive-use factors and average monthly precipitation in inches for various locations in western United States.

Month	Washington							
	Prosser		Spokane		Sunnyside		Walla Walla	
	f	r	f	r	f	r	f	r
January	1.95	1.00	1.70	2.16	1.87	0.87	2.07	1.94
February	2.36	0.77	2.02	1.81	2.33	.65	2.41	1.81
March	3.80	.49	3.28	1.20	3.71	.37	3.82	1.61
April	4.82	.54	4.43	1.13	4.78	.38	4.84	1.51
May	6.21	.50	5.83	1.42	6.17	.50	6.19	1.61
June	7.03	.51	7.37	0.69	6.98	.51	7.01	1.12
July	7.74	.15	7.43	.69	7.67	.20	7.87	0.39
August	6.92	.25	6.72	.62	6.86	.23	7.12	.49
September	5.24	.43	5.00	.90	5.15	.47	5.37	.95
October	3.97	.74	3.63	1.17	3.91	.57	4.06	1.53
November	2.55	1.04	2.47	2.09	2.52	.93	2.72	2.02
December	2.01	1.14	1.80	2.19	1.95	.88	2.14	2.06
Total	54.55	7.56	51.62	16.07	53.90	6.56	55.62	17.04
Frost-free period	4/28 - 10/4		4/12 - 10/13		5/2 - 10/10		3/31 - 11/5	

Month	Washington		Wyoming					
	Yakima		Cheyenne		Kemmerer		Worland	
	f	r	f	r	f	r	f	r
January	1.72	0.91	1.70	0.42	1.15	0.61	0.97	0.43
February	2.22	.82	1.82	.67	1.38	.66	1.40	.26
March	3.71	.23	2.75	1.02	2.29	.73	2.79	.41
April	4.64	.55	3.67	1.99	3.55	.81	4.08	1.01
May	6.06	.45	5.08	2.43	4.96	.90	5.57	1.34
June	6.88	.34	6.13	1.61	5.70	1.01	6.58	1.29
July	7.63	.28	6.87	2.10	6.56	0.75	7.41	0.81
August	6.79	.34	6.29	1.55	5.92	.89	6.60	.56
September	5.21	.55	4.78	1.20	4.44	.64	4.87	.85
October	3.91	.65	3.46	0.96	3.30	.84	3.57	.70
November	2.41	1.24	2.32	.52	1.89	.65	2.07	.37
December	1.92	0.92	1.84	.55	1.44	.63	1.19	.25
Total	53.11	7.28	46.71	15.02	42.58	9.12	47.10	8.20
Frost-free period	4/15 - 10/22		5/14 - 10/2		6/7 - 9/15		5/10 - 9/27	

f = Monthly consumptive-use factor = mean monthly temperature multiplied by monthly percent of daytime hours.

r = Average monthly precipitation.

Table 15. - Records of consumptive use of water by irrigated crops and calculated consumptive-use factors and crop coefficients.

Location	Year	Growing season or period	Consumptive use (U)	Consumptive-use factor (F)	Consumptive-use coefficient (K)	Reference
			Inches			
ALFALFA						
State College, N. Mex.	Normal	4/1-10/31	40.0	44.45	0.90	(4)
Carlsbad, N. Mex.	1940	4/18-11/10	38.6	43.59	.88	(5)
Carlsbad, N. Mex.	Normal	3/28-11/3	36.8	47.39	.78	(5)
Fort Stockton, Tex.	1940	4/13-11/11	40.5	46.28	.88	(5)
Fort Stockton, Tex.	Normal	3/31-11/12	39.7	48.97	.81	(5)
San Fernando, Calif.	1939	5/26-9/9	19.3	23.35	.83	1/
San Fernando, Calif.	1940	4/1-10/31	37.4	43.73	.86	1/
Bonners Ferry, Idaho	1940-47	5/5-9/25	24.0	27.18	.88	2/
Scottsbluff, Nebr.	1932-36	5/14-9/27	25.9	29.04	.89	3/
Prosser, Wash.	1947	4/22-11/5	36.0	38.50	.93	4/
Logan, Utah	1902-29	5/7-10/11	25.0	32.30	.77	(17)
Vernal, Utah	1948	5/17-10/6	23.6	27.30	.86	5/
Ferron, Utah	1948	5/9-10/6	24.2	30.23	.84	5/
Davis, Calif.	Normal	4/1-10/31	37.0	44.82	.83	6/
Davis, Calif.	1939	4/1-9/30	30.4	39.40	.77	7/
Mesa, Ariz.	1948	2/10-12/3	52.5	57.51*	.91	8/
Ontario, Ore.	1941-42	5/1-10/5	29.4	35.50	.83	9/
Gooding, Idaho		5/23-9/24	21.6	26.18	.83	(19)
BEANS						
Davis, Calif.		6/1-9/30	14.40	29.14	0.49	6/
Davis, Calif.		7/1-9/30	12.84	21.92	.59	6/
Davis, Calif. (Lima beans)		6/1-9/30	18.0	29.14	.62	6/
CORN						
Bonners Ferry, Idaho	1947	5/8-9/27	28.25	29.35	0.96	2/
Vernal, Utah	1948	6/10-9/20	19.4	20.52	.95	5/
Davis, Calif.		6/1-9/30	12.0	27.08	.45	6/
Logan, Utah	1902-29	6/1-9/30	25.0	25.99	.96	(17)
Mercedes, Tex.	1918	3/15-7/15	20.0	28.52	.70	10/
COTTON						
Mesa, Ariz.	1935	4/1-10/31	30.9	49.08	0.63	(11)
Mesa, Ariz.	1936	4/1-10/31	29.8	51.12	.58	(11)
Mesa, Ariz.	Normal	4/1-10/31	31.0	49.52	.63	(11)
Bakersfield, Calif.	1927-30	4/1-10/31	29.2	47.14	.62	(3)
Los Banos, Calif.	1932	5/1-10/31	25.5	44.19	.58	(2)
Los Banos, Calif.	1934	5/1-10/31	23.6	40.17	.58	(1)

*Includes only one-third of the "rest month" of August.

Table 15. (cont.) - Records of consumptive use of water by irrigated crops and calculated consumptive-use factors and crop coefficients

Location	Year	Growing season or period	Consumptive use (U)	Consumptive-use factor (F)	Consumptive-use coefficient (K)	Reference
			Inches			
Cotton - cont.						
State College, N. Mex.	1936	4/1-10/31	26.9	44.81	0.60	(4)
Carlsbad, N. Mex.	Normal	3/28-11/3	28.7	47.39	61	(5)
Fort Stockton, Tex.	1940	4/13-11/11	28.9	46.28	.62	(5)
FLAX						
Mesa, Ariz.		11/1-6/30	34.0	42.05	0.81	8/
SMALL GRAINS						
Scottsbluff, Nebr.	1932-35	4/20-7/25	14.72	20.02	0.74	3/
Bonners Ferry, Idaho	1930-47	5/5-8/5	17.50	19.48	.90*	2/
Prosser, Wash	1944	3/20-7/16	18.00	23.32	.77	4/
San Luis Valley, Colo.	1936	6/1-8/31	14.05	18.03	.78*	(4)
Logan, Utah	1902-29	5/10-8/10	17.5	20.00	.87	(17)
Vernal, Utah	1948	5/25-8/21	16.6	18.12	.91	5/
Ferron, Utah	1948	5/13-8/21	17.8	20.86	.85	5/
Davis, Calif		3/1-6/7	12.0	17.73	.68	6/
GRAIN SORGHUMS (Hegari)						
Mesa, Ariz.		7/1-10/31	21.4	29.78	0.72	8/
ORCHARD - CITRUS						
Mesa, Ariz. (Grapefruit)	1931-34	3/1-10/31	40.2	58.26	0.69	(12)
Mesa, Ariz. (Grapefruit)	1931-34	Annual	48.6	73.57	.66	(12)
Mesa, Ariz. (Oranges)	1931-34	3/1-10/31	32.4	58.26	.56	(12)
Mesa, Ariz. (Oranges)	1931-34	Annual	39.6	73.57	.54	(12)
Tustin, Calif. (Oranges)	1929	4/1-10/31	20.9	44.11	.47	(20)
Azusa, Calif (Oranges)	1929-30	4/1-9/30	18.1	38.69	.49	(8)
Azusa, Calif. (Oranges)	1929	4/1-10/31	21.8	43.19	.50	(8)
San Fernando, Calif. (Oranges)	1940	4/1-10/31	22.1	43.73	.51	1/
ORCHARD - WALNUTS						
Tustin, Calif.	1928	4/1-9/30	26.30	37.90	0.69	(2)
Tustin, Calif.	1929	4/1-9/30	27.43	38.63	.71	(2)
ORCHARD - DECIDUOUS						
Ontario, Calif. (Peaches)	1928	4/1-9/30	28.4	37.73	0.75	(5)
Davis, Calif.		3/1-11/30	26.4	51.61	.51	6/
Wenatchee, Wash.	1908	4/15-10/22	23.0	38.15	.60	(9)
Albuquerque, N. Mex.	1936	5/1-9/31	19.5	33.94	.58	(4)

*High water table.

Table 15. (cont.) - Records of consumptive use of water by irrigated crops and calculated consumptive-use factors and crop coefficients.

Location	Year	Growing season or period	Consumptive use (U)	Consumptive-use factor (F)	Consumptive-use coefficient (K)	Reference
			Inches			
PASTURE						
Vernal, Utah	1948	5/17-10/6	25.0	27.42	0.91	5/
Columbia Basin, Wash.		4/5-10/15	24.0	37.53	.64	11/
Redmond, Ore.	1945	4/25-9/15	19.0	27.73	.68	12/
PEAS						
Davis, Calif.		3/1-6/30	9.6	22.93	0.42	6/
POTATOES						
San Luis Valley, Colo.						
Wright Station	1936	6/1-9/15	15.38	20.31	0.76*	(4)
West Station	1936	6/1-9/30	19.89	22.59	.88*	(4)
Bonners Ferry, Idaho	1947	5/8-9/27	22.95	29.35	.78	2/
Utah County, Utah	1938	5/15-9/15	22.50	27.23	.83	13/
Scottsbluff, Nebr.	1932-33					
	1935	6/20-9/30	15.40	21.89	.70	3/
Ontario, Ore.	1941-42	4/20-8/31	17.90	29.81	.60	9/
Prosser, Wash.	1945	4/20-8/4	16.65	22.81	.73	4/
Prosser, Wash	1947	3/20-7/20	23.0	26.90	.86	4/
Davis, Calif.		3/1-6/30	16.8	22.93	.73	14/
Logan, Utah	1902-29	5/20-9/15	15.0	25.27	.60	(17)
Redmond, Ore.	1945	6/15-9/15	9.6	18.66	.52	12/
SOY BEANS						
Mesa, Ariz.		6/1-10/31	22.3	38.01	0.60	8/
SUGAR BEETS						
Spanish Fork, Utah	1938	4/15-10/15	22.82	31.97	0.71	13/
Scottsbluff, Nebr.	1932-36	4/20-10/15	24.00	35.45	.68	3/
Davis, Calif.		4/1-9/30	25.20	34.63	.73	6/
Logan, Utah	1902-29	4/15-10/15	25.00	35.62	.70	(17)
Columbia Basin, Wash.		4/1-10/15	25.60	39.94	.64	11/
TOMATOES						
Davis, Calif.	1933-35	6/1-10/31	22.8	32.6	0.70	7/
Mercedes, Tex.	1918-20	3/25-6/30	17.0	22.7	.75	10/

*High water table.

Table 15. (cont.) - Records of consumptive use of water by irrigated crops and calculated consumptive-use factors and crop coefficients.

Location	Year	Growing season or period	Consumptive use (U)	Consumptive use factor (F)	Consumptive-use coefficient (K)	Reference
			Inches			
TRUCK						
Stockton, Calif.	1925-26	5/1-9/30	21 4	33.91	0 63	(18)
Stockton, Calif.	1925-28	4/1-10/31	24.6	44.18	.56	(18)

1/ See footnote 5, page 5.
2/ See footnote 4, page 5.
3/ See footnote 6, page 5.
4/ Mech, S. J. Progress Report, Irrigation Branch Experiment Station, Prosser, Washington 1948. (Typewritten)
5/ Criddle, Wayne D., and Peterson, Dean F , Jr. Consumptive Water Use and Requirements A Progress Report on Colorado River Area Investigations in Utah. U. S Dept. of Agr., SCS Div. of Irrigation and Utah Agr. Expt. Sta. 74 pp. 1949. (Mimeographed)
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11/ U. S. Dept. of the Interior. Irrigation Water Requirements, Columbia Basin Joint Investigations Problems 4 and 5. Bur. of Reclamation, Washington, D C 176 pp illus. 1945. (Mimeographed)
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13/ Israelsen, O. W., Criddle, Wayne D., and Fuhriman, Dean K. Water Application Efficiency Studies in Utah County, Utah: A Progress Report. Utah Agr Expt. Sta and Div of Irrigation, Soil Conserv. Serv., U S. Dept. of Agr 79 pp., illus. 1939. (Typewritten)
14/ See footnote 3, page 4.

Table 16. - Daytime hour percentages for each month of the year for latitudes 24 to 50 degrees north of equator. 1/

Month	Latitudes in degrees north of equator													
	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
January	7.58	7.49	7.40	7.30	7.20	7.10	6.99	6.87	6.76	6.62	6.49	6.33	6.17	5.98
February	7.17	7.12	7.07	7.03	6.97	6.91	6.86	6.79	6.73	6.65	6.58	6.50	6.42	6.32
March	8.40	8.40	8.39	8.38	8.37	8.36	8.35	8.34	8.33	8.31	8.30	8.29	8.27	8.25
April	8.60	8.64	8.68	8.72	8.75	8.80	8.85	8.90	8.95	9.00	9.05	9.12	9.18	9.25
May	9.30	9.38	9.46	9.53	9.63	9.72	9.81	9.92	10.02	10.14	10.26	10.39	10.53	10.69
June	9.20	9.30	9.38	9.49	9.60	9.70	9.83	9.95	10.08	10.21	10.38	10.54	10.71	10.93
July	9.41	9.49	9.58	9.67	9.77	9.88	9.99	10.10	10.22	10.35	10.49	10.64	10.80	10.99
August	9.05	9.10	9.16	9.22	9.28	9.33	9.40	9.47	9.54	9.62	9.70	9.79	9.89	10.00
September	8.31	8.31	8.32	8.34	8.34	8.36	8.36	8.38	8.38	8.40	8.41	8.42	8.44	8.44
October	8.09	8.06	8.02	7.99	7.93	7.90	7.85	7.80	7.75	7.70	7.63	7.58	7.51	7.43
November	7.43	7.36	7.27	7.19	7.11	7.02	6.92	6.82	6.72	6.62	6.49	6.36	6.22	6.07
December	7.46	7.35	7.27	7.14	7.05	6.92	6.79	6.66	6.52	6.38	6.22	6.04	5.86	5.65
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

1/ Computed from "Sunshine Tables", U. S. Weather Bureau Bul. 805, 1905 ed.