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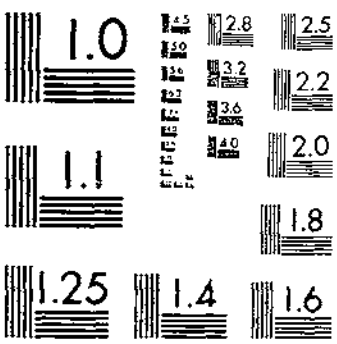

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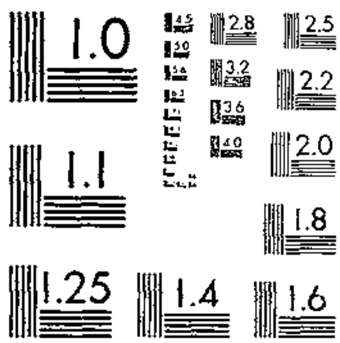

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Determining Consumptive Use and Irrigation Water Requirements

Technical Bulletin No. 1275

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
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CONTENTS

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Determining Consumptive Use and Irrigation Water Requirements

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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 believed to have the greatest effect on consumptive use on which data are generally available are temperature, precipitation, humidity, wind movement, and growing season. Irrigation practices, as well as kind of crops grown, their stage of growth, and species, also influence the amount of water consumed.

This report includes results of experimental studies in the United States and several foreign countries. An empirical formula is developed from these results, showing the relationship between temperature, length of growing season, monthly percentage of annual daytime hours, and consumptive use of water. From this relationship, consumptive use of water by crops and natural vegetation and an irrigation requirement can readily be estimated for any area where the basic climatological data are available.

The procedure was developed by correlating measured consumptive-use data with monthly temperature, monthly percentages of yearly daytime hours, precipitation, and growing or irrigation season. The coefficients thus developed allow for the computation of consumptive use of each crop if the monthly temperature, latitude, and growing period of the crop are known and if the computed monthly percentage of annual daytime hours are available.

Estimated seasonal consumptive use in inches can be computed from the formula

$$U=KF$$

where U=use of water in inches;

K=empirical seasonal coefficient;

F=sum of the monthly factors (f) for the season (sum of the products of mean monthly temperature (t) in degrees Fahrenheit and monthly percentage of annual daytime hours (p)).

The equation for monthly or short-period consumptive use in inches is $u=kf$.

The seasonal coefficient (*K*) for each crop appears to be approximately constant for most areas where irrigation is practiced. However, the coefficients do not appear to be constant for consecutive short periods during the growing season. Adjustments can be made in areas where data are available. For short periods and higher temperatures, the coefficient *k* appears to be larger. But temperature is not the only factor affecting consumptive-use relations. Each crop has its own particular growth and water-use pattern. Thus, for short periods, use coefficients vary, depending upon temperature and stage of growth.

The net amount of irrigation water necessary to satisfy consumptive use during any period is found by subtracting the effective precipitation and other available water from the total requirement for the period. This net requirement of irrigation water, divided by the irrigation efficiency, is the overall water requirement to satisfy the needs of the crop. If efficiency measurements are not available, they can be estimated by taking into account irrigation practices, soil characteristics, topography, skill of the irrigator, degree of land preparation, and availability and cost of water supplies. Irrigation efficiency may be measured in the field, but such measurements are expensive and are often estimated by making allowances for certain wastes such as ditch seepage, deep percolation, and surface runoff. The net consumptive irrigation requirement corrected for conveyance and application losses is the irrigation diversion requirement. The terms used in this report are also defined.

NEED FOR METHOD

Conservation of water supplies, as well as soils, is of first importance in the agricultural economy of the West. Although irrigation has been used in various parts of the world for centuries, modern irrigation was not practiced in Western United States until about 1850. During the last century, the science of irrigation has advanced rapidly. This is especially true 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 large irrigation structures.

A knowledge of consumptive use (evapotranspiration) [1] is necessary in planning farm irrigation systems and for improving irrigation practices. Irrigation and consumptive water-requirement data are used more and more widely in planning water distribution. By using information found in this bulletin and in similar reports, engineers and technicians can readily estimate irrigation water needs. Common water-measuring devices supply information on the quantity of water actually delivered to the farm. With this knowledge, evaluation of the losses occurring between the farm headgate and the plant roots is possible. Such losses—frequently more than 50 percent—may be reduced materially with improved water conservation practices.

[1] See appendix, p. 39, for definitions of terms used in this bulletin.

There is a need to correlate evaporation from water and land surfaces and transpiration from plants with the climatological factors and soil conditions. If longtime measurements of all the climatic factors affecting consumptive use were available, an empirical formula taking into account the effect of each factor could be developed and applied with reasonable accuracy for average conditions in any area. However, even in the more intensively settled areas, only part of the influencing factors have been measured. On new project lands that are still sparsely settled, it is unusual to have any factors measured except precipitation and temperature. And, in many instances, records of these influences are limited or not available.

New sources of irrigation water supplies are becoming limited, whereas the area of underdeveloped irrigable land is still extensive. As the cost of water increases, more careful estimates of water requirements on projects are necessary. Only the land that can 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 $500 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 produce properly and will not be able to pay the charges; but if the supply exceeds the needs, water costs may exceed the ability of the users to pay.

As a result, State, Federal, and other agencies responsible for the planning, construction, operation, maintenance, and administration of multiple-purpose projects, and those responsible for guiding and assisting farmers in the solution of their irrigation problems need basic water-requirement data.

If certain climatological data are available, this bulletin describes a method for estimating the irrigation needs and the consumptive use of water by crop, and thus the irrigation requirements for a given area.

PAST INVESTIGATIONS

Transpiration of water by plants has been studied for the past two centuries, and likewise evaporation of water has been studied over a long period *(1)*.[2] However, it was not until the first part of this century that the terms "consumptive use" and "evapotranspiration" came into general usage. And it has been only since 1935 that sufficient data have been available on this subject so that designers of irrigation and drainage systems and hydrologists have had confidence in the use of such material.

GENERAL STUDIES

The effect of sunshine and heat in stimulating transpiration was studied in England as early as 1691, according to Abbe *(1)*. Measurements of transpiration of various kinds of plants indicate a close

[2] Italic numbers in parentheses refer to Literature Cited, p. 36.

correlation between transpiration and evaporation from free-water surfaces, air temperature, solar radiation, and wet-bulb depression readings.

Several formulas have been developed in the past for determining evaporation and consumptive use of water by crops and other vegetation from meteorological data. Some 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. In 1924 Hedke, as reported by Blaney and coworkers *(13)*, 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 U.S. Bureau of Reclamation conducted intermittently from 1937 to 1940 by Lowry and Johnson *(35)*, a somewhat similar method was developed that has been widely used by the Bureau in making its estimates of valley consumptive use. This method also assumed 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, 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 *(29)*.

Thornthwaite *(44)*, working in Eastern United States, developed a method that seems rather well adapted to the more humid areas.

In 1948, Penman *(39)* of England led in the development of some of the more fundamental and rational approaches to the problem. However, all methods presently known have their limitations and require empirical coefficients, to correct for plant growth processes and physiological characteristics.

In 1955, Halkais, Veihmeyer, and Hendrickson *(28)* reported on a study of the relation between evaporation from atmometers and consumptive water requirements of crops. They claimed that an empirical relationship existed between monthly consumptive use and the difference in evaporation from black and white atmometers.

In 1960, Munson *(37)* of the Bureau of Reclamation developed the "P. E. Index Method" for estimating monthly and annual consumptive water requirements based on "Precipitation-Evaporation" ratios, temperatures, and field conditions.

Many others in the United States have, from time to time, worked on the problem of developing a method for estimating consumptive use of water by crops and other vegetation. Oftentimes, a method that is developed for one area, and appears to be practicable, has little application in other areas. However, studies in Japan, The Philippines, India, Pakistan, Jordan, Israel *(8)*, Spain, Greece, Turkey, France, Iraq, Italy, England *(39)*, Holland, Cuba, Venezuela, Brazil, Chile, Colombia, and many other countries have added to our general fund of knowledge on this subject.

U.S. DEPARTMENT OF AGRICULTURE STUDIES

At various times since 1900, the research agencies of the U.S. Department of Agriculture, in cooperation with State agricultural experiment stations and other agencies, have measured evapotranspiration of different agricultural crops and natural vegetation in many sections of the United States. Often evaporation, temperature, humidity, precipitation, and wind movement were all recorded at the same time. However, such complete data are not available for many areas. Thus, transposing consumptive-use measurements must be based on available climatological observations that usually include only temperature and precipitation.

One of the first studies (*24*) of evapotranspiration losses of irrigated crops was made in 1903 by the U.S. Department of Agriculture in California. Extensive studies (*17*) of evaporation, evapotranspiration, temperature, humidity, and wind movement were conducted by the senior author in 1919 at the Irrigation Field Laboratory located at Denver, Colo.

In 1930 the practicability of using the evaporation pan and temperature records as an index for estimating evapotranspiration losses from moist areas was demonstrated in southern California (*18*); similar use of such data was made in 1936 in the Joint Upper Rio Grande Investigation (*13*). Studies in 1931–44 in northern Idaho indicated a relationship between evaporation, temperature, and consumptive use (*22*).

Measurements of use of water by alfalfa in San Fernando Valley, Calif., in 1939–40 showed a good relationship between evapotranspiration, evaporation from a water surface, and temperature (*17*).

Studies of use of water by crops at Scottsbluff, Nebr., from 1932 to 1936 can be correlated with temperatures and evaporation (*20*).

Studies conducted by the authors and others in 1939–40, in connection with the Joint Pecos River Investigation of the National Resources Planning Board (*36*), indicated that data on evaporation, evapotranspiration, mean monthly temperature, monthly percentage of daytime hours, growing season, monthly precipitation, and efficiency of irrigation could be used to estimate irrigation requirements. 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 (*7, 16*). 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 these formulas might be used in estimating consumptive use by irrigated crops having access to an ample water supply. Because of the general lack of humidity data, the authors in 1945 (*11*) simplified the Pecos formulas by eliminating the humidity factor.

With the increased emphasis on irrigation in Eastern United States after World War II, there developed increased need for information on water requirement, particularly by the Soil Conservation Service, whose responsibility included assisting farmers in the design and construction of suitable irrigation systems. Because of the lack of data for the more humid areas, research was begun on water requirements

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of crops by the Department of Agriculture. But measurements are somewhat more difficult to obtain in humid areas because of the heavier and more frequent rainfall. Although water application could be rather well controlled under western conditions, the irrigator and experimenter has little or no control of how much and how frequently water, through precipitation, is applied to eastern lands. Nevertheless, considerable time and money have been expended in an attempt to measure water requirements of crops in the Eastern States and with considerable success.

In general, data are now available so that irrigation systems can be planned and operated with a reasonable degree of efficiency even under the higher rainfall conditions. And, even though only small amounts of irrigation water are required in such areas to get high crop yields, these small amounts often mean the difference between profit and loss. Many crops, if allowed to become too dry just once during the entire growing season, may produce little or no marketable yield. The water requirements of crops, as well as drought conditions, in Eastern United States have been studied by several investigators, including van Bavel (*48*).

In an attempt to develop a usable method of determining consumptive use and water requirements for Hawaii in 1960, Blewitt related pan evaporation empirically with individual crop consumptive requirements (*19*).

From the period 1948 through 1954, the authors assisted in the preparation, or prepared, bulletins setting up water requirement figures for certain Western States, a list of which is included in the appendix, p. 40.

METHODS

As previously stated, various methods have been used to measure 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 (*6*).

The principal approaches used in determining consumptive use have been tank (lysimeter) experiments, studies of soil moisture, and observations of ground-water fluctuations; and, for large areas, the inflow-outflow, effective-heat, and integration methods (*6, 13*). One of the more common methods of determining the use of water by individual crops or other plants is to grow them in tanks, or lysimeters, and measure the quantity of water necessary to maintain the growth satisfactorily. For years metal tanks as large as 10 feet in diameter, and more recently plastic tanks having 1,000 square feet of surface area or larger, have been used. In most past consumptive-use studies steel tanks have been about 2 to 6 feet in diameter and 4 to 6 feet deep. Double tanks (lysimeters) of galvanized iron have frequently been used (*18*). The inner tank, which is not watertight, holds the column of undisturbed soil in place. The outer tank is watertight and usually 2 or 3 inches wider in diameter and several inches longer. The outer, or larger, tank is set in the ground flush with the land surface. The U.S. Agricultural Research Service and the U.S. Geological Survey have used plastic tanks of various sizes. An installation, using plastic lining, is illustrated in figure 1.

Another common method used in determining the consumptive use of individual crops employs soil-moisture depletion studies (*4, 6*).

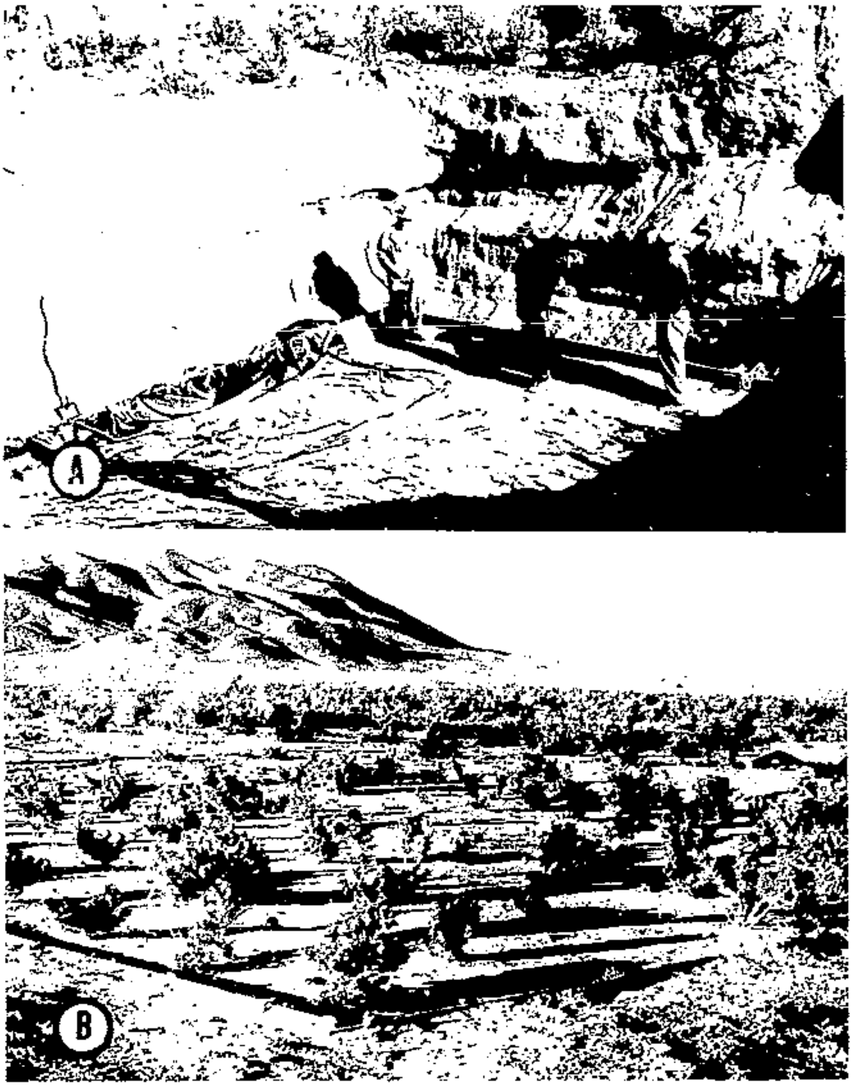

FIGURE 1.—An evaporation plastic tank installed on the Humboldt River project, near Winnemucca, Nev. *A*, Installing plastic membrane; 12-inch boards along side of pit outline the sides of the tank; membrane on the far side is folded back to show the boards, whereas on the left it is draped over the boards. Sand was spread evenly to a depth of 4 to 5 inches on top of membrane. *B*, Greasewood plants growing in the evapotranspiration tank (shown in *A* under construction) September 30, 1960. Of the 105 plants set on April 30, 1960, 80 rooted and thrived. Some replacement planting was done before the 1961 growing season. Photographs courtesy U.S. Geological Survey.

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 periodically. Samples are taken in 1-foot increments to depths of 3 to 10 feet, depending upon the crop and root zone. Equipment has been developed in southern California, consisting of a compressed-air unit, soil tube, and soil-tube jack *(18)* to obtain samples. For shallow depths, either a soil tube or auger may be used. Soil blocks for measuring electrically the moisture content or neutron-scatter moisture meter readings *(38)* may also be used to measure moisture content.

MEASURED CONSUMPTIVE USE

After centuries of irrigation in various countries of the world and with modern civilization dependent upon foods and fibers produced under irrigation, it seems strange that more is not known about actual water requirements of crops grown under various site conditions. However, since 1935, intensive studies have been underway throughout the United States and many other countries in an effort to find the basic water requirements of plants. The more common crops, including alfalfa, cotton, small grains, and grass pasture, have been studied most intensely. From an overall acreage and total water requirement standpoint, these crops are by far the most important. Information on seasonal uses of water under average field conditions available on such crops is believed to be fairly complete now, and considerable is known on the variability in use-rates that frequently occur.

With respect to many minor crops, and those not commonly grown in the United States, a paucity of data still exists. Years of study of the behavior of such crops under different site conditions will probably be necessary before rates of consumptive use can be definitely determined.

Seasonal Uses

Many early studies on consumptive use of water were made only on a seasonal basis, with little consideration given for monthly, weekly, or daily use-rates. For many purposes, data on a seasonal basis are sufficient. Certainly many storage reservoirs can be safely and efficiently designed with a knowledge of only seasonal water requirements. And, in general, seasonal consumptive water requirements do not vary too widely from year to year. Where growing-period rainfall varies widely between seasons, the total seasonal consumptive water requirement will remain reasonably constant, but irrigation water requirement may be determined largely by the rainfall. The measured use of water by various crops under widely varying climatic conditions is shown in table 1. More complete data on measured use-rates are given in appendix, table 15.

Most drainage systems can be designed without detailed short-time use of water rates and determination of basin-wide water supplies, and water inventories hardly need more than seasonal and annual consumptive use-rates.

TABLE 1.—*Examples of measured seasonal consumptive use and computed average daily and peak consumptive use of water for various crops at different locations in Western United States* [1]

Crop and location	Year of study	Growing season or period	Consumptive use			
			Total	Computed daily		Peak month
				Average	Peak	
Alfalfa at—			*Inches*	*Inches*	*Inches*	
Mesa, Ariz.	1945–46	([2])	51.0	0.20	0.35	July
San Fernando, Calif.	1940	4/1 –10/31	37.4	.17	.25	July
Davis, Calif.	------	4/1 –10/31	37.0	.17	.27	
St. George, Utah	1956–57	4/1 – 9/30	42.2	.23	.31	June
Logan, Utah	1902–27	5/7 –10/11	25.0	.16	.27	July
Beans at—						
Davis, Calif.	------	6/1 – 9/30	14.4	.12	.22	Aug.
Lompoc, Calif.	1959	6/1 – 9/30	14.4	.12	.15	July
Corn at—						
Davis, Calif.	------	6/1 – 9/30	12.0	.10	.14	Aug.
Vernal, Utah	------	6/10– 9/20	19.4	.20	------	
Redfield, S. Dak.	------	5/1 – 9/30	20.7	.13	.25	Aug.
Cotton at—						
Mesa, Ariz.	------	4/1 –10/31	34.9	.16	.27	Aug.
Shafter, Calif.	------	4/1 –10/31	29.8	.14	.31	Aug.
Flax at—						
Mesa, Ariz.	1951	10/1 – 6/20	37.0	.14	.25	Apr.
Redfield, S. Dak.	1954	5/1 – 8/31	17.8	.14	.28	Aug.
Grains, small, at—						
San Luis Valley, Colo.	1936	6/1 – 8/31	14.0	.15	------	
Logan, Utah	------	5/25– 8/21	16.6	.17	.24	June
Davis, Calif.	------	3/1 – 6/7	12.0	.12	------	
Garden City, Kans.	------	1/1 – 5/31	22.2	.15	.26	June
Orchards:						
Avocados at Fallbrook, Calif.	1953	4/1 –10/31	23.2	.11	.19	July
Oranges at—						
San Fernando, Calif.	1940	4/1 –10/31	22.1	.10	.12	Aug.
Phoenix, Ariz.	1931–34	1/1 –12/31	38.6	.13	.17	July
Grapefruit at Phoenix, Ariz.	1931–34	1/1 –12/31	47.6	.13	.21	Aug.
Lemons at San Fernando, Calif.	1940	4/1 –10/31	21.8	.11	.13	July
Deciduous fruits at—						
Ontario, Calif.	1933	4/1 – 9/30	28.4	.15	------	
San Joaquin, Calif.	------	4/1 –10/31	27.2	.14	.22	July
Walnuts at—						
Justin, Calif.	1930	4/1 – 9/30	27.4	.15	------	
Davis, Calif.	1933–35	4/1 – 9/30	24.0	.15	.27	July
Pasture at—						
Merced, Calif.	1955–56	6/1 –10/31	24.4	.16	.19	July
Columbia Basin	------	4/5 –10/15	24.0	.13	------	
Vernal, Utah	------	5/17–10/6	25.0	.18	------	

See footnotes at end of table.

TABLE 1.—*Examples of measured seasonal consumptive use and computed average daily and peak consumptive use of water for various crops at different locations in Western United States*[1]—Continued

Crop and location	Year of study	Growing season or period	Consumptive use			
			Total	Computed daily		Peak month
				Average	Peak	
			Inches	*Inches*	*Inches*	
Potatoes at—						
Bonner's Ferry, Idaho.	1947	5/8 – 9/27	23.0	0.19	------	
Deep River N. Dak.	1954–56	5/1 – 9/30	18.4	.12	0.20	July
Redfield, S. Dak	1954	5/1 – 9/30	20.2	.13	.20	Aug.
Logan, Utah	--------	5/20– 9/15	15.0	.13	.25	Aug.
San Joaquin, Calif	--------	5/1 – 9/30	18.0	.12	.21	July
Sorghum, grain (hegari), at Mesa, Ariz.	--------	7/1 –11/30	21.4	.17	.23	Sept.
Soybeans at Mesa, Ariz.	1931–54	6/1 –10/31	23.2	.15	.23	Aug.
Sugar beets at—						
San Joaquin, Calif	--------	4/1 – 9/30	27.6	.15	.23	July
Scottsbluff, Nebr	1932–35	5/1 –10/31	24.3	.14	.22	Aug.
Redfield, S. Dak	1954	5/1 –10/31	30.1	.16	.25	Aug.
Logan, Utah	--------	4/15–10/15	25.0	.14	------	Aug.
Tomatoes at Davis, Calif.	1933–35	6/1 –10/31	22.8	.15	.20	July
Vegetables:						
Asparagus at San Joaquin, Calif.	--------	4/1 –10/31	27.8	.13	.26	Aug.
Onions at San Joaquin, Calif.	--------	3/1 – 8/31	19.2	.11	.20	June
Truck crops, miscellaneous, at San Joaquin, Calif.	--------	4/1 –10/31	26.4	.12	.20	June

[1] See references contained in appendix, table 15.
[2] Annual period.

Short-Time Use-Rates

With the growing use of sprinkler irrigation systems and need for better information on the most economical capacities of irrigation systems, there has been an increased need for monthly, weekly, and even daily consumptive use of water rates. Thus, beginning about 1950, considerable effort has been directed by the Agricultural Research Service (*14*) and other agencies toward gathering such data. Several investigators have reported highly variable rates of use on a short-time basis. The data are probably correct but affected by many influencing factors, many of which have not been under the control of or measured by the investigator. Variations in solar radiation probably account for part of this variation. Consumptive use is not well correlated with temperature for short-time periods, although for long-time periods the correlation is high. However, data on solar radiation were not available for this report. Some measured monthly rates of use of water by various crops at selected sites are shown in table 2.

Observations indicate that the use of water by crops varies widely throughout the season and such variation cannot be explained by climatic data generally available. For instance, work in Texas (*14*) suggests that the average rate of consumptive use by grain sorghum planted June 15 is about 0.06 inch per day during the emergence period in the latter part of June. By the middle of July the use rate is up to about 0.20 inch per day, and the rate reaches a peak at about 0.30 inch per day about August 7 when the sorghum is in the boot stage. By the time the plant blooms—about August 15—the rate has decreased per day, and it continues to decrease until the sorghum is completely mature about the middle of October. The rate then holds constant at about 0.05 inch per day until harvested.

INFLUENCE OF VARIOUS FACTORS ON IRRIGATION 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 the factors may differ with locality and water consumption may fluctuate from year to year. Some effects involve the human factor; others are related to the natural influences of the environment and to the growth characteristics of the plants.

The more important of the natural influences are climate, water supply, soils, and topography. The climatic factors that particularly affect consumptive use are temperature, solar radiation, precipitation, humidity, wind movement, length of growing season, latitude, and sunlight. Data were not available for solar radiation.

PRECIPITATION

The amount and rate of precipitation may have some minor effect on the amount of water consumptively used during any summer. Under certain conditions, precipitation may occur as 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 but do decrease the withdrawal from the stored moisture. Such precipitation may be lost largely by evaporation directly from the surface of the plant foliage and the land surface.

Part of the precipitation from heavy storms may be lost by surface runoff. Other storms may be of such intensity and amount that a large percentage of the moisture will enter the soil and become available for plant transpiration. This available soil moisture may materially reduce the amount of irrigation water needed. Various methods have been used to estimate what the effective precipitation is under the different climate, soil, and crop conditions. Table 3 shows one of the methods used.

TABLE 2.—*Examples of measured monthly consumptive use of water for irrigated crops at selected locations in Western United States*

Crop and location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Reference
Alfalfa at—	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	
Mesa, Ariz	1.0	2.0	3.5	5.0	6.5	9.0	12.0	(1)	[1 2] 3.0	4.0	3.0	2.0	*(15)*
San Fernando Valley, Calif	1.3	1.6	3.1	3.3	6.7	5.4	7.8	4.2	5.6	4.4	3.1	1.3	*(14)*
Sacramento Delta, Calif			1.2	3.6	4.8	6.0	7.8	6.6	6.0	2.4			*(9)*
Scottsbluff, Nebr				.7	4.0	7.0	7.1	6.4	1.5				*(20)*
Deep River Farm, N. Dak				.3	4.5	6.7	6.2	3.9	1.7				*(14)*
St. George, Utah				4.7	8.2	9.2	8.4	6.7	5.0				*(14)*
Citrus fruit:													
Grapefruit at Phoenix, Ariz	1.7	2.2	2.8	3.8	4.7	5.4	6.4	6.4	5.4	3.9	2.7	2.2	*(14, 31)*
Oranges at Los Angeles, Calif				2.2	2.2	3.1	3.4	3.7	3.1	2.9			*(9)*
Cotton at—													
Phoenix, Ariz				1.6	2.1	4.0	7.5	8.4	6.9	4.4			*(14, 30)*
Shafter, Calif				.5	1.0	4.0	8.5	9.7	5.8	3.2			*(9)*
Weslaco, Tex			1.4	1.2	5.3	3.2	3.0						*(14)*
Corn at—													
Davis, Calif						2.9	10.2	10.1	4.8	1.2			*(49)*
Mandan, N. Dak					.9	4.2	5.7	5.1	1.3				*(14)*
Redfield, S. Dak					.9	4.6	6.2	7.8	1.2				*(14)*
Grain (winter wheat) at Amarillo, Tex	1.1	1.4	2.5	5.6	8.3	5.5					1.2	1.3	*(14)*
Pasture, irrigated, at—													
Murrieta, Calif					4.8	5.3	5.7	5.6	6.4	3.6			*(14)*
Merced, Calif						5.4	6.0	5.3	4.1	3.6			*(14)*

[1] Rest period from Aug. 1 to Sept. 15.
[2] Value for Sept. 16 to 30 only.

TABLE 3.—*Example of total and effective monthly precipitation for a given area* [1]

Total monthly precipitation that might occur (*inches*)	Monthly rainfall considered effective	
	Part of each inch increment	Accumulated total
	Inches	*Inches*
1	0. 95	0. 95
2	. 90	1. 85
3	. 82	2. 67
4	. 65	3. 32
5	. 45	3. 77
6	. 25	4. 02
Over 6	. 05	----------------

[1] Definition given in appendix, p. 39.

TEMPERATURE

The rate of consumptive use of water by crops in any particular locality is probably affected more by temperature, which for long-time periods is a good measure of solar radiation, than by any other factor. Abnormally low temperatures 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. 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.

The following is quoted from "Climate and Crops in Humid Areas" by Riley and Grissom (*41*):

Effect of temperature on crops.—Each crop has its own optimum, maximum and minimum temperature standards, however, most crops make their best development between 60° F and 90° F. Many plants make no growth when the temperature is down to 40° F whereas an extreme case, sorghum, practically stops growth when the temperature is down to 60° F. Depending on maturity and condition, most plants are killed by a temperature of 32° F or lower, and many others by 100° F or over.

The relation of temperature to crop production has evolved into two frequently quoted laws. According to A. D. Hopkin's Bioclimatic Law; starting in the southwest part of the country, such events as seeding time are generally delayed 4 days by each advance of one degree north latitude, five degrees of eastern longitude, and 400 ft. of increased altitude (4).

Van Hoff-Arrhenius' law for monomolecular chemical reactions holds true within normal temperature ranges and plant growth increases with each rise in temperature, approximately doubling for each 10° C increase. An extension of this law makes possible the "growing degree day" that is widely used by the vegetable packing industry as a guide for all phases of operation from the day of seedling to the final day of harvest.

(4) By A. D. Hopkins, "Bioclimatics, A science of life and climate relations," U.S. Dept. of Agri. Miscellaneous Publication No. 280, 1938, pp. 1-188.

HUMIDITY

Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity. During periods of low relative humidity, greater rate of use of water by vegetation may be expected (*1*).

WIND MOVEMENT

Evaporation of water from land and plant surfaces takes place 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. However, there is a limit in the amount of water that can be utilized. As soon as the land surface is dry, evaporation practically stops and transpiration is limited by the ability of the plants to extract and convey the soil moisture through the plants.

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 despite later freezes. Sometimes growth persists after the first so-called killing frost in the fall. In the spring, and to less extent in the fall, daily minimum temperatures may fluctuate several degrees above and below 32° F. for several days before remaining generally above or below the freezing point. The hardier crops survive these fluctuations and continue unharmed during a few hours of subfreezing temperature. In fact, many hardy crops, especially grasses, may mature even though growing season temperatures repeatedly drop below freezing. In southern Arizona and California alfalfa and citrus trees grow throughout the year (*3, 15*).

Although the frost-free season may be used as a guide for computing consumptive use, actual 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. Studies of the effect of climate on plant life were reported as early as 1905 (*1*). Phenological studies such as those underway in the western region of the United States, with headquarters at Bozeman, Mont., will greatly assist in making proper evaluation of the growing seasons.

LATITUDE AND SUNLIGHT

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. Since the sun is the source of all energy used in crop growth and evaporation of water, 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 potentially can be consumed in a given area. However, there are other factors that also cause important differences in the consumptive use-rates. Naturally, unless water is available from some source (precipitation, natural ground water, or irrigation), there can be no consumptive use. In those areas of the arid and semiarid West where the major source is irrigation, both the quantity and seasonal distribution of the available supply will affect consumptive use. Where water is plentiful and cheap, there is a tendency for farmers to overirrigate. If the soil surface is frequently wet and the resulting evaporation is high, the combined evaporation and transpiration or consumptive use may likewise increase. Also, under more optimum soil moisture conditions, yields of crops such as alfalfa may be higher than average and more water consumed. In irrigating some crops, such as potatoes, water is applied to the field not only for the purpose of supplying the consumptive water needs of the crop but also to help maintain a favorable microclimatic condition.

QUALITY OF WATER

Some investigations have shown that the quality of the water supply may have an appreciable effect on consumptive use. Whether or not plants actually transpire more or less if water is highly saline may be debatable. However, if it is necessary to apply additional water to the land to leach 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 cropped area.

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 small increase in use of water. However, an increase in fertility of the soil causes a decrease in the amount of water consumed per unit of crop yield.

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 likewise decrease. It is recognized that some damage to crops is caused every year by pests and diseases. Ordinarily the losses may not vary greatly from year to year, but in those years when they are unusually severe consumptive use may be lowered materially.

ESTIMATING WATER REQUIREMENTS

In planning irrigation projects or farm irrigation systems and practices where few or no measurements of water requirements are available, one usually finds it necessary to estimate water needs from basic climatological and irrigation data.

The procedure described in this bulletin may be used to transpose observed consumptive-use data from one area to other areas for which only climatological data are available. After total consumptive use is computed, the net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the amount of water supplied from natural sources from the total consumptive water requirement. This net requirement for any period divided by the irrigation efficiency, gives the irrigation water requirement of the crop for that period.

Actual measurements of consumptive use under each of the physical and climatic conditions of any large area are expensive and time-consuming. The results of research and measurements of the consumptive use of water, along with meteorological observations, provide basic data required for estimating water requirements for irrigated lands where few or no data, except climatological, may be available.

The method developed by the authors in 1945 (*11*), and revised in 1950 (*12*), to estimate consumptive use of water by irrigated crops from climatological data has been used in most of the United States and in many foreign countries. It has been found to be satisfactory for computing seasonal use where measured use-data are not available. The consumptive-use formula ($U=KF$) was first developed primarily for determining seasonal coefficients (K). However, it is recognized that coefficients for computing monthly and peak rates of water consumption are needed to meet the demands of action agencies. Since 1950 more data have been obtained by research studies on consumptive use by months and for shorter periods.

CONSUMPTIVE USE OF WATER

Although it is recognized that numerous factors must be taken into consideration to determine accurately consumptive use of water, the effect of temperature and sunshine upon plant growth as measures of solar radiation is, without doubt, the most important of the climatic factors. Temperature and precipitation records are more readily available than most other climatic data throughout present and potential agricultural areas of the world. Records of actual sunshine are not generally available, but the effect of sunshine is very important on the rate of plant growth and the amount of water plants will consume.

The effect of sunshine can be introduced by using the length of days during the crop-growing season at various latitudes. As an example, the length of the daytime at the Equator varies little throughout the year, whereas at 50° N. latitude, the length of the day in summer is much longer than in winter. Thus, at equal temperatures, photosynthesis can take place for several hours longer each June day at the north latitude than at the Equator. Crop growth and water consumption vary with the opportunity for photosynthesis.

Monthly percentages of annual daytime hours computed from possible sunshine hours (*1*) for latitudes covering most cropland areas of the world are shown in appendix, table 16. It is realized that computed daytime hours may be somewhat misleading, particularly in areas where heavy fog or stormy weather exists during the crop-growing season; however, temperatures tend to correct this effect. If humidity records are available, these may also be used as a correction (*16*). It is to be understood that if actual data are available, these should be properly correlated and used. Undoubtedly, as records are improved in the future, the theoretical values will be replaced by actual values in many computations.

CONSUMPTIVE-USE FORMULA

Disregarding many influencing factors, consumptive use varies with the temperature, length of day, and available moisture regardless of its source (precipitation, irrigation water, or natural ground water). Multiplying the mean monthly temperature (t) by the possible monthly percentage of daytime hours of the year (p) gives a monthly consumptive-use factor (f). It is assumed that crop consumptive use varies directly as this factor when an ample water supply is available. Expressed mathematically in English units $u=kf$ and U=sum of $kf=KF$ where,

t=Mean monthly temperature, in degrees Fahrenheit.
p=Monthly percentage of daytime hours of the year.
$f=\frac{t\times p}{100}$=monthly consumptive-use factor.
u=Monthly consumptive use, in inches.
U=Seasonal consumptive use (or evapotranspiration), in inches.
F=Sum of the monthly consumptive-use factors for the period (sum of the products of mean monthly temperature and monthly percentage of daytime hours of the year).
K=Empirical consumptive-use crop coefficient for irrigation season or growing period. (This has been found to be reasonably constant for all areas.)

In metric units,

$u=kp\left(\frac{45.7t+813}{100}\right)$=Monthly consumptive use, in millimeters.
t=Mean monthly temperature, in degrees Centigrade.

The consumptive-use factor (F) may be computed for areas for which monthly temperature records are available, if the percentage of hours that are shown in appendix table 16 are used. Then, the total crop consumptive use (U) is obtained by multiplying (F) by the empirical consumptive-use crop coefficient (K). This relationship allows the computation of consumptive use anywhere in the world for crops for which coefficients have been experimentally established or which can be estimated. Appendix tables 17 and 19 contain calculated normal monthly consumptive-use factors (f) and average monthly precipitation (r) for areas in Western United States and in various areas of the world. From these data the seasonal factor (F) can be determined for any growing period at these locations.

Seasonal Consumptive-Use Coefficients

A summary of measured consumptive-use values (U) for important crops at various locations, calculated consumptive-use factors (F), and the computed crop coefficients (K), is given in appendix table 15. As may be observed, the computed coefficients by the formula $K=\frac{U}{F}$ show some variation. Such measurements are difficult to make and may be subject to error because of the many diverse conditions under which the studies were conducted by the various investigators. Not only did climate vary, but usually the soils, water supplies available to the crop, methods of measuring consumptive use, crop yields, and other influencing factors also varied widely from place to place. Thus, a variation in the computed coefficients (K) is to be expected. However, based on a *personal knowledge of the physical* conditions under which many of the studies were conducted, the authors have analyzed all the available data and prepared table 4. This table lists coefficients recommended for various crops grown under normal conditions, regardless of location. The authors recognize the paucity of data available, particularly for many crops of the world. Further studies may verify or modify these coefficients. In those areas where reliable experimental data are available, consumptive-use coefficients may be adjusted to fit local conditions or the basic consumptive-use data may be used directly.

Monthly Consumptive-Use Coefficients

Although seasonal coefficients (K) as reported by various investigators show variation, monthly coefficients show greater variation. When dealing with monthly or short-time coefficients, one must recognize the number of factors that might influence growth besides climate. For instance, a crop may be attacked by insects and lose much of its foliage, thereby greatly reducing the amount of evapotranspiration that will take place for 30 days. Nevertheless, if the insects are controlled by man or naturally, and if other factors remain favorable, the crop yield at the end of the season and the total seasonal water consumption may be near normal. Immediately after cutting alfalfa for hay, the transpiration rate decreases. Under such conditions, the computed seasonal consumptive-use coefficient may be normal, whereas the monthly values will vary widely from normal.

The authors have analyzed the most reliable monthly data available and prepared table 5 and appendix table 18, which suggest monthly coefficients (k) for various crops grown under normal irrigation practice for different climates and areas in Western United States. These values were taken from smoothed curves based on field measurements. The tabulations indicate that alfalfa grows the year around in southern Arizona and California areas, whereas the growing season does not start until April in colder northern climates, such as North Dakota and Utah. It is the authors' opinion that considerably more research will be needed before daily or short-time consumptive use may be accurately predicted. However, table 1 indicates that daily peak use may be employed to estimate capacity of sprinkler irrigation systems.

TABLE 4.—*Seasonal consumptive-use coefficients (K) for irrigated crops in Western United States*

Crop	Length of normal growing season or period [1]	Consumptive-use coefficient (K) [2]
Alfalfa	Between frosts	0.80 to 0.90
Bananas	Full year	.80 to 1.00
Beans	3 months	.60 to .70
Cocoa	Full year	.70 to .80
Coffee	Full year	.70 to .80
Corn (Maize)	4 months	.75 to .85
Cotton	7 months	.60 to .70
Dates	Full year	.65 to .80
Flax	7 to 8 months	.70 to .80
Grains, small	3 months	.75 to .85
Grain, sorghums	4 to 5 months	.70 to .80
Oilseeds	3 to 5 months	.65 to .75
Orchard crops:		
Avocado	Full year	.50 to .55
Grapefruit	Full year	.55 to .65
Orange and lemon	Full year	.45 to .55
Walnuts	Between frosts	.60 to .70
Deciduous	Between frosts	.60 to .70
Pasture crops:		
Grass	Between frosts	.75 to .85
Ladino whiteclover	Between frosts	.80 to .85
Potatoes	3 to 5 months	.65 to .75
Rice	3 to 5 months	1.00 to 1.10
Sisal	Full year	.65 to .70
Sugar beets	6 months	.65 to .75
Sugarcane	Full year	.80 to .90
Tobacco	4 months	.70 to .80
Tomatoes	4 months	.65 to .70
Truck crops, small	2 to 4 months	.60 to .70
Vineyard	5 to 7 months	.50 to .60

[1] Length of season depends largely on variety and time of year when the crop is grown. Annual crops grown during the winter period may take much longer than if grown in the summertime.

[2] The lower values of K for use in the Blaney-Criddle formula, $U=KF$, are for the more humid areas, and the higher values are for the more arid climates.

ASSUMPTIONS IN APPLYING FORMULA

In order to apply results of a consumptive-use-of-water study in one area to other areas, it is usually necessary to make certain minor assumptions. As previously indicated, if sufficient basic information is available, such actual data should be used. But rarely are all needed data known in sufficient detail. In general, the more actual data available, the more accurate should be the estimates or assumptions. Where necessary information is lacking, the following assumptions must be made in applying the consumptive-use formula to transfer data between areas:

1. Seasonal consumptive use (U) of water varies directly with the consumptive-use factor (F).
2. Crop growth and yields are not limited by inadequate water at any time during the growing season.

TABLE 5. *Examples of suggested monthly consumptive-use coefficients (k) for some irrigated crops at various locations in Western States* [1]

Crop and location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alfalfa:												
Mesa, Ariz	0.35	0.55	0.75	0.90	1.05	1.15	1.15	1.10	1.00	0.85	0.65	0.45
Los Angeles, Calif	.35	.45	.60	.70	.85	.95	1.00	1.00	.95	.80	.55	.30
Davis, Calif				.70	.80	.90	1.10	1.00	.80	.70		
Logan, Utah				.55	.80	.95	1.00	.95	.80	.50		
Corn at Mandan, N. Dak					.50	.65	.75	.80	.70			
Cotton:												
Phoenix, Ariz				.20	.40	.60	.90	1.00	.95	.75		
Bakersfield, Calif					.30	.45	.90	1.00	1.00	.75		
Weslaco, Tex			.20	.45	.70	.85	.85	.80	.55			
Grapefruit at Phoenix, Ariz	.40	.50	.60	.65	.70	.75	.75	.75	.75	.70	.60	.50
Oranges at Los Angeles, Calif	.30	.35	.40	.45	.50	.55	.55	.55	.50	.50	.45	.30
Potatoes:												
Davis, Calif				.45	.80	.95	.90					
Logan, Utah						.40	.65	.85	.80			
North Dakota					.45	.75	.90	.80	.40			
Grain, small:												
Wheat at Phoenix, Ariz	.20	.40	.80	1.10	.60							
Oats at Scottsbluff, Nebr					.50	.90	.85					
Sorghum:												
Phoenix, Ariz						.40	1.00	.85	.70			
Great Plains Field Sta., Tex						.30	.75	1.10	.85	.50		

[1] Additional coefficients are shown in appendix table 18.

3. The fertility and productivity of the soils at the various locations are similar.
4. Growing periods for alfalfa, pasture, orchard crops, and "natural" vegetation, although usually extending beyond the frost-free periods, are usually indicated by such periods. Yields of crops dependent upon vegetative growth only vary with the length of the growing period.

Figure 2 is a nomograph developed for the solution of the consumptive-use formula, $u=kf$, in the English and metric systems. If the mean monthly temperature and the latitude of the area are known, it is possible to estimate the normal monthly consumptive use (u) of any crop for which (k) is known.

As an example, assume that it is desired to know what the July consumptive use of water by sugar beets might be in an area of lat. 36° N., where the mean temperature during the month was 70° F. For this condition, the July consumptive-use coefficient for sugar beets is estimated to be 0.70. From appendix table 16, p is 9.99 percent. Entering the nomograph (fig. 2) with the above values of t and p, we find that $f=6.9$. With a k of 0.70 the use of water by sugar beets during July will be about 4.8 inches. Had the crop been alfalfa with a k of 1.00, the normal July use would be about 6.9 inches. In other words, 7 inches of water must be made available for crop use during the month. This requirement may be met from precipitation,

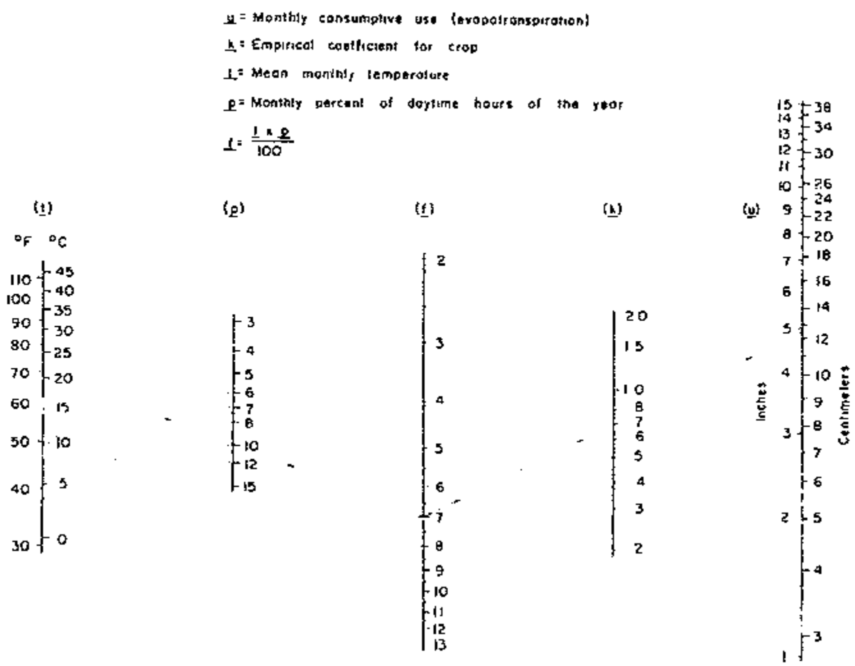

FIGURE 2.—Nomograph for solution of monthly consumptive-use formula:

$$u=kf=k\left(\frac{tp}{100}\right).$$

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carryover soil moisture stored previously, ground water, and irrigation. In the hot, dry western areas, most, if not all, of this requirement must be met by irrigation. As we move eastward, more and more of the crop needs may be met by summer precipitation.

IRRIGATION REQUIREMENTS

Basic consumptive-use data are used in estimating the irrigation water requirement of existing or proposed projects and for crop production on individual farms. The consumptive irrigation water requirement is dependent not only on the total consumptive need, but also on that contributed from such natural sources as usable summer precipitation, soil moisture contributed by winter rains, and any contribution from ground water.

In some areas of low precipitation it is necessary to irrigate before a crop is planted. In other areas there may be sufficient moisture stored from precipitation not only to germinate the seed but also to start and maintain plant growth during part of the summer. Irrigation water is only needed to supplement moisture available from other sources. However, the net consumptive irrigation requirement can be met on a practicable basis only by having available at the farm headgate more water than is needed by the crop. The excess is that needed to take care of necessary distribution and application losses that occur. This total is estimated by dividing the net consumptive irrigation requirement by the irrigation efficiency.

IRRIGATION EFFICIENCIES

Knowledge of consumptive uses is important in the case of a large irrigation project, and especially for river systems as a whole. However, it may not be so important to the individual farm as the efficiency with which the water is conveyed, distributed, and applied, especially on a long, narrow project. Irrigation authorities have estimated that less than 30 percent of the water diverted from the source actually becomes available for use by the plant in some areas. This, for example, means that in order to supply a 27-inch depth of water per acre to alfalfa for actual consumptive use, at least 90 acre-inches (7½ acre-feet) would have to be diverted from the river or other source. Of the unused 70 percent, a large part is usually made up of transmission and distribution losses in unlined canals, laterals, and farm ditches. Application losses—evaporation, deep percolation, and surface runoff—account for the rest. Such losses indicate a need for improvement in the use of available water resources.

Irrigation efficiency is the percentage of irrigation water that is made 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. (See appendix, p. 39.) Research workers have considered efficiency of irrigation (water-application efficiency) as the percentage of water that can be accounted for as the increase of 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 U.S. Department of Agriculture in cooperation with State agricultural experiment stations and other agencies in Western States, particularly California (*4*), New Mexico (*36*), Utah (*33*), and Washington.[3]

If the farm laterals are 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. This will allow for a corresponding decrease in the total amount of water that must be delivered to the land for crop production.

Methods of determining irrigation efficiency have been described in other reports (*4*, *33*). 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 irrigation site conditions.

Effect of Soils

Probably the factor having the greatest effect on irrigation efficiency, aside from the handling by the irrigator himself, is the soil on the farm and that soil through which the canals and ditches run. This applies particularly to older projects, where farm irrigation systems were not necessarily laid out according to soil characteristics. In general, considerable loss of water by deep percolation occurs in the lighter soils. On the heavier soils, much water may be lost through surface runoff. Typical irrigation efficiencies for several different soil conditions are shown in table 6.

TABLE 6.—*Typical water-application losses and irrigation efficiencies for different soil conditions*

Item	General soil type		
	Open, porous	Medium loam	Heavy clay
	Percent	*Percent*	*Percent*
Farm-lateral loss[1]	15	10	5
Surface runoff loss	5	10	25
Deep percolation loss	35	15	10
Field-irrigation efficiency[2]	60	75	65
Farm-irrigation efficiency[2]	45	65	60

[1] Unlined ditches (loss in new-lined ditches and pipelines is usually about 1 percent).

[2] See appendix for definitions, p. 39.

[3] Mech, S. J. PROGRESS REPORT. Irrigation Branch Experiment Station, Prosser, Wash. 1948. (Typewritten.)

One of the major reasons for low irrigation efficiencies is the change of intake rate that occurs throughout the irrigation season and from year to year within the crop rotation period. Because of this rate-of-intake variation, which might range from one to four within any one season and at least double between seasons, considerable flexibility must be built into the irrigation system if high efficiencies are to be obtained. The size of stream per unit area must be large when intake rates are high and smaller as the intake rates decrease.

Effect of Crops

As a rule, it is possible to get higher efficiency of irrigation with close-growing crops than with those grown in rows. Also, application efficiencies 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 "oversoaked" 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 when 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 hill under young plants. As the plants develop and the root systems grow, 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, where adapted, is conducive to relatively high efficiency in the use of water. At the other end of the scale, wild flooding is probably the least efficient of all methods and is usually not justified where the cost of water is high. Flooding frequently results in nonuniform distribution and excessive waste of water and is likely to create serious drainage problems.

High Efficiencies Essential

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.

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 of good natural drainage and where deeply percolating water will not waterlog productive soil and will soon be recovered as return flow, or by pumping. In some areas, water must be applied for leaching purposes to decrease the accumulation of harmful salts in surface soils. But efficient water application on the higher lands delays the time when drainage of adjacent lower lands may be required.

USABLE PRECIPITATION

The amount of growing-season precipitation that is usable by plants is difficult to predict because of the many conditions encountered. Undoubtedly, not all rainwater will enter and be stored in the soil. In some areas of light rainfall, practically all summer precipitation may be lost by evaporation from the foliage and adjacent land surface. None may be retained in the soil for transpiration by the crop. However, in such areas, the total summer precipitation is probably a relatively small amount of the seasonal consumptive requirements of the crops. The showers, although adding little or nothing to the usable soil moisture supply, are commonly accompanied by cloudy weather, during which evapotranspiration is slowed down. Thus, such storms may be of value in meeting the water needs of crops.

In those areas where growing-season rainfall is heavy and intense, some will be lost, depending upon the intake rate and storage capacity of the soil in the root zone of the crop use. Likewise, even though the soil may absorb the rainfall, any in excess of that which the root zone will retain is lost to the crop above.

Unless detailed information is available on the character of the storms and the surface runoff and deep percolation that occurs from each, the authors recommend that "effective summer precipitation" be estimated, using monthly precipitation data and the relationship as shown in table 3. But here again, local experience may be more useful than any arbitrary formula that might be set up to cover all conditions of rainfall, soils, crops, topography, and climate.

WINTER SOIL-MOISTURE CARRYOVER CONTRIBUTION

As with precipitation, the contribution of carryover soil moisture to the seasonal water requirement is difficult to evaluate. In some areas, winter precipitation is sufficient to bring the soil moisture in the root zone of the plants up to field capacity (*4*). Where late-season water supplies are short, the soil moisture is usually well below field capacity and possibly down to the wilting point in the fall.

For crops with a 6-foot root zone, the amount of usable water that could be stored might range from 1 to 2 inches of water per foot depth of soil, or 6 to 12 inches in the 6-foot root zone. This is a major part of the annual requirement of some crops and can be supplied by winter precipitation in some areas in wet years. However, in areas where irrigation water is plentiful, it is not unusual to find the soil moisture content at the end of the season nearly as high as at the beginning. Thus, there is no storage capacity left in the root zone and the contribution from winter precipitation is negligible. Nevertheless, the quantity of moisture carried over in the soil from winter precipitation tends to offset any deficiency in the estimated irrigation water requirements.

GROUND WATER CONTRIBUTION

In areas of high natural ground water, the irrigation requirement may be materially less than if ground water were not available. However, if the high ground water is the result of excess irrigation, the overall demand on the irrigation supply by the crops is not decreased. In such a case, part of the irrigation is obtained by underground methods. As an example, studies in San Fernando Valley in southern California indicated a consumptive use of water by alfalfa of 37 inches during the irrigation season (*17*). In areas of high water table in this valley only 24 inches of surface irrigation water was required to produce a good yield of alfalfa. The additional 13 inches came from underground water supplies and a small amount of summer precipitation. Alfalfa, which is a phreatophyte, will produce a crop in some areas of high water with very little irrigation.

APPLICATION OF CONSUMPTIVE-USE FORMULA TO SPECIFIC AREAS

The amounts of water required to irrigate an individual crop, a single farm, or any entire irrigation project may be estimated by the procedure described by Blaney (*10*).

In the following section this procedure has been applied under several different climatic conditions found in the United States. Five different examples for individual crops are presented, covering coastal areas to hot humid interior areas. An example showing use of the method for computing total farm irrigation requirements for an intermountain area is included. This latter procedure can be expanded to cover an entire irrigation project or a complete valley. The values for sprinkler irrigation systems in Hawaii need to be modified.

COASTAL AREA IN SOUTHERN CALIFORNIA

Irrigation is the most essential item in the production of citrus fruits in southern California. The total annual rainfall in that area is insufficient to meet the needs of the crops. Normally, rainfall occurs from November to April, inclusive, and provides moisture for winter use. However, rainfall distribution in some years may be such as to make some winter irrigation necessary. Water is usually delivered to the farm headgate through pipe or concrete-lined canals. There is practically no conveyance loss from the underground pipe distribution system between the farm headgate and the field to be irrigated. Thus the farm-irrigation efficiency is usually about the same as the field-irrigation efficiency.

The procedure for computing the normal monthly irrigation requirements of a mature orange grove in Orange County is given in table 7. On March 31 about 3.7 inches of moisture is stored in the soil from winter rains, so no irrigation is required in April. The total irrigation requirement for the period April 30 to October 31 is estimated at 21.9 inches. In years of normal distribution of rainfall, very little irrigation is needed until May. In wet years 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, Calif.*

Month	Mean temperature	Daytime hours	Consumptive use		Consumptive use	Average rainfall	Average effective rainfall [2]	Consumptive-use minus effective rainfall	Irrigation requirement [3]
			Factor	Coefficient					
	(t)	(p)	(f)	(k) [1]	(u)	(r)	(r_e)	$(u-r_e)$	(i)
	° F.	*Percent*			*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	53. 0	7. 09	3. 76	0. 20	0. 82	2. 27	2. 09	−1. 27	....
February	54. 6	6. 90	3. 77	. 30	1. 13	3. 25	2. 94	−1. 81	....
March	57. 1	8. 35	4. 77	. 35	1. 67	2. 57	2. 32	−. 65	....
April	59. 9	8. 79	5. 27	. 40	2. 11	. 98	. 95	1. 16	(4)
May	63. 5	9. 71	6. 17	. 40	2. 47	. 38	. 36	2. 11	2. 6
June	67. 1	9. 69	6. 50	. 50	3. 25	. 04	(5)	3. 25	4. 0
July	71. 4	9. 87	7. 05	. 55	3. 88	. 01	(5)	3. 88	4. 8
August	71. 9	9. 33	6. 71	. 50	3. 35	. 05	(5)	3. 35	4. 1
September	69. 5	8. 36	5. 81	. 54	3. 14	. 22	(5)	3. 14	3. 7
October	64. 7	7. 90	5. 11	. 40	2. 04	. 71	. 68	1. 36	1. 7
November	59. 1	7. 02	4. 15	. 40	1. 66	. 91	. 86	. 80	1. 0
December	54. 7	6. 92	3. 78	. 35	1. 32	3. 01	2. 76	−1. 44	....
Total, or mean	62. 2				26. 84	14. 40	13. 27	....	21. 9

[1] k for months of April to November are from table 6 of reference (*9*) based on measured values; k for January, February, March, and December are extrapolated, where $k=\frac{u}{f}$.

[2] Determined in accordance with table 3 except for minor rainfall as indicated.

[3] Based on irrigation efficiency of 80 percent under good basin irrigation practice in Orange County with continuous tree growth.

[4] Winter carryover soil moisture, March 31 = 3.7 inches. Therefore, no irrigation required in April.

[5] The small amount of rainfall is negligible.

SALT RIVER VALLEY, ARIZ.

The climate of the Salt River Valley is characterized by high temperatures, long hot summers and mild winters, low annual rainfall, and low humidity. Research studies have been made on use of water by alfalfa, cotton, citrus, sorghum, and other crops in this valley. The consumptive water requirements of cotton in the vicinity of Phoenix are generally typical of the water needs of this crop in other hot interior valleys of the West and in other areas of the world. However, summer precipitation may make a marked difference in the consumptive irrigation requirement (*15*).

The computed monthly irrigation requirements of cotton in the Salt River Valley of Arizona are shown in table 8. This table shows a total consumptive use of about 36 inches, of which 32 must be supplied from irrigation. With an irrigation efficiency of 70 percent, about 46 inches, or 3.8 acre-feet, of water must be delivered for cotton grown in this climate.

TABLE 8.—*Computed normal monthly consumptive use and irrigation requirements for cotton in the vicinity of Mesa, Salt River Valley, Ariz.*

Month	Consumptive use		Consumptive use	Rainfall		Consumptive use minus effective rainfall	Irrigation requirement[4]
	Factor	Coefficient		Total	Effective		
	(f)[1]	(k)[2]	(u)	(r)	(r_e)[3]	$(u-r_e)$	(i)
			Inches	*Inches*	*Inches*	*Inches*	*Inches*
April	5.89	0.19	1.12	0.40	0.38	0.74	1.05
May	7.28	.38	2.77	.12	[5] .11	2.77	3.96
June	8.17	.61	4.98	.07	[5] .07	4.98	7.11
July	8.85	.89	7.88	1.07	1.01	6.87	9.82
August	8.25	.98	8.08	.95	.90	7.18	10.26
September	6.91	.97	6.70	.75	.71	5.99	8.55
October	5.58	.77	4.30	.47	.45	3.85	5.50
Total			35.83	3.83	3.63	32.02	46.25

[1] See appendix table 17.
[2] See appendix table 18.
[3] See table 3.
[4] Based on a field irrigation efficiency of 70 percent.
[5] The small amount of rainfall is negligible.

CALDWELL AREA, IDAHO

In the northern area of the United States midsummer daily water requirements of the crops are high, partially because of the longer days at the northern latitudes. The monthly consumptive use by a grass-alfalfa mixture near Caldwell, Idaho, and the monthly irrigation requirement are shown in table 9. The computed irrigation requirement to the farm is 38 acre-inches.

TABLE 9.—*Computed normal monthly consumptive use and irrigation requirements for grass-alfalfa near Caldwell, Idaho*

Month	Consumptive use		Consumptive use	Rainfall		Consumptive use minus effective rainfall	Irrigation requirement[4]
	Factor	Coefficient		Total	Effective		
	(f)[1]	(k)[2]	(u)	(r)	(r_e)[3]	$(u-r_e)$	(i)
			Inches	*Inches*	*Inches*	*Inches*	*Inches*
May 7–31[5]	4. 30	0. 83	3. 57	1. 08	1. 02	2. 55	4. 25
June	6. 68	. 89	5. 95	. 92	. 87	5. 08	8. 47
July	7. 58	. 90	6. 82	. 24	. 23	6. 59	10. 98
August	6. 87	. 83	5. 70	. 19	. 18	5. 52	9. 20
September	5. 15	. 69	3. 55	. 53	. 50	3. 05	5. 08
October 1–3.	. 38	. 35	. 13	. 12	. 11	. 02	
Total			25. 72	3. 08	2. 91	22. 81	38. 01

[1] See appendix table 17.
[2] See appendix table 18.
[3] See table 3.
[4] Based on 60 percent farm-irrigation efficiency.
[5] Assumed to be three-fourths of amount for the full month.

ALTUS AREA, OKLA.

Most crops, including grain, cotton, and alfalfa, are grown without irrigation in many semihumid southern areas of the Midwest. However, in dry years, yields frequently are low. Particularly, alfalfa will show increased production under irrigation. One such area is the Altus Bureau of Reclamation Project, Oklahoma.

Annual precipitation at Altus ranges from about 14 to 48 inches. The mean annual precipitation is 26 inches. Of this 26, about 20 inches falls during the period April to October, inclusive. Table 10 illustrates a procedure suggested in estimating the normal water requirements and the distribution of irrigation water for a field of alfalfa. In years of average rainfall, with a field-irrigation efficiency of 75 percent, the total irrigation water required for an alfalfa field would be $\frac{22}{0.75}$ or 29 inches. During periods of high-intensity rainfall, usually some water will be noneffective because of surface runoff. Under the conditions of relatively heavy winter precipitation, it was assumed that nearly 3 inches of winter precipitation can be stored in the soil for use by alfalfa during the following summer. This was taken into consideration in preparing table 10, which shows a total consumptive irrigation requirement of only 22 inches.

SOUTH ATLANTIC COASTAL AREA, CHARLESTON, S.C.

In recent years, application of irrigation water to supplement rainfall has greatly increased along the Atlantic coast. Much of the irrigation in the East is done by the sprinkler method, and estimates

TABLE 10.—*Computed normal monthly consumptive use and irrigation water requirements for alfalfa for the major growing season, Altus area, Okla.*

Month	Consumptive use			Rainfall					Irrigation requirement		
	Factor (f)[1]	Assumed coefficient[2] (k)[2]	Monthly requirement (u=kf)	Monthly (r)	Amount effective (r_e)[3]	Effective during growing season (r_e)	Winter evaporation from soil[4]	Natural carryover as soil moisture[5]	For consumptive use of crops[6]	At the field headgate[7]	
			Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Feet
January	2.74			0.76	0.76		0.50	0.26			
February	3.09			.84	.84		.50	.34			
March	4.43			1.54	1.44		.75	.69			
April	5.49	0.50	2.74	2.78	2.49	2.49			(8)		
May	6.86	.80	5.49	3.50	3.01	3.01			(9)		
June	7.78	1.00	7.78	3.18	2.80	2.80			[10] 4.77	6.36	0.53
July	8.33	1.10	9.16	1.84	1.71	1.71			7.45	9.93	.83
August	7.82	1.05	8.21	2.49	2.26	2.26			5.95	7.93	.66
September	6.34	1.00	6.34	2.83	2.53	2.53			3.81	5.08	.42
October	5.07	.50	2.54	3.21	2.82	[11] 2.54		.28			
November	3.65			1.24	1.17		.50	.67			
December	2.88			1.28	1.20		.50	.70			
Total or average	64.48	.85	42.26	25.49	23.03	17.34	2.75	2.94	21.98	29.30	2.44

[1] From appendix table 17.
[2] Assumed from experimental data in other areas.
[3] Computed from table 3.
[4] Assumed.
[5] Difference between effective precipitation and loss by evaporation.
[6] Consumptive water requirement minus precipitation and residual carryover soil moisture available during the month.
[7] Based on a field irrigation efficiency of 75 percent. This may be applied during the month as shown, or some may be stored ahead of time.
[8] Consumptive requirement of 2.74 inches minus effective precipitation of 2.49 would require withdrawal of 0.25 inches from the soil moisture reserve of 2.94 inches at the end of March, but would not require irrigation. The soil moisture reserve at the end of April would then be 2.69 inches.
[9] 5.49 minus 3.01 = 2.48 to come from soil moisture carryover of 2.69 leaving 0.21 inch as carryover at the end of May.
[10] 7.78 inches minus 2.80 = 4.98 inches to come from carryover soil moisture (0.21 in.) and irrigation (4.77).
[11] Only 2.54 inches is needed to satisfy consumptive requirement and 0.28 inch to replenish soil moisture.

of both monthly and seasonal requirements or water are needed in designing the sprinkler system and other structures. In such irrigated areas, monthly and seasonal distribution of precipitation is an extremely important factor. Precipitation records for the growing season during typical years should be analyzed by storms in order that irrigation requirements can be properly estimated. Also, surface runoff should be considered when the rainfall rates exceed the infiltration capacity of the soil. It may be that the standard reduction to obtain effective precipitation, as shown in table 3, will not always apply without some further correction for the site condition. However, only local data can show this.

Owing to the high humidity in the Eastern coastal area, consumptive-use coefficients developed for arid and semiarid regions should be reduced. Further research is needed to verify the relation of monthly temperature with monthly consumptive use in humid climates. Meanwhile, the tentative coefficients indicated in table 5 may be used for humid areas and further refined if local data so indicates.

The normal mean monthly precipitation records at Charleston, S.C., indicate sufficient rainfall to produce some crops during the growing season, whereas other crops will require supplemental irrigation in the summer months for optimum yield and quality. In dry summers there is a definite need for irrigation of most crops. Table 11 illustrates the method of making tentative estimates of monthly consumptive use and irrigation requirements for a dry year at Charleston for an improved grass pasture based on an analysis of temperature, evaporation, and precipitation. The total irrigation requirement of this crop from March 1 to October 31 is computed as about 28 inches.

MONTROSE AREA, COLO.

An example of computing water requirements is illustrated in tables 12 to 14. The calculations necessary to determine monthly consumptive-use factors (f) and effective rainfall (r_e) are shown in table 12. These computations do not include any carryover soil moisture from winter precipitation or any contribution from ground water.

In some farm-planning programs it is necessary to estimate irrigation requirements of the several crops at the point of water delivery to the field. This may be accomplished by dividing the net consumptive use (total consumptive use minus effective precipitation) by field irrigation efficiency, as shown in table 13. For example, the irrigation water required to satisfy the consumptive use of alfalfa is 26.45−4.46, or 22 inches. Assuming a field irrigation efficiency of 70 percent, then $\frac{22}{0.70}=31$ inches, the amount of irrigation water that would be required at the field for the season, May 6 to October 6. This is equivalent to 2.75 acre-feet per acre. The total amount of water that should be delivered to the farm headgate to irrigate the alfalfa may be estimated by making an allowance for any conveyance loss from the farm headgate to the field.

TABLE 11.—*Computed monthly consumptive use and irrigation requirement for grass pasture, Charleston, S.C., for dry year 1925*

Month	Mean monthly temperature	Monthly percent of daytime hours	Monthly consumptive-use factor	Monthly consumptive-use coefficient	Monthly precipitation		Monthly consumptive use	Consumptive use minus rainfall	Irrigation requirement [4]
					Total	Effective			
	(t)	(p)	(f) [1]	(k) [2]	(r)	(r_e)	(u) [3]	($u-r_e$)	(i)
	°F.	Percent	Inches		Inches	Inches	Inches	Inches	Inches
March	59.2	8.36	4.95	0.50	1.28	1.20	2.47	1.27	1.81
April	66.8	8.77	5.86	.60	1.89	1.75	3.52	1.77	2.53
May	71.0	9.67	6.86	.70	1.96	1.81	4.80	2.99	4.27
June	79.8	9.63	7.68	.75	5.49	3.84	5.76	1.92	2.74
July	82.8	9.83	8.14	.80	2.38	2.16	6.51	4.35	6.21
August	81.2	9.31	7.56	.80	1.62	1.51	6.05	4.54	6.49
September	77.0	8.34	6.42	.70	1.94	1.79	4.49	2.70	3.86
October	68.8	7.91	5.44	.50	3.08	2.52	2.72	.20	.29
Total			52.94		19.64	16.58	36.32	19.74	28.20

[1] $f = \frac{t \times p}{100}$.
[2] Estimated.
[3] $u = kf$.
[4] Based on irrigation efficiency of 70 percent.

TABLE 12.—*Example of observed monthly temperatures and precipitation and calculated consumptive-use factors and effective rainfall for the Montrose area, Colo.*

Month	Mean temperature	Percent daytime hours	Consumptive use factor, $\frac{t \times p}{100}$	Precipitation		Consumptive-use factors and effective rainfall for crops during the frostfree or growing period					
				Normal	Effective	Alfalfa, grass, hay, and orchard, 5/6 to 10/6		Corn and other annuals, 5/9 to 9/6		Grain and beans, 5/6 to 8/6	
	(t)	(p)	(f)	(r) [1]	(r_e)	(f)	(r_e) [2]	(f)	(r_e) [2]	(f)	(r_e) [2]
	°F.			Inches	Inches		Inches		Inches		Inches
January	24. 6	6. 84	1. 68	0. 55	0. 52						
February	31. 7	6. 78	2. 15	. 47	. 45						
March	39. 8	8. 34	3. 32	. 76	. 72						
April	48. 4	8. 92	4. 32	1. 00	. 95						
May	57. 3	9. 94	5. 70	1. 05	1. 00	4. 60	0. 81	4. 60	0. 81	4. 60	0. 81
June	66. 5	9. 98	6. 64	. 47	. 45	6. 64	. 45	6. 64	. 45	6. 64	. 45
July	72. 2	10. 13	7. 31	. 79	. 75	7. 31	. 75	7. 31	. 75	7. 31	. 75
August	69. 8	9. 49	6. 62	1. 31	1. 23	6. 62	1. 22	6. 62	1. 22	1. 28	. 24
September	62. 0	8. 38	5. 20	1. 11	1. 05	5. 20	1. 05	1. 04	. 21		
October	50. 0	7. 78	3. 89	. 96	. 91	. 75	. 18				
November	37. 6	6. 80	2. 56	. 60	. 57						
December	26. 8	6. 62	1. 77	. 69	. 66						
Total		100. 00	51. 16	9. 76	9. 26	31. 12	4. 46	26. 21	3. 44	19. 83	2. 25

[1] r=average precipitation.
[2] r_e=effective precipitation, see table 3.

TABLE 13.—*Example of computation of seasonal consumptive use and irrigation requirements for crops in the Montrose area, Colo.*[1]

Land use	Frostfree or growing season	Consumptive use			Computed effective rainfall	U minus R	Field irrigation efficiency	Irrigation requirement
		Factor (F)	Coefficient (K)	Amount (U)	(R_e)	R	(E)	(I)
				Inches	*Inches*	*Inches*	*Percent*	*Inches*
Alfalfa	5/6–10/6	31. 12	0. 85	26. 45	4. 46	21. 99	70	31. 3
Grass hay	5/6–10/6	31. 12	. 75	23. 34	4. 46	18. 88	60	31. 5
Corn	5/6– 9/6	26. 21	. 75	19. 66	3. 44	16. 22	65	25. 0
Small grain	5/6– 8/6	19. 83	. 75	14. 87	2. 25	12. 62	65	19. 4
Orchards	5/6–10/6	31. 13	. 65	20. 23	4. 46	15. 77	70	22. 5
Seeped land	5/6–10/6	31. 12	. 80	24. 90	4. 46	20. 44		
Dense natural vegetation	5/6–10/6	31. 12	1. 20	37. 34	4. 46	32. 88		

[1] $U=KF$=consumptive use for growing or irrigation season.
K=empirical use-coefficient determined experimentally. (See table 4.)
F=sum of monthly use factors (f) for the growing or irrigation season.
R_e=sum of monthly effective precipitation for growing or irrigation season.
$I=\frac{U-R}{E}$=irrigation requirement at head of the field; no carryover of soil moisture from winter precipitation, considered as effective in this example.

TABLE 14.—*Example of the method used to compute the normal amount of irrigation water required at headgate at a typical 80-acre farm near Montrose, Colo.*

Land use	Land area	Irrigation water required for consumptive use [1]		Farm irrigation efficiency [2]	Water required for crops at farm headgate	
		Per acre	Total		Per acre [3]	Total
Irrigated	*Acres*	*Acre-feet*	*Acre-feet*	*Percent*	*Acre-feet*	*Acre-feet*
Alfalfa	35	1.83	64	60	3.05	107
Grass hay	20	1.57	31	50	3.14	63
Corn	10	1.35	14	55	2.45	24
Orchard	10	1.31	13	60	2.18	22
Incidental [4]						
Roads	3	0				0
Dense natural vegetation	1	2.72	3			
Seeped lands [5]	1	1.68	2			
Total or average for normal season	80	1.59	127	59	2.70	216

[1] Consumptive use (U) minus effective precipitation (R_e) for growing season. (See table 3.)
[2] Assumed reasonable for this area. (See table 6.)
[3] Amount of water to be delivered at the farm headgate, in acre-feet, to satisfy crop requirements.
[4] Most of this use might be eliminated by land leveling and better water management, and the water put to a higher or more beneficial use.
[5] Vegetation along ditchbanks and on low land.

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. The computed values for a Montrose farm are shown in table 14. It is noted that in this example some incidental consumption of irrigation water occurs because of the farming operations. However, this incidental use does not require any additional delivery allowance at the farm headgate. Under the above assumptions 1.59 acre-feet per acre would be consumed on the 80-acre farm and 2.70 acre-feet would need to be delivered for each acre in the farm. The average delivery for actual cropped acres would be 2.88 acre-feet.

HAWAII

Blewitt (*19*) in 1960 presented a method of estimating water requirement values needed in the design of sprinkler irrigation systems for use in Hawaii. The method was developed principally for use in estimating peak period rates of use rather than monthly or seasonal uses.

Because of the large variations in wind, cloud cover, humidity, and evaporation in the agricultural areas of Hawaii, it appears that the

Blaney-Criddle method of estimating consumptive use will need modification before it can be applied to these islands. Blewitt modified the B-C method by using monthly evaporation as correction factors. This modified procedure seems to give satisfactory results for the islands and may be useful in other areas of the world where coastal conditions prevail.

LITERATURE CITED

[Many processed articles are no longer available]

(1) ABBE, CLEVELAND.
1905. A FIRST REPORT ON THE RELATIONS BETWEEN CLIMATES AND CROPS U.S. Dept. Agr. Weather Bur. Bul. 26, 386 pp.

(2) ADAMS, FRANK, VEIHMEYER, F. J., AND BROWN, L. N.
1942. COTTON IRRIGATION INVESTIGATIONS IN SAN JOAQUIN VALLEY, CALIFORNIA, 1926 TO 1935. Calif. Agr. Expt. Sta. Bul. 668, 93 pp., illus.

(3) BECKETT, S. H.
1930. IRRIGATION REQUIREMENTS IN SOUTHERN CALIFORNIA. Calif. Dept. Pub. Works, Water Resources Div. Bul. 32 (ch. 9), pp. 57-60.

(4) ——— BLANEY, H. F., AND TAYLOR, C. A.
1930. IRRIGATION WATER REQUIREMENT STUDIES OF CITRUS AND AVOCADO TREES IN SAN DIEGO COUNTY, CALIFORNIA, 1926 AND 1927. Calif. Agr. Expt. Sta. Bul. 489, 51 pp., illus.

(5) ——— AND DUNSHEE, C. F.
1932. WATER REQUIREMENTS OF COTTON ON SANDY LOAM SOILS IN SOUTHERN SAN JOAQUIN VALLEY. Calif. Agr. Expt. Sta. Bul. 537, 48 pp., illus.

(6) BLANEY, H. F.
1938. FIELD METHODS OF DETERMINING CONSUMPTIVE USE OF WATER. Natl. Cong. Cuban Engin. Proc. 4, 16 pp.

(7) ———
1954. EVAPOTRANSPIRATION MEASUREMENTS IN WESTERN UNITED STATES. Assoc. Internatl. d'Hydrol. Sci., vol. 3, Bul. 38, pp. 150-160, illus.

(8) ———
1959. IRRIGATION RESEARCH AND WATER UTILIZATION IN ISRAEL. U.S. Internatl. Coop. Admin. USOM Agr. Rpt., 116 pp. Washington, D.C. [Processed.]

(9) ———
1959. MONTHLY CONSUMPTIVE USE REQUIREMENTS FOR IRRIGATED CROPS. Amer. Soc. Civil Engin. Proc., Irrig. and Drainage Div. Jour. (IR-1, Paper 1963) 85: 1-12, illus.

(10) ———
1960. DETERMINING IRRIGATION REQUIREMENTS FROM CONSUMPTIVE USE WATER RATES. Fifth Internatl. Cong. Agr. Engin. Trans. (1958) 1: 292-304. Brussels.

(11) ——— AND CRIDDLE, W. D.
1945. A METHOD OF ESTIMATING WATER REQUIREMENTS IN IRRIGATED AREAS FROM CLIMATOLOGICAL DATA. U.S. Dept. Agr. Soil Conserv. Serv., 17 pp. [Processed.]

(12) ——— AND CRIDDLE, W. D.
1950. DETERMINING WATER REQUIREMENTS IN IRRIGATED AREAS FROM CLIMATOLOGICAL AND IRRIGATION DATA. U.S. Dept. Agr. Soil Conserv. Serv. SCS-TP-96, 44 pp., illus. [Processed.]

(13) ——— EWING, P. A., ISRAELSEN, O. W., AND OTHERS.
1938. REGIONAL PLANNING, PART VI—UPPER RIO GRANDE: PART III, WATER UTILIZATION. Natl. Resources Com., pp. 293-428, illus.

(14) ——— HAISE, H. R., AND JENSEN, M. E.
1959. CONSUMPTIVE USE BY IRRIGATED CROPS IN WESTERN UNITED STATES. U.S. Dept. Agr., Agr. Res. Serv. 53 pp. [Processed.]

(15) BLANEY, H. F., AND HARRIS, KARL.
1951. CONSUMPTIVE USE AND IRRIGATION REQUIREMENTS OF CROPS IN ARIZONA. U.S. Dept. Agr. Soil Conserv. Serv., 49 pp., illus. [Processed.]
(16) ——— AND MORIN, K. V.
1942. EVAPORATION AND CONSUMPTIVE USE OF WATER EMPIRICAL FORMULAS. Amer. Geophys. Union Trans., pt. 1 (August): 76–83.
(17) ——— RICH, L. R., CRIDDLE, W. D., AND OTHERS.
1952. CONSUMPTIVE USE OF WATER. Amer. Soc. Civil Engin. Trans. (paper 2524) 117: 948–967, illus.
(18) ——— TAYLOR, C. A., AND YOUNG, A. A.
1930. RAINFALL PENETRATION AND CONSUMPTIVE USE OF WATER IN SANTA ANA RIVER VALLEY AND COASTAL PLAIN. Calif. Div. Water Resources Bul. 33, 162 pp., illus.
(19) BLEWITT, R. I.
1960. ESTIMATING CONSUMPTIVE USE FOR CROPS IN HAWAII. U.S. Dept. Agr. Soil Conserv. Serv.—Hawaii Tech. Notes 10, 9 pp. [Processed.]
(20) BOWEN, LESLIE.
1936. THE MECHANICS OF IRRIGATION AND CROP SELECTION. U.S. Dept. Agr. Div. Irrig. [Processed.]
(21) CHRISTOPOULOS, C. P.
1959. [DISCUSSION OF "MONTHLY CONSUMPTIVE USE REQUIREMENTS FOR IRRIGATED CROPS."] Amer. Soc. Civil Engin. Proc., Irrig. and Drainage Div. Jour. (IR–4, pt. 1) 85: 76–77.
(22) CRIDDLE, W. D., AND MARR, J. C.
1945. CONSUMPTIVE USE OF WATER IN IDAHO. U.S. Dept. Agr. Soil Conserv. Serv., 46 pp., illus. [Processed.]
(23) ——— AND PETERSON, D. F., Jr.
1949. CONSUMPTIVE WATER USE AND REQUIREMENTS: A PROGRESS REPORT ON COLORADO RIVER AREA INVESTIGATIONS IN UTAH. U.S. Dept. Agr. Soil Conserv. Serv., 74 pp. [Processed.]
(24) FORTIER, SAMUEL.
1907. EVAPORATION LOSSES IN IRRIGATION AND WATER REQUIREMENTS OF CROPS. U.S. Dept. Agr. Off. Expt. Stas. Bul. 177, 64 pp., illus.
(25) ———
1927. ORCHARD IRRIGATION. U.S. Dept. Agr. Farmers' Bul. 1518, 27 pp., illus.
(26) ——— BLANEY, H. F., EWING, P. A., AND OTHERS.
1940. IRRIGATION PRACTICES IN GROWING ALFALFA. U.S. Dept. Agr. Farmers' Bul. 1630, 26 pp., illus. (Rev.)
(27) FUHRIMAN, D. K., AND SMITH, R. M.
1951. CONSERVATION AND CONSUMPTIVE USE OF WATER WITH SUGAR CANE UNDER IRRIGATION IN THE SOUTH COASTAL AREA OF PUERTO RICO. P.R. Univ. Jour. Agr. 35: 1–47, illus.
(28) HALKAIS, N. A., VEIHMEYER, F. J., AND HENDRICKSON, A. H.
1955. DETERMINING WATER NEEDS FOR CROPS FROM CLIMATIC DATA. Hilgardia 24 (9): 207–233, illus.
(29) HARGREAVES, G. H.
1947. A SUGGESTED METHOD OF STANDARDIZING IRRIGATION REQUIREMENTS FOR CENTRAL VALLEY CROPS. U.S. Dept. Int. Bur. Reclam., 35 pp., illus. [Processed.]
(30) HARRIS, KARL, AND HAWKINS, R. S.
1942. IRRIGATION REQUIREMENTS OF COTTON ON CLAY LOAM SOILS IN THE SALT RIVER VALLEY. Ariz. Agr. Expt. Sta. Bul. 181, pp. 421–459, illus.
(31) ——— KINNISON, A. F., AND ALBERT, O. W.
1936. USE OF WATER BY WASHINGTON NAVEL ORANGES AND MARSH GRAPEFRUIT TREES IN SALT RIVER VALLEY, ARIZONA. Ariz. Agr. Expt. Sta. Bul. 153, pp. 441–496, illus.
(32) ISRAELSEN, O. W., CRIDDLE, W. D., AND FUHRIMAN, D. K.
1939. WATER APPLICATION EFFICIENCY STUDIES IN UTAH COUNTY, UTAH: A PROGRESS REPORT. Utah Agr. Expt. Sta., 79 pp., illus. [Processed.]
(33) ——— CRIDDLE, W. D., FUHRIMAN, D. K., AND HANSEN, V. E.
1944. WATER-APPLICATION EFFICIENCIES IN IRRIGATION. Utah Agr. Expt. Sta. Bul. 311, 55 pp., illus.

(34) LIST, R. J.
1951. SMITHSONIAN METEOROLOGICAL TABLES. Smithsn. Misc. Collect. vol. 114, (Pub. 4014), 527 pp., illus. Ed. 6.

(35) LOWRY, R. L., JR., AND JOHNSON, A. F.
1941. CONSUMPTIVE USE OF WATER FOR AGRICULTURE. Amer. Soc. Civ. Engin. Proc. 67: 595–616, illus.

(36) MCLAUGHLIN, W. W., BLANEY, H. F., EWING, P. A., AND OTHERS.
1942. CONSUMPTIVE WATER USE AND REQUIREMENTS. *In* The Pecos River Joint Investigation Reports of Participating Agencies. Natl. Resources Planning Bd., pp. 170–230, illus. [Processed.]

(37) MUNSON, W. C.
1960. METHOD FOR ESTIMATING CONSUMPTIVE USE OF WATER FOR AGRICULTURE. Amer. Soc. Civ. Engin. Proc., Irrig. and Drain. Jour. (IR–4, pt. 1) 86: 45–57.

(38) NIXON, P. R., AND LAWLESS, G. P.
1960. TRANSLOCATION OF MOISTURE WITH TIME IN UNSATURATED SOIL PROFILES. Jour. Geophys. Res. 65: 2, 655–661.

(39) PENMAN, J. L.
1948. NATURAL EVAPORATION FROM OPEN WATER, BARE SOIL, AND GRASS. Roy. Soc. London, Proc., Ser. A, 193: 120–145.

(40) PITTMAN, D. W., AND STEWART, GEORGE.
1930. TWENTY-EIGHT YEARS OF IRRIGATION EXPERIMENTS NEAR LOGAN, UTAH, 1902–29 INCLUSIVE. Utah Agr. Expt. Sta. Bul. 219, 15 pp., illus.

(41) RILEY, J. A., AND GRISSOM, P. H.
1961. CLIMATE AND CROPS IN HUMID AREAS. Amer. Soc. Civ. Engin. Trans. 126, Part III: 492–513, illus.

(42) ROCKWELL, W. L.
1914–20. DUTY OF WATER IN IRRIGATION. U.S. Dept. Agr. Bur. Pub. Roads, 77 pp. [Processed.]

(43) STOUT, O. V. P.
1931. CONSUMPTIVE USE OF WATER IN THE DELTA OF SACRAMENTO AND SAN JOAQUIN RIVERS. Calif. Dept. Pub. Works, Water Resources Div. Bul. 29, pp. 68–75, illus.

(44) THORNTHWAITE, C. W.
1948. AN APPROACH TOWARD A RATIONAL CLASSIFICATION OF CLIMATE. Geog. Rev. 38: 55–94, illus.

(45) U.S. DEPARTMENT OF AGRICULTURE.
1941. CLIMATES OF THE STATES. *In* Climate and Man, U.S. Dept. Agr. Yearbook 1941, pp. 749–1210, illus.

(46) U.S. DEPARTMENT OF THE INTERIOR.
1945. IRRIGATION WATER REQUIREMENTS, COLUMBIA BASIN JOINT INVESTIGATION PROBLEMS, 4 AND 5. U.S. Bur. Reclam. Washington, D.C. 176 pp., illus. [Processed.]

(47) U.S. NAVAL OBSERVATORY.
1946. TABLES OF SUNRISE, SUNSET, AND TWILIGHT. (Supplement to the American Ephemeris, 1946). 196 pp., illus. Washington, D.C.

(48) VAN BAVEL, C. H. M.
1956. ESTIMATING SOIL MOISTURE CONDITIONS AND TIME FOR IRRIGATION WITH THE EVAPOTRANSPIRATION METHOD. U.S. Dept. Agr., Agr. Res. Serv. ARS-41-11, 16 pp., illus. [Processed.]

(49) YOUNG, A. A.
1945. IRRIGATION REQUIREMENTS OF CALIFORNIA CROPS. Calif. Dept. Pub. Works, Water Resources Div. Bul. 51, 132 pp., illus.

APPENDIX

DEFINITIONS OF CONSUMPTIVE USE AND IRRIGATION TERMS

Consumptive use (*evapotranspiration*).—The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, snow, or intercepted precipitation in any specified time. Consumptive use may be expressed in volume per unit area, such as acre-inches per acre, or in depth, such as inches or millimeters.

Transpiration.—The net quantity of water absorbed through the crop roots and transpired, plus that used directly in the building of plant tissue. It does not include evaporation from the soil or intercepted precipitation. It is expressed in terms of volume per unit area or as depth in feet or inches.

Consumptive water requirement.—The amount of water potentially required to meet the evapotranspiration needs of vegetative areas so that plant production is not limited from lack of water.

Consumptive irrigation requirement.—The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production.

Irrigation efficiency.—The percentage of irrigation water that is stored in the soil and available for consumptive use by the crops. When the water is measured at the farm headgate it is called farm-irrigation efficiency; when measured at the field, it is designated as field-irrigation efficiency; and when measured at the point of diversion, it may be called project-efficiency.

Irrigation water requirement.—The consumptive irrigation water requirement divided by the irrigation efficiency.

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

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 2 to 4 days after an ordinary irrigation, the time-interval depending on the soil type.

Wilting point.—The moisture percentage of the soil below which little or no plant growth occurs.

Effective precipitation.—Precipitation falling during the growing period of the crop that is available to meet the consumptive water requirements of crops. It does not include deep percolation below the root zone nor surface runoff.

Carryover soil moisture.—Moisture stored in the root zone soils during the winter while the crop is dormant or before it is planted. This moisture is available to help meet the consumptive water needs of the crop.

LIST OF BULLETINS ON WATER REQUIREMENTS FOR CERTAIN WESTERN STATES

Arizona

BLANEY, H. F., AND HARRIS, KARL. CONSUMPTIVE USE AND IRRIGATION REQUIREMENTS OF CROPS IN ARIZONA. U.S. Dept. Agr. Soil Conserv. Serv., 46 pp. 1951. [Processed.]

California

BLANEY, H. F., AND EWING, P. A. IRRIGATION PRACTICES AND CONSUMPTIVE USE OF WATER IN SALINAS VALLEY, CALIFORNIA. Salinas Basin Invests., Calif., Div. Water Resources Bul. 52, app. C, pp. 195-226. 1946.

STATE WATER RESOURCES BOARD. WATER UTILIZATION AND REQUIREMENTS IN CALIFORNIA. Bul. 2, ch. 2, v. 1., 227 pp. 1955.

Colorado

BLANEY, H. F., AND CRIDDLE, W. D. CONSUMPTIVE USE AND IRRIGATION WATER REQUIREMENTS OF CROPS IN COLORADO. U.S. Dept. Agr. Soil Conserv. Serv., 55 pp. 1949. [Processed.]

Idaho

JENSEN, M. C., AND CRIDDLE, W. D. ESTIMATED IRRIGATION WATER REQUIREMENTS FOR IDAHO. Idaho Agr. Expt. Sta. Bul. 291, 23 pp. 1952.

Kansas

HANSON, R. E., AND MEYER, W. R. IRRIGATION REQUIREMENTS: ESTIMATES FOR KANSAS. Kans. Engin. Expt. Sta. Bul. 69, 44 pp., illus. 1953.

Montana

MONSON, O. W., CRIDDLE, W. D., AND DAVIS, STERLING. ESTIMATED WATER REQUIREMENTS OF CROPS IN IRRIGATED AREAS OF MONTANA. Mont. Agr. Expt. Sta. Bul. 494, 23 pp., illus. 1953.

Nevada

HOUSTON, C. E. CONSUMPTIVE USE OF WATER BY ALFALFA IN WESTERN NEVADA. Nev. Agr. Expt. Sta. Bul. 191, 20 pp., illus. 1955.

New Mexico

BLANEY, H. F., HANSON, E. G., AND LITZ, G. M. CONSUMPTIVE USE AND IRRIGATION WATER REQUIREMENTS OF CROPS IN NEW MEXICO. U.S. Dept. Agr. Soil Conserv. Serv., 34 pp., illus. 1950. [Processed.]

North Dakota

DAVIS, STERLING, EVANS, N. A., AND HAZEN, A. G. ESTIMATES OF IRRIGATION WATER REQUIREMENTS FOR CROPS IN NORTH DAKOTA. N. Dak. Agr. Expt. Sta. Bul. 377, 18 pp., illus. 1952.

Oklahoma

GARTON, J. E., AND CRIDDLE, W. D. ESTIMATES OF CONSUMPTIVE-USE AND IRRIGATION WATER REQUIREMENTS OF CROPS IN OKLAHOMA. Okla. Agr. Expt. Sta. Tech. Bul. T-57, 26 pp., illus. 1955.

Oregon

TILESTON, F. M., AND WOLFE, J. W. IRRIGATION REQUIREMENTS (ESTIMATES FOR OREGON). Oreg. Agr. Expt. Sta. Bul. 500, 32 pp., illus. 1951.

South Dakota

ERIE, L. J. CONSUMPTIVE USE AND IRRIGATION WATER REQUIREMENTS OF CROPS IN SOUTH DAKOTA. U.S. Dept. Agr. Soil Conserv. Serv., 34 pp., illus. 1952. [Processed.]

Texas

McDANIELS, L. L. CONSUMPTIVE USE OF WATER BY MAJOR CROPS IN TEXAS. Tex. Bd. Water Engin. Bul. 6019, 47 pp. 1960.

Utah

ROSKELLEY, C. O., AND CRIDDLE, W. D. CONSUMPTIVE USE OF WATER AND IRRIGATION REQUIREMENTS OF CROPS IN UTAH. Utah State Engin. Tech. Pub. 8, 30 pp. 1952.

Washington

MOLENAAR, ALDERT, CRIDDLE, W. D., AND PAIRE, C. H. ESTIMATES OF CONSUMPTIVE USE AND IRRIGATION REQUIREMENTS OF CROPS IN WASHINGTON. Wash. Agr. Expt. Sta. Cir. 201, 20 pp., illus. 1952.

Wyoming

TOMILSON, B. R. ESTIMATE OF WATER REQUIREMENTS OF CROPS. Wyo. Agr. Expt. Sta. Bul. 303, 28 pp. 1951.

TABLES 15 TO 18

TABLE 15.—*Records of measured seasonal consumptive use of water by irrigated crops and calculated consumptive-use factors (F) and crop coefficients (K) at various sites in Western United States*

Crop and location	Year	Growing season or period	Consumptive use (U)	Consumptive-use factor (F)	Consumptive-use coefficient (K)	Reference
Alfalfa at			*Inches*			
Carlsbad, N. Mex.	1940	4/18–11/10	38.6	43.59	0.88	(36)
Fort Stockton, Tex.	1940	4/13–11/11	40.5	46.28	.88	(36)
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	(22)
Scottsbluff, Nebr.	1932-36	5/14– 9/27	25.9	29.04	.89	(20)
Prosser, Wash.	1947	4/22–11/5	36.0	38.50	.93	(7)
Logan, Utah	1902–29	5/7 –10/11	25.0	32.30	.77	(40)
Vernal, Utah	1948	5/17–10/6	23.6	27.30	.86	(23)
Ferron, Utah	1948	5/9 –10/6	24.2	30.23	.84	(23)
Davis, Calif.	1939	4/1 – 9/30	30.4	39.40	.77	(9)
Mesa, Ariz.	1945–46	2/10–12/3	51.0	57.79	.88	(15)
Ontario, Oreg.	1941–42	5/1 –10/5	29.4	35.50	.83	(3)
Gooding, Idaho	---------	5/23– 9/24	21.6	26.18	.83	(26)
Beans at—						
Davis, Calif.	-------	6/1 – 9/30	14.40	29.14	.49	(6)
Davis, Calif.	-------	7/1 – 9/30	12.84	21.92	.59	(6)
Beans (lima) at Davis, Calif	--------	6/1 – 9/30	18.0	29.14	.62	(6)
Corn at—						
Bonners Ferry, Idaho	1947	5/8 – 9/27	28.25	29.35	.96	(22)
Vernal, Utah	1948	6/10– 9/20	19.40	20.52	.95	(23)
Davis, Calif.	-------	6/1 – 9/30	12.0	27.08	.45	(6)
Logan, Utah	1902–29	6/1 – 9/30	25.0	25.00	.96	(40)
Mercedes, Tex.	1918	3/15– 7/15	20.0	28.52	.70	(42)
Cotton at—						
Mesa, Ariz.	1935–36	4/1 –10/31	31.0	50.0	.62	(15)
Bakersfield, Calif	1927–30	4/1 –10/31	29.2	47.14	.62	(5)
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	(2)
State College, N. Mex	1936	4/1 –10/31	26.9	44.81	.60	(13)
Carlsbad, N. Mex.	(7)	3/28–11/3	28.7	47.30	.61	(36)
Fort Stockton, Tex.	1940	4/13–11/11	28.9	46.28	.62	(36)
Dates at Tempe, Ariz.	1931–32	Annual	47.7	73.21	.65	(15)
Flax at Mesa, Ariz.	1943–44	10/14– 6/30	31.0	42.23	.80	(15)
Small grains at—						
Scottsbluff, Nebr.	1932–35	4/20– 7/25	14.72	20.02	.74	(20)
Bonners Ferry, Idaho	1930–47	5/5 – 8/5	17.50	19.48	.90	(22)
Prosser, Wash.	1944	3/20– 7/16	18.00	23.32	.77	(7)
San Luis Valley, Colo	1936	6/1 – 8/31	14.05	18.03	.78	(13)
Logan, Utah	1902–29	5/10– 8/10	17.5	20.00	.87	(40)
Vernal, Utah	1948	5/25– 8/21	16.6	18.12	.91	(23)
Ferron, Utah	1948	5/13– 8/21	17.8	20.86	.85	(23)
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	.72	(9)
Orchard fruits						
Citrus fruit:						
Grapefruit at						
Mesa, Ariz.	1931-34	3/1 –10/31	40.2	58.26	.69	(31)
Mesa, Ariz.	1931-34	Annual	47.6	73.57	.65	(31)
Oranges at—						
Mesa, Ariz.	1931-34	3/1 –10/31	32.4	58.26	.56	(31)
Mesa, Ariz.	1931-34	Annual	38.6	73.57	.52	(31)
Tustin, Calif.	1929	4/1 –10/31	20.9	44.11	.47	(49)
Azusa, Calif.	1929-30	4/1 – 9/30	18.1	38.69	.49	(18)
Azusa, Calif.	1929	4/1 –10/31	21.8	43.19	.50	(18)
San Fernando, Calif.	1940	4/1 –10/31	22.1	43.73	.51	(1)
Lemons at San Fernando, Calif.	1940	4/1 –10/31	21.8	43.73	.50	(1)
Walnuts at—						
Tustin, Calif.	1928	4/1 – 9/30	26.30	37.90	.69	(3)
Tustin, Calif.	1929	4/1 – 9/30	27.43	35.63	.71	(3)

See footnotes at end of table.

TABLE 15.—*Records of measured seasonal consumptive use of water by irrigated crops and calculated consumptive-use factors (F) and crop coefficients (K) at various sites in Western United States*—Continued

Crop and location	Year	Growing season or period	Consumptive use (U)	Consumptive-use factor (F)	Consumptive-use coefficient (K)	Reference
Orchard fruits—Con.						
Deciduous fruits at—						
Ontario, Calif. (peaches)	1928	4/1 – 9/30	18.4	37.73	0.75	*(18)*
Davis, Calif.		3/1 -11/30	26.4	51.61	.51	(6)
Wenatchee, Wash.	1908	4/15–10/22	23.0	38.15	.60	*(25)*
Albuquerque, N. Mex.	1936	5/1 – 9/31	19.5	33.94	.58	*(15)*
Pasture at—			*Inches*			
Vernal, Utah	1948	5/17–10/6	25.0	27.42	.91	*(23)*
Columbia Basin, Wash		4/5 –10/15	24.0	37.53	.64	*(46)*
Redmond, Oreg.	1945	4/25– 9/15	10.0	27.73	.68	(10)
Peas at Davis, Calif.		3/1 – 6/30	9.6	22.93	.42	(3)
Potatoes at—						
San Luis Valley, Colo.						
Wright Station	1936	6/1 – 9/15	15.38	20.31	[8] .76	*(13)*
West Station	1936	6/1 – 9/30	19.89	22.59	[8] .88	*(13)*
Bonners Ferry, Idaho	1947	5/8 – 9/27	22.95	29.35	.78	*(22)*
Utah County, Utah	1938	5/15– 9/15	22.50	27.23	.83	*(32)*
Scottsbluff, Nebr.	1932-35	6/20– 9/30	15.40	21.89	.70	*(20)*
Ontario, Oreg.	1941–42	4/20– 8/31	17.90	29.81	.60	(5)
Prosser, Wash.	1945	4/20– 8/4	16.65	22.81	.73	(2)
Prosser, Wash.	1947	3/20– 7/20	23.0	26.90	.86	(2)
Davis, Calif.		3/1 – 6/30	16.8	22.93	.73	*(29)*
Logan, Utah	1902–20	5/20– 9/15	15.0	25.27	.60	*(40)*
Redmond, Oreg.	1945	6/15– 9/15	9.8	18.66	.52	(10)
Soybeans at Mesa, Ariz.	1947–48	6/1 –10/31	22.3	38.01	.60	(9)
Sugar beets at—						
Spanish Fork, Utah	1938	4/15–10/15	22.82	31.97	71	*(32)*
Scottsbluff, Nebr.	1932-36	4/20–10/15	24.00	35.45	.68	*(20)*
Davis, Calif.		4/1 – 9/30	25.20	34.63	.73	(3)
Logan, Utah	1902-29	4/15-10/15	25.00	35.62	.70	*(40)*
Columbia Basin, Wash		4/1 –10/15	25.60	39.94	.64	*(46)*
Tomatoes at—						
Davis, Calif.	1933-35	6/1 –10/31	22.80	32.60	.70	(3)
Mercedes, Tex.	1918-20	3/25– 6/30	17.0	22.70	.75	*(42)*
Truck crops at—						
Stockton, Calif.	1925-26	5/1 – 9/30	21.4	33.91	.63	*(43)*
Stockton, Calif.	1925-28	4/1 –10/31	24.6	44.18	.56	*(43)*

[1] Blaney, Harry F., and Stockwell, Homer J. Progress Reports on Cooperative Research Studies on Water Utilization, San Fernando Valley, Calif. 1940–41. (Typewritten.)

[2] Mech, S. J. Progress Report, Irrigation Branch Experiment Station, Prosser, Washington 1948. (Typewritten.)

[3] Veihmeyer, Frank J. Irrigation Studies. University of Calif. 1939. (Typewritten.)

[4] Includes rest period Aug. 1 to Sept. 15.

[5] Sanford, Hollis, and Criddle, Wayne D. Unpublished Studies, 1941–43. (Typewritten.)

[6] Sullivan, A. B. Irrigation Requirement of Sacramento Valley Crops; Sacramento Valley Investigations Memorandum Report. U.S. Department of Interior, Bureau of Reclamation. 1941. (Typewritten.)

[7] Normal temperature used for computing *F* and normal growing season.

[8] High water table.

[9] Harris, Karl. Irrigation Studies. U.S. Department of Agriculture, Soil Conservation Service Division of Irrigation, Phoenix, Ariz. 1947 and 1948. (Typewritten.)

[10] McCulloch, A. W., Sandoz, M. F., and Baldwin, M. G. Irrigation Practices in the Redmond Area, Oregon. A Progress Report. Soil Conservation Service 1945. (Typewritten.)

TABLE 16.—*Monthly percentage of daytime hours of the year* [1]

FOR LATITUDES 0° TO 65° NORTH OF THE EQUATOR

Latitude North	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°	3.45	5.14	7.90	9.92	12.65	14.12	13.60	11.25	8.55	6.60	4.12	2.64
64°	3.75	5.30	7.93	9.87	12.42	13.60	13.31	11.15	8.58	6.70	4.35	3.04
63°	4.01	5.40	7.95	9.83	12.22	13.22	13.02	11.04	8.60	6.79	4.55	3.37
62°	4.25	5.52	7.99	9.75	12.03	12.91	12.79	10.92	8.50	6.86	4.72	3.67
61°	4.46	5.61	8.01	9.71	11.88	12.63	12.55	10.84	8.55	6.94	4.89	3.93
60°	4.67	5.70	8.05	9.66	11.72	12.39	12.33	10.72	8.57	7.00	5.04	4.15
59°	4.81	5.78	8.05	9.60	11.61	12.23	12.21	10.60	8.56	7.07	5.09	4.31
58°	4.99	5.85	8.06	9.55	11.44	12.00	12.00	10.56	8.56	7.13	5.13	4.55
57°	5.14	5.93	8.07	9.51	11.32	11.77	11.87	10.47	8.54	7.19	5.27	4.60
56°	5.29	6.00	8.10	9.45	11.20	11.67	11.69	10.40	8.52	7.25	5.54	4.89
55°	5.39	6.06	8.12	9.41	11.11	11.53	11.59	10.32	8.51	7.30	5.62	5.01
54°	5.53	6.12	8.15	9.36	11.00	11.40	11.43	10.27	8.50	7.33	5.74	5.17
53°	5.64	6.19	8.16	9.32	10.88	11.31	11.34	10.19	8.52	7.38	5.83	5.31
52°	5.75	6.23	8.17	9.28	10.81	11.13	11.22	10.15	8.49	7.40	5.94	5.43
51°	5.87	6.25	8.21	9.26	10.76	11.07	11.13	10.05	8.48	7.41	5.97	5.46
50°	5.98	6.32	8.25	9.25	10.69	10.93	10.99	10.00	8.44	7.43	6.07	5.65
48°	6.13	6.42	8.22	9.15	10.50	10.72	10.83	9.92	8.45	7.56	6.24	5.86
46°	6.30	6.50	8.24	9.09	10.37	10.54	10.66	9.82	8.44	7.61	6.38	6.05
44°	6.45	6.50	8.25	9.04	10.22	10.38	10.50	9.73	8.43	7.67	6.51	6.23
42°	6.60	6.66	8.28	8.97	10.10	10.21	10.37	9.64	8.42	7.73	6.63	6.39
40°	6.73	6.73	8.30	8.92	9.99	10.08	10.34	9.56	8.41	7.78	6.73	6.53
38°	6.87	6.79	8.34	8.90	9.92	9.95	10.10	9.47	8.38	7.80	6.82	6.66
36°	6.99	6.86	8.35	8.85	9.81	9.83	9.99	9.40	8.36	7.85	6.92	6.79
34°	7.10	6.91	8.36	8.80	9.72	9.70	9.88	9.33	8.36	7.90	7.02	6.92
32°	7.20	6.97	8.37	8.72	9.63	9.60	9.77	9.28	8.34	7.93	7.11	7.05
30°	7.30	7.03	8.38	8.72	9.53	9.49	9.67	9.22	8.34	7.99	7.19	7.14
28°	7.40	7.02	8.39	8.68	9.46	9.38	9.58	9.16	8.32	8.02	7.27	7.27
26°	7.49	7.12	8.40	8.64	9.37	9.30	9.49	9.10	8.32	8.06	7.36	7.35
24°	7.58	7.17	8.40	8.60	9.30	9.19	9.41	9.05	8.31	8.10	7.43	7.46
22°	7.76	7.22	8.41	8.57	9.22	9.12	9.31	9.00	8.30	8.13	7.50	7.56
20°	7.73	7.26	8.20	8.52	9.14	9.02	9.25	8.95	8.30	8.19	7.58	7.88
18°	7.88	7.26	8.40	8.46	9.06	8.99	9.20	8.81	8.29	8.24	7.67	7.89
16°	7.94	7.30	8.42	8.45	8.98	8.95	9.07	8.80	8.28	8.24	7.72	7.90
14°	7.98	7.39	8.43	8.44	8.90	8.73	8.99	8.79	8.28	8.28	7.85	8.04
12°	8.08	7.40	8.44	8.43	8.84	8.64	8.90	8.78	8.27	8.28	7.85	8.05
10°	8.11	7.40	8.44	8.43	8.81	8.57	8.84	8.74	8.26	8.29	7.89	8.08
8°	8.13	7.41	8.45	8.39	8.75	8.51	8.77	8.70	8.25	8.31	7.89	8.11
6°	8.19	7.49	8.45	8.39	8.73	8.48	8.75	8.69	8.25	8.41	7.95	8.19
4°	8.20	7.58	8.46	8.33	8.65	8.40	8.67	8.63	8.21	8.43	7.95	8.20
2°	8.43	7.62	8.47	8.22	8.51	8.25	8.52	8.50	8.20	8.45	8.16	8.42
0°	8.49	7.67	8.49	8.22	8.49	8.22	8.49	8.49	8.19	8.49	8.22	8.49

FOR LATITUDES 0° TO 50° SOUTH OF THE EQUATOR

Latitude South	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0°	8.49	7.67	8.49	8.22	8.49	8.22	8.49	8.49	8.19	8.49	8.22	8.49
2°	8.55	7.71	8.49	8.19	8.44	8.17	8.43	8.44	8.19	8.52	8.27	8.55
4°	8.64	7.76	8.50	8.17	8.39	8.08	8.20	8.41	8.19	8.56	8.33	8.65
6°	8.71	7.81	8.50	8.12	8.30	8.00	8.19	8.37	8.18	8.59	8.38	8.74
8°	8.79	7.84	8.51	8.11	8.24	7.91	8.13	8.32	8.18	8.62	8.47	8.84
10°	8.85	7.86	8.52	8.09	8.18	7.84	8.11	8.28	8.18	8.65	8.52	8.90
12°	8.91	7.91	8.53	8.06	8.15	7.79	8.08	8.26	8.17	8.67	8.58	8.95
14°	8.97	7.97	8.54	8.03	8.07	7.70	7.98	8.19	8.16	8.69	8.65	9.01
16°	9.09	8.02	8.56	7.98	7.96	7.57	7.94	8.14	8.14	8.78	8.72	9.17
18°	9.18	8.06	8.57	7.93	7.90	7.50	7.88	8.09	8.14	8.80	8.80	9.24
20°	9.25	8.09	8.58	7.92	7.83	7.41	7.79	8.05	8.13	8.83	8.87	9.32
22°	9.36	8.12	8.58	7.89	7.74	7.30	7.76	8.03	8.13	8.86	8.90	9.38
24°	9.44	8.17	8.59	7.87	7.60	7.24	7.58	7.99	8.12	8.90	8.96	9.47
26°	9.52	8.28	8.60	7.81	7.56	7.07	7.49	7.87	8.11	8.94	9.10	9.61
28°	9.61	8.31	8.61	7.79	7.49	6.99	7.40	7.85	8.10	8.97	9.19	9.74
30°	9.69	8.33	8.63	7.75	7.43	6.94	7.30	7.80	8.09	9.00	9.24	9.80
32°	9.76	8.36	8.64	7.70	7.39	6.85	7.20	7.73	8.08	9.04	9.31	9.87
34°	9.88	8.41	8.65	7.68	7.30	6.73	7.10	7.69	8.06	9.07	9.38	9.99
36°	10.06	8.53	8.67	7.61	7.10	6.59	6.99	7.59	8.06	9.15	9.51	10.21
38°	10.14	8.61	8.68	7.59	7.03	6.46	6.87	7.51	8.05	9.19	9.60	10.31
40°	10.24	8.65	8.70	7.54	6.96	6.33	6.73	7.46	8.04	9.23	9.69	10.42
42°	10.39	8.72	8.71	7.49	6.85	6.20	6.60	7.39	8.01	9.27	9.79	10.57
44°	10.52	8.81	8.72	7.44	6.73	6.04	6.45	7.30	8.00	9.34	9.91	10.72
46°	10.68	8.88	8.73	7.39	6.61	5.87	6.30	7.21	7.98	9.41	10.03	10.90
48°	10.85	8.98	8.76	7.32	6.45	5.69	6.13	7.12	7.96	9.47	10.17	11.09
50°	11.03	9.06	8.77	7.25	6.31	5.48	5.98	7.03	7.95	9.53	10.32	11.30

[1] From references (*34, table 171*) and (*38*).

TABLE 17.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches for various locations in Western United States and Hawaii* [1]

Month	Arizona						California	
	Phoenix		Safford		Yuma		Bakersfield	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	3.64	0.80	3.14	0.64	3.90	0.45	3.33	1.10
February	3.82	.77	3.40	.70	4.07	.41	3.58	1.01
March	5.07	.68	4.51	.58	5.36	.34	4.74	1.06
April	5.59	.40	5.35	.31	6.10	.10	5.55	.52
May	7.28	.12	6.73	.20	7.38	.04	6.87	.36
June	8.17	.07	7.61	.31	8.16	.02	7.61	.07
July	8.85	1.07	8.20	1.58	8.91	.18	8.38	.01
August	8.25	.95	7.52	1.77	8.41	.50	7.69	.01
September	6.91	.75	6.26	1.21	6.98	.31	6.20	.13
October	5.58	.47	5.04	.59	5.81	.26	5.13	.37
November	4.20	.70	3.67	.65	4.42	.29	3.68	.46
December	3.62	1.00	3.15	.84	3.87	.53	3.33	.86
Total	71.28	7.78	64.58	9.38	73.35	3.47	65.84	5.96
Frost-free period	2/5-12/6		4/5-11/4		1/12-12/26		2/21-11/25	

Month	California							
	El Centro		Escondido		Merced		Red Bluff	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	3.58	0.28	3.70	2.68	3.16	2.30	3.06	4.55
February	4.00	.61	3.70	4.64	3.38	1.91	3.35	3.87
March	5.37	.29	4.72	2.89	4.45	1.87	4.53	3.04
April	6.17	.10	5.26	1.55	5.27	1.01	5.33	1.67
May	7.58	0	6.20	.27	6.57	.48	6.70	1.06
June	8.20	.01	6.40	.11	7.35	.11	7.58	.45
July	9.07	.09	7.22	.02	8.08	.01	8.34	.05
August	8.56	.27	6.93	.23	7.39	.02	7.61	.01
September	7.19	.50	5.95	.35	6.06	.18	6.14	.62
October	5.95	.24	5.14	1.16	4.95	.49	4.98	1.34
November	4.44	.10	4.06	1.14	3.67	1.17	3.60	2.74
December	3.93	.74	3.73	4.67	3.14	1.80	3.20	4.40
Total	74.31	3.23	63.10	19.02	53.47	11.35	64.24	23.73
Frost-free period	1/20-12/9		3/0-11/25		3/9-11/20		3/5-12/5	

See footnote at end of table.

TABLE 17.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches for various locations in Western United States and Hawaii* [1]—Continued

Month	California				Colorado			
	Sacramento		Santa Ana		Fort Collins		Grand Junction	
	f	r	f	r	f	r	f	r
		Inches		*Inches*		*Inches*		*Inches*
January	3.13	3.72	3.77	2.27	1.76	0.42	1.72	0.62
February	3.30	3.09	3.78	3.25	1.89	.57	2.29	.60
March	4.52	2.57	4.77	2.57	3.02	1.01	3.57	.82
April	5.18	1.51	5.27	.98	4.10	2.05	4.67	.80
May	6.30	.77	6.17	.38	5.49	2.79	6.20	.72
June	6.93	.15	6.50	.04	6.45	1.56	7.22	.43
July	7.42	0	7.05	.01	7.11	1.61	7.98	.75
August	6.92	0	6.71	.05	6.50	1.36	7.19	1.19
September	5.81	.38	5.81	.22	4.98	1.30	5.60	1.03
October	4.89	.02	5.11	.71	3.73	1.13	4.22	.86
November	3.64	1.88	4.15	.91	2.42	.48	2.71	.57
December	3.06	3.03	3.80	3.01	1.81	.45	1.92	.68
Total	61.19	18.02	62.89	14.40	49.26	14.73	55.29	9.07
Frost-free period	2/6-12/10		2/7-12/7		5/7-9/29		4/13-10/25	

Month	Colorado		Idaho					
	Montrose		Boise		Idaho Falls		Lewiston	
	f	r	f	r	f	r	f	r
		Inches		*Inches*		*Inches*		*Inches*
January	1.68	0.55	1.82	1.73	1.26	1.31	2.09	1.41
February	2.15	.47	2.22	1.48	1.55	.97	2.42	1.22
March	3.32	.76	3.41	1.35	2.79	1.08	3.77	1.22
April	4.32	1.00	4.44	1.18	4.05	.94	4.84	1.12
May	5.70	1.05	5.74	1.43	5.45	1.24	6.25	1.49
June	6.64	.47	6.68	.92	6.26	1.21	7.12	1.46
July	7.31	.79	7.58	.24	7.19	.62	8.13	.48
August	6.62	1.31	6.87	.10	6.45	.59	8.01	.48
September	5.20	1.11	5.15	.53	4.70	.82	5.40	.90
October	3.89	.96	3.53	1.24	3.60	.98	4.02	1.23
November	2.56	.60	2.58	1.28	2.18	.79	2.64	1.47
December	1.77	.69	1.90	1.57	1.45	1.06	2.12	1.47
Total	51.16	9.76	52.25	13.14	47.02	11.61	56.81	13.92
Frost-free period	5/6-10/6		4/23-10/17		5/15-9/19		4/5-10/26	

See footnote at end of table.

Table 17.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches for various locations in Western United States and Hawaii* [1]—Continued

Month	Idaho		Kansas				Montana	
	Twin Falls		Garden City		Wichita		Agricultural College	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	1.77	0.89	2.12	0.35	2.21	0.71	1.30	0.87
February	2.16	.84	2.32	.86	2.39	1.24	1.48	.81
March	3.35	.85	3.65	1.02	3.80	1.63	2.50	1.21
April	4.39	1.07	4.81	2.05	4.98	3.90	3.76	1.69
May	5.75	.94	6.32	2.58	6.45	4.66	5.15	3.06
June	6.53	.79	7.30	2.95	7.45	4.58	6.03	2.89
July	7.57	.30	7.07	2.54	8.10	2.89	6.87	1.28
August	6.67	.23	7.37	2.24	7.53	3.43	6.21	1.09
September	5.00	.43	5.83	1.91	5.99	3.33	4.53	1.67
October	3.93	.74	4.41	1.25	4.65	2.45	3.35	1.42
November	2.48	1.05	2.93	.76	3.13	1.77	2.03	1.00
December	1.84	.75	2.17	.50	2.32	1.02	1.41	.98
Total	51.44	8.88	57.20	19.01	59.00	30.37	44.63	18.03
Frost-free period	5/18–9/26		4/25–10/16		4/10–10/27		5/24–9/16	

Month	Montana		Nebraska				New Mexico	
	Missoula		McCook		Scottsbluff		Albuquerque	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	1.16	0.85	1.85	0.41	1.72	0.41	2.40	0.46
February	1.54	.80	2.11	.67	1.88	.52	2.69	.32
March	2.77	.82	3.34	.95	3.02	.88	3.85	.47
April	4.01	.90	4.59	2.12	4.20	2.10	4.87	.81
May	5.46	1.75	6.14	2.89	5.71	2.72	6.23	1.25
June	6.34	2.00	7.17	3.31	6.79	2.63	7.09	.91
July	7.17	.80	7.97	2.88	7.58	1.73	7.65	1.22
August	6.32	.75	7.25	2.50	6.87	1.42	6.98	1.62
September	4.51	1.25	5.56	1.77	5.19	1.30	5.95	1.58
October	3.26	.95	4.20	1.12	3.83	.95	4.46	.83
November	1.98	.90	2.61	.66	2.45	.48	3.01	.52
December	1.27	.95	1.91	.60	1.81	.52	2.54	.61
Total	45.79	12.72	54.73	19.88	51.05	15.66	57.39	10.60
Frost-free period	5/18–9/23		5/3–10/6		5/11–9/26		4/13–10/28	

[1] See footnote at end of table.

TABLE 17.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches for various locations in Western United States and Hawaii*[1]—Continued

Month	New Mexico				Nevada			
	Carlsbad		State College		Carson City		Yerington	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	3.18	0.34	2.96	0.32	2.20	2.12	2.06	0.62
February	3.37	.39	3.12	.43	2.40	1.77	2.46	.60
March	4.64	.55	4.29	.32	3.45	1.30	3.56	.43
April	5.56	.80	5.15	.22	4.25	.69	4.40	.42
May	6.89	1.19	6.29	.30	5.49	.52	5.65	.48
June	7.61	1.63	7.29	.55	6.23	.33	6.37	.41
July	7.93	2.15	7.72	1.73	7.04	.17	7.17	.17
August	7.55	1.80	7.17	1.73	6.42	.18	6.63	.24
September	6.15	1.91	5.94	1.35	5.00	.26	5.09	.27
October	5.04	1.41	4.77	.70	3.87	.58	3.95	.33
November	3.70	.53	3.45	.54	2.69	1.26	2.67	.36
December	3.06	.58	2.85	.49	2.24	1.74	2.11	.52
Total	64.68	13.28	61.00	8.68	51.28	10.92	52.12	4.85
Frost-free period	3/29–11/4		4/6–10/31		5/25–9/19		5/23–9/18	

Month	Oklahoma		Oregon					
	Altus		Baker		Hood River		Medford	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	2.74	0.76	1.60	1.39	2.09	5.18	2.50	2.31
February	3.09	.84	1.90	1.27	2.40	3.98	2.81	2.08
March	4.43	1.54	3.12	1.10	3.61	3.24	3.90	1.50
April	5.49	2.78	4.30	1.09	4.57	1.69	4.69	1.33
May	6.86	3.50	5.33	1.55	5.83	1.10	5.91	1.40
June	7.78	3.48	6.11	1.34	6.47	.77	6.74	.76
July	8.33	1.84	6.92	.58	7.15	.18	7.51	.30
August	7.82	2.49	6.26	.49	6.50	.26	6.85	.37
September	6.34	2.83	4.72	.49	5.04	1.18	5.33	.65
October	5.07	3.21	3.55	.91	3.92	.99	4.12	1.41
November	3.65	1.24	2.32	1.05	2.65	5.32	2.60	2.34
December	2.88	1.28	1.68	1.70	2.15	6.23	2.42	2.88
Total	64.48	25.49	47.64	12.96	52.38	31.30	55.71	16.83
Frost-free period	3/28–11/9		5/12–10/3		4/20–10/20		5/6–10/4	

See footnote at end of table.

TABLE 17.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches for various locations in Western United States and Hawaii*[1]—Continued

Month	Texas						Utah	
	Amarillo		Fort Stockton		Lubbock		Logan	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	2.33	0.51	3.45	0.47	2.85	0.49	1.59	1.55
February	2.48	.73	3.61	.53	3.09	.55	1.86	1.51
March	3.78	.71	4.87	.55	4.28	.93	3.05	1.92
April	4.75	1.83	5.74	.76	5.25	1.42	4.28	1.91
May	6.07	2.79	7.08	1.56	6.57	2.54	5.63	1.96
June	6.98	2.84	7.69	1.75	7.37	2.47	6.53	.97
July	7.54	2.34	7.94	1.89	7.80	2.13	7.59	.57
August	6.98	3.08	7.47	2.07	7.28	1.98	6.86	.69
September	5.67	2.30	6.25	2.72	6.05	2.90	5.19	1.19
October	4.39	1.66	5.25	1.37	4.83	2.29	3.57	1.60
November	2.87	.92	3.93	.72	3.47	.66	2.46	1.30
December	2.43	.50	3.39	.52	2.84	.79	1.60	1.27
Total	56.27	21.01	66.67	15.11	61.58	19.15	50.54	16.44
Frost-free period	4/11-11/2		4/1-11/3		4/12-11/3		5/7-10/11	

Month	Utah		Washington				Wyoming	
	Salt Lake City		Prosser		Yakima		Cheyenne	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*
January	1.96	1.31	1.95	1.00	1.72	0.91	1.70	0.42
February	2.26	1.57	2.36	.77	2.22	1.82	1.82	.67
March	3.47	1.98	3.80	.49	3.71	.23	2.75	1.02
April	4.45	2.05	4.82	.54	4.64	.55	3.67	1.99
May	5.77	1.92	6.21	.50	6.06	.45	5.08	2.43
June	6.83	.80	7.03	.51	6.88	.34	6.13	1.61
July	7.77	.51	7.74	.15	7.63	.28	6.87	2.10
August	7.13	.85	6.92	.25	6.79	.34	6.29	1.55
September	5.40	.98	5.24	.43	5.21	.55	4.78	1.20
October	4.06	1.41	3.97	.74	3.91	.65	3.46	.96
November	2.75	1.35	2.55	1.04	2.41	1.24	2.32	.52
December	2.06	1.43	2.01	1.14	1.92	.92	1.54	.55
Total	53.91	16.13	54.55	7.56	53.11	7.28	46.71	15.02
Frost-free period	4/13-10/22		4/28-10/4		4/15-10/22		5/14-10/2	

[1] See footnote at end of table.

TABLE 17.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches for various locations in Western United States and Hawaii* [1]—Continued

Month	Wyoming		Hawaii [2]			
	Worland		Honolulu W. B. Airport		Waianai	
	f	r	f	r	f	r
		Inches		*Inches*		*Inches*
January	0.07	0.43	5.62	4.08	5.57	2.41
February	1.40	.26	5.15	5.31	5.16	1.53
March	2.79	.41	6.04	4.81	6.08	1.96
April	4.08	1.01	6.26	1.46	6.45	.38
May	5.57	1.34	6.87	.72	7.05	.49
June	6.58	1.29	6.98	.50	7.23	.50
July	7.41	.81	7.20	1.02	7.49	.32
August	6.60	.56	7.02	1.73	7.35	.39
September	4.87	.85	6.49	.70	6.65	.59
October	3.57	.70	6.27	1.62	6.43	1.76
November	2.07	.37	5.67	3.26	5.74	1.65
December	1.19	.25	5.54	4.21	5.63	2.60
Total	47.10	8.20	75.07	29.42	76.81	14.58
Frost-free period	5/10-9/27					

[1] Mean monthly temperatures and average monthly precipitation are from climatological data, annual summaries for 1948, U.S. Weather Bureau. Frost-free periods are from reference (45).
[2] Excerpt from table accompanying letter from Ronald I. Blewitt, State Conservation Engineer, SCS, dated 7/5/60.

TABLE 18.—*Suggested monthly crop coefficients (k) for selected locations* [1]

Crop, location, and frost-free period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alfalfa												
Arizona: Salt River Valley, Mesa (2/5 to 12/6)	0.35	0.55	0.75	0.90	1.05	1.15	1.15	1.10	1.00	0.85	0.65	0.45
California:												
Davis (2/6 to 12/10)				.70	.80	.90	1.00	1.00	.80	.70		
San Fernando Valley, Los Angeles (1/3 to 12/28)	.35	.45	.60	.70	.85	.95	1.00	1.00	.95	.80	.55	.30
Sacramento-San Joaquin Delta -												
Stockton (2/14 to 12/10)		.28	.41	.60	.80	.95	1.03	1.05	.98	.80	.60	.25
Upper Salinas (4/10 to 11/7)				.37	.56	.75	.92	1.00	1.03	.98	.82	
Sacramento Valley, Sacramento (2/6 to 12/10)			.57	.78	.93	1.02	1.01	.95	.84	.63	.42	
North Dakota: Deep River Development Farm, Mandan (5/11 to 9/26)				.50	.96	1.00	.86	.80	.53			
Nebraska: Scottsbluff (5/11 to 9/26)				.40	.74	.96	1.02	.95	.75	.38		
South Dakota: Redfield Development Farm, Redfield (5/12 to 9/29)				.44	.80	1.06	1.16	1.15	1.00	.50		
Utah:												
Logan (5/7 to 10/11)				.55	.80	.95	1.00	.95	.80	.50		
St. George (4/10 to 10/23)			.59	.88	1.05	1.10	1.07	.96	.78	.44		
Alfalfa-Grass												
Idaho: Caldwell, Black Canyon (5/6 to 10/3), on sodium soil				.67	.83	.89	.00	.83	.69			

See footnote at end of table.

TABLE 18.—*Suggested monthly crop coefficients (k) for selected locations* [1]—Con.

Crop, location, and frost-free period	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Avocados												
California:												
Fallbrook, Escondido (3/9 to 11/25)	0.15	0.25	0.35	0.45	0.54	0.60	0.64	0.63	0.57	0.46	0.39	0.21
Goleta, Santa Barbara (1/22 to 12/19)	.15	.25	.40	.52	.63	.73	.75	.69	.60	.48	.32	.19
Carpenteria, Santa Barbara (3/9 to 11/25)	.15	.25	.38	.45	.57	.60	.59	.52	.42	.35	.25	.15
Beans, small white												
California: Santa Ynez Valley, Santa Barbara (1/22 to 12/19)	-----	-----	-----	-----	-----	.60	.70	.70	.60	-----	-----	-----
Beans, Soy												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	-----	-----	-----	-----	-----	.30	.64	.91	.50	-----	-----	-----
Cantaloups												
Arizona: Mesa (3/7 to 11/19)	-----	-----	-----	.39	.68	.90	.90	-----	-----	-----	-----	-----
Corn												
Arizona: Phoenix (2/5 to 12/16)	-----	-----	-----	1.09	1.20	.20	-----	-----	-----	-----	-----	-----
California: Davis and Sacramento (2/6 to 12/10)	-----	-----	-----	-----	.12	.40	.80	.62	.45	-----	-----	-----
North Dakota: Redfield Development Farm, Mandan (5/11 to 9/26)	-----	-----	-----	-----	.50	.65	.75	.80	.70	-----	-----	-----
Cotton												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	-----	-----	-----	.20	.40	.60	.90	1.00	.95	.75	-----	-----
California: Firebaugh-Shafter, Bakersfield (2/12 to 11/25)	-----	-----	-----	-----	.30	.45	.90	1.00	1.00	-----	-----	-----
Texas: Weslaco (2/7 to 12/22)	-----	-----	.20	.45	.70	.85	.85	.80	.55	-----	-----	-----
Flax												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	1.00	1.14	1.17	1.12	.92	.50	-----	-----	-----	.27	.45	.75
South Dakota: Redfield Development Farm, Redfield (5/12 to 9/29)	-----	-----	-----	-----	.55	.70	1.00	1.10	-----	-----	-----	-----
Grass or Clover												
Grass, lawn—												
California: Pasadena (2/3 to 12/13)	.24	.38	.55	.70	.88	.92	.94	.92	.80	.72	.51	.35
Bromegrass—												
North Dakota: Deep River Development Farm, Mandan (5/11 to 9/26)	-----	-----	-----	.40	.70	.98	1.10	1.02	.50	.25	-----	-----
Red clover—												
Idaho: Black Canyon, Caldwell (5/7 to 10/3)	-----	-----	-----	.36	.61	.82	.57	.84	.72	.41	-----	-----
Clover—												
Washington: Prosser (4/28 to 10/14)	-----	-----	-----	-----	.94	.17	1.22	1.15	.98	.53	-----	-----

See footnote at end of table.

TABLE 18.—*Suggested monthly crop coefficients (k) for selected locations* [1]—Con.

Crop, location, and frost-free period	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Guar												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	-----	-----	-----	-----	-----	-----	0.30	0.82	0.82	0.48	-----	-----
Melons												
California: Murrieta (3/16 to 11/19)	-----	-----	-----	-----	-----	0.45	.70	.74	.64	-----	-----	-----
Orchard Fruits												
Deciduous fruit—												
California: San Joaquin Delta (2/14 to 11/28)	-----	-----	0.23	0.45	0.70	.85	.88	.85	.47	.20	-----	-----
Grapefruit—												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	0.40	0.50	.60	.65	.70	.75	.75	.75	.75	.70	0.60	0.50
Lemons—												
California: (2/27 to 12/11)	-----	-----	.40	.40	.50	.55	.60	.60	.60	.50	.40	-----
Oranges—												
Arizona: Salt River Valley, Phoenix (2/5 to 12/26)	.26	.33	.39	.45	.50	.54	.58	.60	.60	.56	.49	.36
California:												
Los Angeles (2/27 to 12/11)	.30	.35	.40	.45	.50	.55	.55	.55	.50	.50	.45	.30
Coastal areas (1/22 to 12/19)	.27	.34	.40	.46	.50	.53	.54	.54	.52	.48	.43	.30
Intermediate (3/6 to 12/5)	.33	.39	.45	.50	.54	.56	.57	.57	.56	.53	.47	.38
Interior areas (3/15 to 11/23)	.37	.44	.49	.54	.57	.60	.62	.62	.60	.57	.51	.43
Walnuts—												
California:												
Davis, Sacramento (2/6 to 12/10)	-----	-----	.13	.30	.55	.84	.98	.88	.60	.37	.20	-----
Southern areas (2/27 to 12/11)	-----	.30	.54	.74	.87	.93	.89	.74	.55	.39	.26	-----
Pastures, Irrigated												
California:												
Davis, Sacramento (2/6 to 12/10)	-----	-----	.10	.27	.42	.52	.57	.55	.35	.15	-----	-----
Murrieta (3/16 to 11/19)	-----	-----	.20	.49	.74	.84	.87	.85	.78	.55	-----	-----
Merced (3/9 to 11/20)	-----	-----	.16	.45	.65	.75	.78	.74	.55	.20	-----	-----
Peas, Papago												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	.25	.55	.98	1.08	1.10	-----	-----	-----	-----	-----	-----	-----
Utah: Logan (5/7 to 10/11)	-----	-----	-----	-----	.24	.50	.90	.98	-----	-----	-----	-----
Potatoes												
Arizona: Salt River Valley, Phoenix (2/5 to 12/16)	-----	.20	.50	1.00	1.20	1.05	-----	-----	-----	-----	-----	-----
California: Davis, Sacramento (2/6 to 12/10)	-----	-----	-----	.45	.80	.95	.90	-----	-----	-----	-----	-----
Nebraska: Scottsbluff (5/11 to 9/26)	-----	-----	-----	-----	-----	.20	.58	.82	.95	-----	-----	-----
North Dakota: Deep River Development Farm, Mandan (5/21 to 9/26)	-----	-----	-----	-----	.45	.75	.90	.80	.40	-----	-----	-----
South Dakota: Redfield Development Farm, Redfield (5/12 to 9/29)	-----	-----	-----	-----	.42	.60	.80	.88	.40	-----	-----	-----
Utah: Logan (5/7 to 10/11)	-----	-----	-----	-----	-----	.40	.65	.85	.81	-----	-----	-----

See footnote at end of table.

TABLE 18.—*Suggested monthly crop coefficients (k) for selected locations* [1]—Con.

Crop, location, and frost-free period	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sorghum												
Arizona: Salt River Valley (2/5 to 12/16)	-----	-----	-----	-----	-----	0.40	1.00	0.85	0.70	-----	-----	-----
Kansas: Garden City (4/25 to 10/16)	-----	-----	-----	-----	-----	.45	1.00	1.17	.86	0.47	-----	-----
Texas: Great Plains Field Station, Lubbock (4/12 to 11/3)	-----	-----	-----	-----	-----	.30	.75	1.10	.85	.50	-----	-----
Sugar Beets												
California:												
Northern (2/6 to 12/10)	-----	-----	-----	0.31	0.60	.96	1.01	.83	-----	-----	-----	-----
Santa Ynez, semi-coastal (2/26 to 11/25)	-----	-----	-----	-----	.40	.67	.76	.70	.50	.29	-----	-----
Coastal unit (1/22 to 12/19)	-----	-----	-----	.37	.42	.43	.44	.43	.38	-----	-----	-----
Montana: Huntley (5/11 to 9/25)	-----	-----	-----	-----	.33	.84	1.06	1.11	1.06	.63	-----	-----
Nebraska: Scottsbluff (5/11 to 9/26)	-----	-----	-----	-----	.27	.50	.80	1.05	1.00	.69	-----	-----
South Dakota, Redfield Development Farm, Redfield (5/12 to 9/29)	-----	-----	-----	-----	.35	.85	1.05	1.10	1.04	.74	-----	-----
Utah: Logan (5/7 to 10/11)	-----	-----	-----	-----	.31	.44	.80	.92	.85	.56	-----	-----
Small Grain												
Barley—												
Arizona: Salt River Valley (2/5 to 12/6)	0.32	0.60	0.98	1.08	.45	-----	-----	-----	-----	-----	-----	0.15
North Dakota: Deep River Development Farm, Mandan (5/11 to 9/26)	-----	-----	-----	.10	.75	1.00	1.00	.40	-----	-----	-----	-----
Utah: Logan (5/7 to 10/11)	-----	-----	-----	-----	.60	.92	.95	-----	-----	-----	-----	-----
Hegari—												
Utah: St. George (4/10 to 10/23)	-----	-----	-----	-----	-----	.35	.76	1.10	1.15	.95	-----	-----
Oats—												
Arizona: Salt River Valley (2/5 to 12/6)	-----	.30	.80	1.10	1.22	.92	.40	-----	-----	-----	-----	-----
Nebraska	-----	-----	-----	-----	.50	.90	.85	-----	-----	-----	-----	-----
Wheat—												
Arizona: Salt River Valley (2/5 to 12/6)	.20	.40	.80	1.10	.60	-----	-----	-----	-----	-----	-----	-----
Kansas: Garden City (4/25 to 10/16)	.40	.72	.97	1.05	.82	-----	-----	-----	-----	-----	-----	-----
Texas: Southwest Great Plains Field Station (4/12 to 11/3)	.63	.82	.93	1.02	1.03	-----	-----	-----	-----	-----	0.38	.45
Tomatoes												
California: Northern Sacramento (2/6 to 12/10)	-----	-----	-----	-----	.41	.74	.93	.98	.89	-----	-----	-----
Truck Garden and Vegetables												
California: Delta (2/14 to 11/28)	-----	-----	-----	.23	.49	.67	.78	.78	.64	.40	-----	-----

[1] Monthly coefficients taken from smoothed curves based on field measurements.

AGRICULTURAL WATER REQUIREMENT STUDIES IN OTHER COUNTRIES

In the past, detailed information on water requirements of various crops grown in arid countries of the world has been extremely limited. Such research has not been conducted except on a limited basis. Estimates for planning, design, and operation of irrigation systems have been based on "rules of thumb" from local experience but without the use of any standard procedure based upon technical information.

Since 1940, studies have been initiated in many countries of the world with the assistance of United Nations Food and Agricultural Organization and U.S. International Cooperation Administration. Subject matter covered at the Third Regional Irrigation Practices Leadership Seminar, Near East-South Asia Region, held at Lahore, Pakistan, February 15–26, 1960, indicates the importance and rapid growth of water-requirements studies (table 19). Of the eight countries represented, nearly all had papers on water-requirement studies underway in their lands. In time, much valuable data will be available for guidance of hydrologists, water resource planners, and engineers for these areas. In the meantime, various empirical methods based on experimental data from the United States and other countries are being used as a basic guide supplemented with local information when available.

TABLE 19.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches in various foreign countries*

Month	Haiti [1]													
	Cap Haitien		Cayes		Damien		Fond des Negres		Gonaives		Hinche		Jeremie	
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*		*Inches*		*Inches*		*Inches*
Jan	5.76	4.09	6.31	2.80	6.13	1.30	5.67	1.53	6.14	0.16	5.72	0.43	5.87	3.62
Feb	5.26	4.25	5.69	3.43	5.67	3.07	5.22	1.73	5.68	.59	5.15	.87	5.33	3.15
Mar	6.25	3.82	6.65	4.17	6.62	2.64	6.00	2.20	6.67	.59	6.25	1.38	6.26	3.23
Apr	6.45	3.82	6.85	7.05	6.81	4.13	6.23	4.41	6.97	1.18	6.57	5.27	6.48	4.02
May	7.03	5.91	7.36	11.46	7.36	7.56	6.71	7.17	7.42	3.23	7.10	11.57	7.06	6.26
June	7.14	3.27	7.30	7.20	7.44	3.15	6.70	5.08	7.61	3.62	6.94	8.54	7.11	4.57
July	7.43	1.61	7.70	5.08	7.70	2.64	6.95	4.33	7.81	2.87	7.34	6.38	7.58	3.34
Aug	7.11	1.65	7.41	8.19	7.59	5.08	6.74	7.13	7.59	2.56	7.18	6.61	7.03	3.85
Sept	6.64	4.02	6.94	9.06	6.96	4.76	6.34	5.75	7.09	3.39	6.57	8.03	6.59	4.06
Oct	6.34	8.08	6.93	13.74	6.75	5.43	6.15	8.54	6.97	2.36	6.27	7.52	6.47	5.59
Nov	5.69	11.02	6.37	7.00	6.22	3.11	5.63	3.70	6.48	.91	5.91	1.89	5.99	7.52
Dec	5.70	7.20	6.35	2.87	6.18	1.06	5.29	1.26	6.38	.43	5.58	.51	5.96	4.33
Total	76.80	59.64	81.86	82.05	81.43	43.93	73.81	52.83	82.81	21.59	76.58	59.01	77.73	53.54

Month	Haiti												West Pakistan, vicinity of Peshawar [2]	
	Jacmel		Mirebalais		Port-au-Prince		Port-de-Paix		Saint Marc		Vallieres			
	f	*r*	*f*	*r*	*f*	*r*	*f*	*r*	*f*	*r*	*f*	*r*	*f*	*r*
		Inches		*Inches*		*Inches*		*Inches*		*Inches*		*Inches*		*Inches*
Jan	5.68	1.38	5.45	1.02	6.13	1.30	5.75	4.61	6.13	0.51	5.43	3.23	3.67	1.44
Feb	5.29	1.69	5.08	1.57	5.60	2.24	5.33	3.15	5.67	.83	5.06	3.15	3.80	1.53
Mar	6.13	3.62	6.09	3.23	6.66	3.30	6.25	2.17	6.70	.79	6.04	2.80	5.30	2.44
Apr	6.23	5.43	6.32	7.44	6.78	6.30	6.26	2.57	6.97	1.93	6.23	4.41	6.42	1.76
May	6.77	8.31	6.77	14.09	7.33	9.09	6.77	3.62	7.50	4.33	6.81	11.73	8.12	.77
June	6.82	4.88	6.79	11.22	7.44	3.94	6.85	3.15	7.49	5.00	6.72	11.50	8.84	.31
July	6.91	2.95	7.11	10.31	7.70	2.91	7.14	2.68	7.77	5.04	7.04	8.19	9.03	1.26
Aug	6.76	5.24	6.78	12.95	7.33	5.75	6.84	3.43	7.47	4.53	6.74	9.41	8.27	2.03
Sept	6.42	5.55	6.29	13.08	6.81	6.89	6.39	4.53	6.91	4.53	6.25	11.02	6.96	.81
Oct	6.28	6.30	6.13	10.94	6.66	6.61	6.55	4.64	6.84	3.70	6.10	9.21	5.82	.23
Nov	5.80	2.90	5.53	4.13	6.12	3.39	5.82	7.75	6.35	1.22	5.43	7.36	4.42	.31
Dec	5.87	1.06	5.58	1.57	6.15	1.34	5.87	4.99	6.29	.47	5.38	5.67	3.72	.67
Total	74.96	49.40	73.92	91.55	80.83	53.15	75.82	47.29	82.09	32.88	73.23	87.68	74.37	13.56

See footnotes at end of table.

TABLE 19.—*Normal monthly consumptive-use factors (f) and average monthly precipitation (r) in inches in various foreign countries*—Continued

Month	Israel, northern Negev [3]				Iraq [4]		Southern Turkey, Seyhan Plain [5]		Jordan Valley, North Shuneh [6]		
	1953–54		1954–55		*f*	*r*	*f*	*r*	1955	1956	1957
	f	*r*	*f*	*r*					*f*	*f*	*f*
		Inches		*Inches*		*Inches*		*Inches*			
January	3.83	0.74	3.63	0.48	79	33	3.32	3.92	----	4.05	3.82
February	3.86	1.6	4.18	(7)	83	38	3.40	4.27	----	4.57	4.38
March	5.18	.16	5.01	.35	115	29	4.57	2.37	----	4.95	5.07
April	5.50	.52	5.79	(7)	141	26	5.52	1.62	6.43	6.09	----
May	7.44	----	6.82	----	186	8	6.95	2.04	7.48	7.22	----
June	7.68	----	7.45	----	211	0	7.61	.79	8.47	8.25	----
July	8.16	----	7.89	----	230	0	8.20	.21	8.44	8.46	----
August	7.71	----	7.27	----	215	0	7.89	.25	8.01	8.28	----
September	6.29	----	6.33	----	173	0	6.47	.71	7.25	7.25	----
October	5.82	----	5.89	(7)	140	0	5.43	1.90	6.60	6.28	----
November	4.40	----	4.66	1.49	103	23	4.13	2.58	5.09	5.13	----
December	4.42	3.1	3.94	5.40	83	32	3.47	3.65	4.29	4.12	----
Total	70.29	6.12	68.68	7.72	1,759	189	66.87	24.31	61.92	74.65	13.27

[1] Data obtained from report on irrigation requirements for Haiti by George H. Hargreaves, civil engineer, IIAA(SCIPA), with the cooperation of Andre Cauvin, hydrology engineer, Haiti Ministry of Agriculture, Port-au-Prince.
[2] From a preliminary report by the authors on "Water Requirements of Peshawar Valley." 1960.
[3] See reference (8).
[4] Excerpt from a report for Government of Iraq, by the Kuljian Corp., "Eski Mosul Irrigation Project—Reconnaissance Report." August 1957.
[5] Data obtained from a report on evapotranspiration in the Seyhan Plain in Southern Turkey by Sadik Toksos, engineer, Bolge, Adana, Turkey.
[6] Data obtained from a report on water requirements of bananas in the Jordan Valley by Izzedin Yunis, director, Irrigation and Water Power, Hashemite Kingdom of Jordan.
[7] Trace.

A brief summary of the development and use of water requirement data in several countries of the world is given below.

Afghanistan

In the preparation of a report on soil and water resources of southwest Afghanistan by Claude L. Fly in 1959, use was made of data obtained in the United States on water requirements and transposed to Afghanistan by the Blaney-Criddle (B-C) methods. Various project developments have used such data in their designs.

Colombia

In 1958–60, Angel Ibarra Caicedo of the Granja Agricola Experimental-Palmira Station, Colombia, measured evapotranspiration by grass, banana, cocoa, and soybean crops; and coefficients for the B-C formula are being computed.

Dominican Republic

Studies of use of water by bananas made in Puerto Libertador, Dominican Republic, by Professor A. A. Bishop of Utah State University in 1950 indicated that the common practice of 2-inch applications of water each 5 days was not necessary. After this observation, it was found that the interval between irrigations could be lengthened and lighter applications made. Maximum consumption rates appeared to be about 0.2 inch per day.

A study of the soil-moisture depletion method of measuring consumptive use was carried on for more than a year. The computed annual consumptive use coefficient (*K*) was 0.81. Never during some fourteen different intervals throughout the period of study did the computed consumptive-use coefficient reach 1.0.

Egypt

In a study of water requirements made in Egypt by Tipton and Kalmbach, Inc., the B-C formula was used to compute consumptive use for alfalfa, citrus, vegetables, and many field crops. The results were correlated with the Egyptian method of computing water requirements. The close correlation of the two methods indicated the validity of the computations.

Greece

Prof. Constantine P. Christopoulos, University of Thessaloniki, Greece, has used the B-C formula for years. In a discussion of a paper on "Monthly Consumptive Use Requirements for Irrigated Crops," Christopoulos (*21*), states:

> In the centigrade scale of temperature and in millimeters the original Blaney-Criddle formula for computing evapotranspiration from climatologic data is:
>
> $$U = KF = \sum kf = \sum kp\ (8 + 0.45t)$$
>
> This formula has had a great success and it is used throughout the world. This success may be largely attributed to the "climatic factor" (f) being easily determined from data of mean monthly temperature (t) and monthly daytime percentage (p) that are everywhere at hand. In contrast, other relevant formulas, simple or complicated, are based on climatological data that are not usually available or they must be measured with elaborate and delicate equipment.

Iraq

From a report by the Kuljian Corp. on the development of lower Diyala for the Government of Iraq, the following quotation is taken regarding the computations for consumptive use of water:

> "* * * Central Iraq in climate is not very dissimilar from some of the arid western states of the U.S.A., and we consider, on review of the evidence available, that the Blaney-Criddle equation for consumptive-use developed in the U.S.A. is *outstandingly the most practical and reliable* formula for use in arid countries, either on new projects or remodeling of existing works." [Emphasis supplied.]

Also of interest in this connection is the use of the method described in this report for determining the consumptive use of water on the Eski Mosul Irrigation Project in Iraq. This report was prepared in 1957 by the Kuljian Corp. for the Government of Iraq. Another report was prepared in 1958 by Sir Murdock McDonald and partners of London.

Israel

Because of its limited water supply, the problem of irrigation requirements and consumptive use of water is of prime importance in connection with Israel's further economic development. A report on irrigation studies in Israel by Blaney (*8*) discussed these matters in considerable detail.

Although the report indicates that Israel has made considerable progress in this field of research since 1953, there are still numerous problems in water utilization remaining to be solved. Checks have been made by Israeli researchers of monthly (k) and seasonal (K) crop consumptive-use coefficients. Soil moisture studies were used to determine consumptive use. These studies indicate that crop coefficients developed by B-C formula from California studies may be used in Israel.

Development of coefficients for crops not produced in California is still needed. Irrigation water requirements of corn and sugar beets grown at the Gilat Experiment Station (near Beersheba) were computed from meteorological data for 1954–55. A comparison of the measured and computed irrigation requirements is shown in table 20. The method of computing water requirements is used in many areas in Israel. The metric (B-C) formula used in Israel is: $u=\frac{kp}{100}(45.7t+813)$=consumptive use, mm.; where k=monthly coefficient, p=monthly percent of annual daytime hours, and t=mean monthly temperature, degrees Centigrade. The computed requirements are being checked by researchers at the Agricultural Experiment Station and at field stations of the Extension Service of Israel.

Table 21 gives data supplied by D. Siev for Degania "B," which is near the south end of Lake Tiberias, Israel.

TABLE 20. *Irrigation water requirements at Gilat near Beersheba, Israel*[1]

Year	Crop	Measured		Computed Blaney-Criddle method		
		Millimeters	*Inches*	*Millimeters*	*Inches*	K[2]
1954	Corn	620	24.8	615-700	24.6-28.0	0.65-0.75
1955	Corn	540	21.6	530-570	21.2-22.8	.65-0.75
1954	Sugar beets	450	18.0	436-504	17.4-20.2	.65-0.75
1955	Sugar beets	470	18.8	430-497	17.2-19.9	.65-0.75

[1] Lower values for coastal area.
[2] Coefficients used to compute consumptive use.

TABLE 21. *Irrigation water requirements at Lake Tiberias, Israel*

Crop	Irrigation period	Interval between irrigations	Depth of water used (U)	Consumptive-use coefficient (K)
		Days	*Inches*	
Banana	April-October	8-9	18.0	0.95
Do	June-September	8-9	21.0	1.05
Do	August-(Peak)	7-8	24.0	1.10
Alfalfa	April-October	15	15.0	.80
Do	April-October	21	15.0	.80
Corn (green for fodder)	July-August	11	16.5	.77

Hashemite Kingdom of Jordan

In a report on "Water Requirement for Bananas in the Jordan Valley, 1958" by Izzeddin Yunis, Daghistani, Director of Irrigation and Water Power, the results of experiments conducted to determine the consumptive use of water in producing bananas are given. In these experiments tanks having a surface area of 5 square meters and a depth of 1 meter were used. Provision was made for drainage and its collection and measurement. Excess water applied to the tank was therefore determined. These tanks were located within the boundaries of a banana orchard so that the tests would be made under natural conditions found in ordinary farming practices. Following normal agriculture practice, the seedling in the tank was limited to three "offshoots" per year and grown for 2 years.

The growth of the plant in the tank was normal to that of other adjacent plants. In another experiment, rows of banana plants in the field were treated separately with applications of 33, 50, and 100 mm. of water (1.30, 1.95, and 3.94 in.) on the same schedule of watering as the single plant in the tank. These different treatments showed a distinct difference in growth and yield. The length of the plant stems increased proportionately to the amount of water applied.

The three bunches of bananas produced the second year by the three offshoots allowed weighed 53 kg. (117 lb.). At the normal planting rate of 1,100 seedlings per hectare during the second year of growth (when yield is highest) the 3,300 offshoots bearing fruit could be expected to produce a calculated yield of 58.3 tons per hectare. Although some very successful banana orchards produce this yield, the normal yield in the Jordan Valley is about half that amount, or approximately 25 tons per hectare.

These experiments were continued for 2 years, as banana plants are not considered mature until the second year. The usual practice is to allow three offshoots to grow around each main tree the second year; from the third year on the practice is to allow three main and three offshoots each year. Annual water consumption is high for the second and succeeding years, after maturity of the plant.

The data from the study showed that the measured use-rates were higher than normally expected under field conditions. This is not an unusual finding. Tank studies usually give higher yields and greater water use per unit of land. In this study, the yield amounted to about 117 tons per hectare, or 5 times the normal and 2½ times what is considered to be a very high yield. The plant populations, based on the tank surface area of 5 square meters would be 2,000 seedlings per hectare which is nearly twice the normal population of 1,100 per hectare.

If the consumptive-use rates are reduced to normal in proportion to the yield and population counts, the maximum monthly consumptive-use coefficient would be about 1.20, with a minimum of about 0.35. The overall average k for the 2-year period would be about 0.75, which includes the first year when the seedlings were developing. If only the data for the second year of growth were used, average annual

K would be about 0.85. It would appear desirable to check these figures by soil moisture depletion studies under actual field conditions before any firm values could be assumed.

Japan

In 1956–57, S. Suzuki and H. Fukuda of the Institute of Irrigation and Drainage, University of Tokyo, measured potential evapotranspiration of upland rice and barley from tanks 4 meters in diameter and 50 cm. deep, with ground-water level 45 cm. below the surface (similar to Thornthwaite tank) and evaporation from standard pan used in Japan, 20 cm. in diameter and 10 cm. high.

> The potential-evapotranspiration (*PE*) was found to be a function only of meteorological factors, regardless of the growth stages of crops. *PE* was about 1.2 times the amount from the pan in each month of the growing season.
> The evapotranspiration by Blaney-Criddle and Thornthwaite's methods were of less accuracy comparing to that from the pan.

However, when accumulated measured average *PE* for 10-day periods of no rain and measured pan evaporation were plotted with computed evapotranspiration by the B-C method, the three curves were fairly close together.

Puerto Rico

Approximately 95 percent of the 125,000 acres of irrigated land in Puerto Rico is planted to sugarcane. The water supply is limited and expensive. Little local information is available as to the actual amount of water needed by the cane or about how to use the available water most efficiently.

In order to obtain information to assist in solving the problems involved in the farming economy of the island, the Agricultural Experiment Station of the University of Puerto Rico instituted studies to determine the amount of water necessary to grow sugarcane, the moisture conditions most favorable for cane growth, the use of practical guides for the most efficient application of irrigation water, and to relate the practical objectives to soil, climate, water, and plant growth characteristics so that the fundamental principles and interrelationships would be clearly understood.

In January 1951 Fuhriman and Smith reported (*27*) the results of water requirement studies in Puerto Rico. These field studies show a maximum average daily use of 0.20 inch per day and a minimum of 0.12 for sugarcane. The overall average was 0.15 inch per day. Since cane grows throughout the year, the annual consumptive use would be about 55 inches at this site and the annual coefficient (*K*) would be 0.58 in the formula $U=KF$.

Southern Turkey, Seyhan Plain

In a paper entitled "Evapotranspiration of the Seyhan Plain in Southern Turkey," Sadik Toksos compares the results of four methods of calculating evapotranspiration or consumptive-use requirements: the Lowry-Johnson, Blaney-Criddle, Penman, and Thornthwaite. The statement is made by Mr. Toksos in his summary that the Lowry-Johnson and the Blaney-Criddle methods cannot be used unless correlation factors and crop coefficients are established by local experiments. This conclusion is different than that arrived at by most other investigators who have used the method. The Blaney-Criddle method was used for a large irrigation project in Southern Turkey in 1959. Crop coefficients established in any area of the world seem to apply reasonably in any other area, particularly to areas of similar climate.

West Pakistan

In October 1956, the Pakistan Water Delegation for the Government of Pakistan empowered Tipton and Kalmbach, Inc.,[4] to suggest a system of works that could be constructed by stages as part of its long-range development plan. Waters from the western rivers of West Pakistan are to replace waters of the eastern rivers formerly used for the irrigation of this land. Waters from the eastern rivers will no longer be available under the terms of a comprehensive plan of development in Pakistan and India.

The determination of crop water requirements for the irrigated lands in West Pakistan was considered to be the logical starting point for such a study. In 1957 Blaney and Criddle were requested to present their views and recommendations for use of available waters. The basic problem seemed to be inadequate irrigation of most of the lands under cultivation, accompanied with serious drainage and salinity problems. Crops raised under existing practices produced only 20 to 40 percent of the yields obtained in other countries.

Climatic data indicated similarity in climate between some of the southwest areas of the United States and the irrigated regions of West Pakistan. The B-C method was therefore used in determining consumptive irrigation water requirements for probably the largest concentrated irrigated area in the world. The authors relied heavily on the research data available from the hot portions of the United States.

Conclusions were that considerable change in the irrigation practices must be made if reasonable yields are to result from the crops. It appears that adequate water is available to meet the needs of all irrigable lands in the Indus Basin in West Pakistan if it is properly controlled and used. But cropping patterns and irrigation practices must be changed and adequate drainage must be supplied to reach a reasonable potential level of production.

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[4] Report filed, 1957.

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