

# Consumptive Use of Water

By  
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~~C~~ONSUMPTIVE USE ~~CONF~~

(Provisional)

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(A paper prepared for the Symposium on Consumptive Use of Water, to be presented at the Irrigation Division session of the Spring meeting of the American Society of Civil Engineers, April 26, 1950, Los Angeles, California)

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## INTRODUCTION

Knowledge concerning the various phases of the hydrologic cycle is incomplete. Consumptive use of water or evapo-transpiration is one of the important elements in this cycle of water movement from the time it falls on the land as rain or snow until it reaches the ocean. The subject of consumptive use, which includes evaporation of moisture from land and transpiration by vegetation, is increasingly significant, particularly in the irrigated areas of the West. It involves problems of water supply, both surface and underground, as well as those of the management and general economics of irrigation and multiple-purpose projects. Data on use of water are essential in planning federal, state and private irrigation projects. The consumptive-use requirement for water has become an important factor in the arbitration of controversies over major stream systems, such as the Rio Grande and the Colorado River, where the public welfare of valleys, cities, states, and even nations is involved (1) (2). Before the available water resources and an equitable division of the use of the waters of a drainage basin in arid and semiarid regions can be satisfactorily ascertained, careful consideration must be given to the consumptive-use requirements for water in various sub-basins (2) (3).

In water-supply and irrigation investigations, engineers are called upon to make, within a limited time, estimates of probable past, present, and future evaporation and evapo-transpiration losses from areas in river valleys when few long-period hydrologic records, except climatological data, are available (2). The results of research on evapo-transpiration provides the practicing engineer with basic data and methods required to estimate consumptive use in utilization of water investigations (3). A progressive improvement of methods and rapid expansion of literature on the subject sometimes make it difficult and tedious for the engineer who

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does not specialize in this field to evaluate the data properly and to select the methods best suited for solving his particular problem.

The subject of the paper, assigned the writer for this symposium, is "definitions, methods and research on consumptive use of water". It is the purpose of this paper to discuss these topics briefly and to outline a procedure developed for computing valley consumptive use from climatological and irrigation data and experimental measurements of evapo-transpiration by agricultural crops and natural or native vegetation.

#### DEFINITIONS AND SOME INTERPRETATIONS

Consumptive use (evapo-transpiration) includes combined loss of water from soils by evaporation and plant transpiration. The process by which water vapor escapes from the living plant, principally the leaves, and enters the atmosphere is known as transpiration. Often transpiration is the largest component of evapo-transpiration. Direct evaporation from moist soil and water and interception by vegetative cover constitutes the remainder of evapo-transpiration use. A large portion of irrigation water applied to farm crops is used in evaporation and transpiration. The remainder is lost by surface runoff from the fields and deep percolation below the root zone. Considered from a valley-wide standpoint, consumptive use includes all transpiration and evaporation losses from lands on which there is vegetative growth of any kind, whether it be agricultural crops or native plants, plus evaporation from bare land and from water surfaces (1).

In some instances there has been confusion as to the meanings of terms employed in reports on use of water. Such terms as consumptive use, evapo-transpiration, transpiration, total evaporation, stream-flow depletion, water requirements, irrigation requirements and duty of water have been interchanged. In this paper the terms "consumptive use" and "evapo-transpiration" are considered synonymous. They are defined as follows:

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

The writer has used the above definition in many reports during the past fifteen years and has found it satisfactory (1) (2) (3). In 1939 it was adopted with minor changes by the Committee on Irrigation of the American Society of Agricultural Engineers. This definition is now in general use by engineers.

#### Other interpretations

Although evaporation and transpiration have been studied for more than 200 years, the term "consumptive use" probably was not applied to water consumption prior to 1900.

Many of the writings concerning the consumptive use of water are in the form of unpublished engineering reports. The term "consumptive use", as originally applied to irrigation, was defined as a seasonal loss of water in acre-feet per acre irrigated. Among the first published writings dealing directly with the consumptive use, a report of a Committee of the American Society of Civil Engineers in 1930, entitled "Consumptive Use of Water in Irrigation" (4) is noteworthy.

The Committee proposed certain definitions for consumptive use of water in a basic sense, and for the farm, the project, and the valley. It also reviewed previous estimates of consumptive use for large river systems and made citations to 21 articles, published and unpublished, dealing with net water requirements and consumptive use. One of the definitions suggested by this committee follows:

"Consumptive Use in a basic Sense: The consumptive use, "U", is here defined as the quantity of water, in acre-feet per cropped acre per year, absorbed by a crop and transpired or used directly in the building of plant tissue, together with that evaporated from the crop-producing land."

Blaney, Taylor and Young (5) in a report in 1930 on rainfall penetration and consumptive use of water, define consumptive use as "the sum of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from the area."

In 1934, the committee on Absorption and Transpiration of the Hydrology Section, American Geophysical Union, proposed the following definition (6):

"Consumptive Use: The quantity of water per annum used by either cropped or natural vegetation in transpiration or in the building of plant-tissue, together with water evaporated from the adjacent soil, snow, or from intercepted precipitation. It is sometimes termed 'evapo-transpiration'."

In 1935, the Special Committee on Irrigation Hydraulics of the American Society of Civil Engineers adopted the following definitions (7):

"Consumptive use: The quantity of water transpired and evaporated from a cropped area."

"Evapo-transpiration: Combined loss of water from soils by evaporation and plant transpiration."

In some reports, the term "total evaporation" is applied to the combined evaporation and transpiration loss in drainage basins. Lee (8) states:

"Total evaporation is the sum of water lost from a given land area during any specific time by transpiration from vegetation and building of plant tissue; by evaporation from water surfaces, moist soil, and snow; and by interception. The term is applied primarily to stream drainage basins for the period of the annual

climatic cycle or subdivision of that period. Total evaporation is essentially precipitation upon the drainage basin minus runoff, corrected for change in storage volume within the basin and for subsurface leakage. It has been variously termed 'evaporation,' 'evaporation from land areas,' 'evapo-transpiration,' 'total loss,' 'water losses,' and 'fly-off.'"

The handbook (9) of the Committee on Hydrology of the Hydraulic Division of the American Society of Civil Engineers, published in 1949, states:

"---the terms 'evapo-transpiration' and 'consumptive use' have received general acceptance, these terms denote the quantity of water transpired by plants during their growth or retained in the plant tissue, plus the moisture evaporated from the surface of the soil and the vegetation, expressed in feet or inches depth of water lost or used in a specified time.---"

The definitions of other terms which are sometimes confused with consumptive use are as follows:

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

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

Stream-flow depletion: The amount of water which flows into a valley, or onto a particular land area, minus the amount which flows out of the valley or off from the particular land area (1).

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

Water requirement: The quantity of water, regardless of its source, required by a crop in a given period of time, for its normal growth under field conditions. It includes surface evaporation and other economically unavoidable wastes. Usually expressed as depth in inches or feet for a given time.

#### RESEARCH STUDIES

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

The rate of evapo-transpiration depends on climate, soil-moisture supply, vegetative cover, soils and land management. The factors included in climate that particularly effect consumptive use are precipitation, temperature, humidity, wind movement, and length of growing season. The quantity of water transpired by plants depends upon the amount of water at their disposal, as well as on temperature and dryness of the air, wind movement, the intensity of sunlight, the stage of the development of the plant, the amount of its foliage, and the nature of its leaf.

The effect of sunshine and heat in stimulating transpiration was studied as early as 1691, according to a review of the literature by Abbe (10). Measurements of transpiration of various kinds of plants by Briggs and Shantz indicate a close correlation between transpiration and evaporation from free-water surfaces, air temperature, solar radiation, and wet-bulb depression readings (11). Scientists have made many other studies of the effects of temperature, moisture, and light on plant growth.

In 1911 Briggs and Shantz of the Bureau of Plant Industry of the United States Department of Agriculture made extensive determinations of the relative water efficiency of plant species grown under arid conditions at Akron, Colorado (12). The results of these studies indicate that the most efficient crops, from the standpoint of water utilization, used 250 to 300 pounds of water per pound of dry matter formed, while less efficient crops used as much as 1,000 pounds of water for each pound of dry matter produced.

Research studies have been made on evaporation from soil and evapo-transpiration by federal, state, and other agencies at various times during the past fifty years in the United States.

One of the first studies (13) in California of evapo-transpiration losses of irrigated crops was made in 1903 by Irrigation Investigations, Office of Experiment Stations, United States Department of Agriculture. At various times since that date this agency, now known as the Division of Irrigation and Water Conservation of Soil Conservation Service, has studied and measured consumptive use by different agricultural crops and natural vegetation in many sections of the West, in cooperation with state agricultural experiment stations, state engineers, and other agencies. Usually evaporation, temperature, humidity, precipitation and wind movement were recorded at the same time. Thus, data are available in many areas for correlating consumptive use measurements with temperature and other climatological observations.

Meteorological conditions influencing evaporation from water surfaces likewise affect evaporation from soils and transpiration from vegetation. Both evaporation and transpiration freely respond to changes in temperature, wind movement, and humidity, so that evaporation from water may, under certain conditions, be used as an index of evapo-transpiration losses for areas in which there is ample water to take care of evaporation and transpiration.

The writer first became interested in the correlation of evaporation, temperature, humidity, and wind movement with evapo-transpiration in 1919, while in charge of research studies at the Irrigation Field Laboratory of

the United States Department of Agriculture, located at Denver, Colorado. These studies included meteorological observations along with measurements of evaporation from various sized pans, evaporation from soil tanks, and consumptive use of water by irrigated crops grown in tanks (14).

The results of these studies and other investigations in California, New Mexico, and other areas, indicate that observed evaporation data may be used as a means of estimating evapo-transpiration by vegetation having access to an ample water supply and when the relation of the two is known for a particular area (1) (3). As an example, for two locations in California, for tules growing in large tanks within the confines of a swamp area, the percentage of consumptive use, with reference to evaporation from a nearby exposed Weather Bureau pan, was 95 percent. The percentage varied from month to month, increasing during the summer and becoming smaller in the cooler months, but 95 percent was the average obtained from a two-year record

From long period records of evaporation, temperature and humidity in New Mexico and Texas, together with consumptive-use measurements at Carlsbad, New Mexico, empirical formulae were developed for computing evaporation and consumptive use where temperature and humidity are available (3). Consideration of these results and the factors involved is shown in the following expression:  $u = k t p (114-h) = k c$  where

- $u$  = Monthly consumptive use (or evaporation) in inches
- $k$  = Monthly empirical coefficient
- $t$  = Mean monthly temperature, °F
- $p$  = Monthly percent of daytime hours of year
- $h$  = Average monthly humidity
- $c = t p (114-h) =$  monthly use index (climatic factor)

The formula  $U = K_a C = k_w c_w + k_s c_s =$  annual consumptive use (or evaporation) in inches, where

- $K_a$  = Empirical coefficient for the entire year
- $C$  = Use Index for entire year
- $k_w$  = Empirical coefficient for winter period
- $k_s$  = Empirical coefficient for growing season or frost-free period
- $c_w$  = Use Index for winter season
- $c_s$  = Use Index for growing season or frost-free period

The values of  $k_w$  and  $k_s$  may be computed from observed values of consumptive use, temperature, and humidity by the relation  $k = \frac{u}{c}$ .

Computed coefficients for winter and summer consumptive use of water for natural vegetation growing along the Pecos River, based on evapo-



transpiration, temperature, and humidity measurements at Carlsbad, New Mexico, for the year 1940, are as follows: sacaton, with water table at 4 feet,  $k_w = 0.0044$  and  $k_s = 0.0139$ ; sacaton, with water table at 2 feet,  $k_w = 0.0063$  and  $k_s = 0.0154$ ; and salt cedar (tamarisk), with water table at 2 feet,  $k_w = 0.0075$  and  $k_s = 0.0216$ . From observed data in New Mexico, the summer seasonal coefficient for alfalfa growing in areas of high water table was computed to be  $k_s = 0.0170$ . The computed annual coefficient K for lake-surface evaporation is 0.0164.

Figure 1 shows the observed and calculated use of water curves for Weather Bureau pan, sacaton tank and bare soil tank, Carlsbad, New Mexico, 1940.

An example of results of research studies of the transpiration use by orange trees in Los Angeles County, California, is shown in table 1. Figure 2 illustrates the difference between evaporation from a lake surface and the use of water by alfalfa and citrus trees in San Fernando Valley, California (15).

Table 1.- Use of water by orange trees, San Fernando Valley, Los Angeles, California, Season 1940 (15).

Period	: Transpiration use, acre-inches per acre			
	: Plot A		: Plot B	
	: Per	: Per	: Per	: Per
: Period	: 30 days	: Period	: 30 days	
Jan. 1 - Feb. 8	1.50	1.15	1.00	.77
Feb. 9 - Mar. 1	1.65	2.46	.94	1.41
Mar. 2 - Apr. 1	2.37	2.37	1.29	1.29
Apr. 2 - Apr. 25	3.27	4.26	1.33	1.73
Apr. 26 - May 9	2.38	5.08	1.14	2.43
May 10 - June 3	2.75	3.46	1.57	1.96
June 4 - June 21	3.03	5.07	1.73	2.88
June 22 - June 27	1.27	6.37	.41	2.10
June 28 - July 14	2.08	3.70	1.61	2.84
July 15 - Aug. 10	1.83	2.04	2.58	2.88
Aug. 11 - Aug. 28	2.53	4.26	1.70	2.83
Aug. 29 - Sept. 23	3.49	4.03	2.08	2.40
Sept. 24 - Oct. 25	3.21	3.13	2.93	2.82
Oct. 26 - Dec. 31	3.64	—	2.99	—
Total to date	35.00	—	23.30	—

Plot A - All year cover crop of Italian rye grass.

Plot B - Winter cover crop of Melilotus alba. Clean cultivated during summer.

The results of some measurements by various investigators of consumptive use by agricultural crops and natural vegetation are shown in tables 2 and 3, respectively.

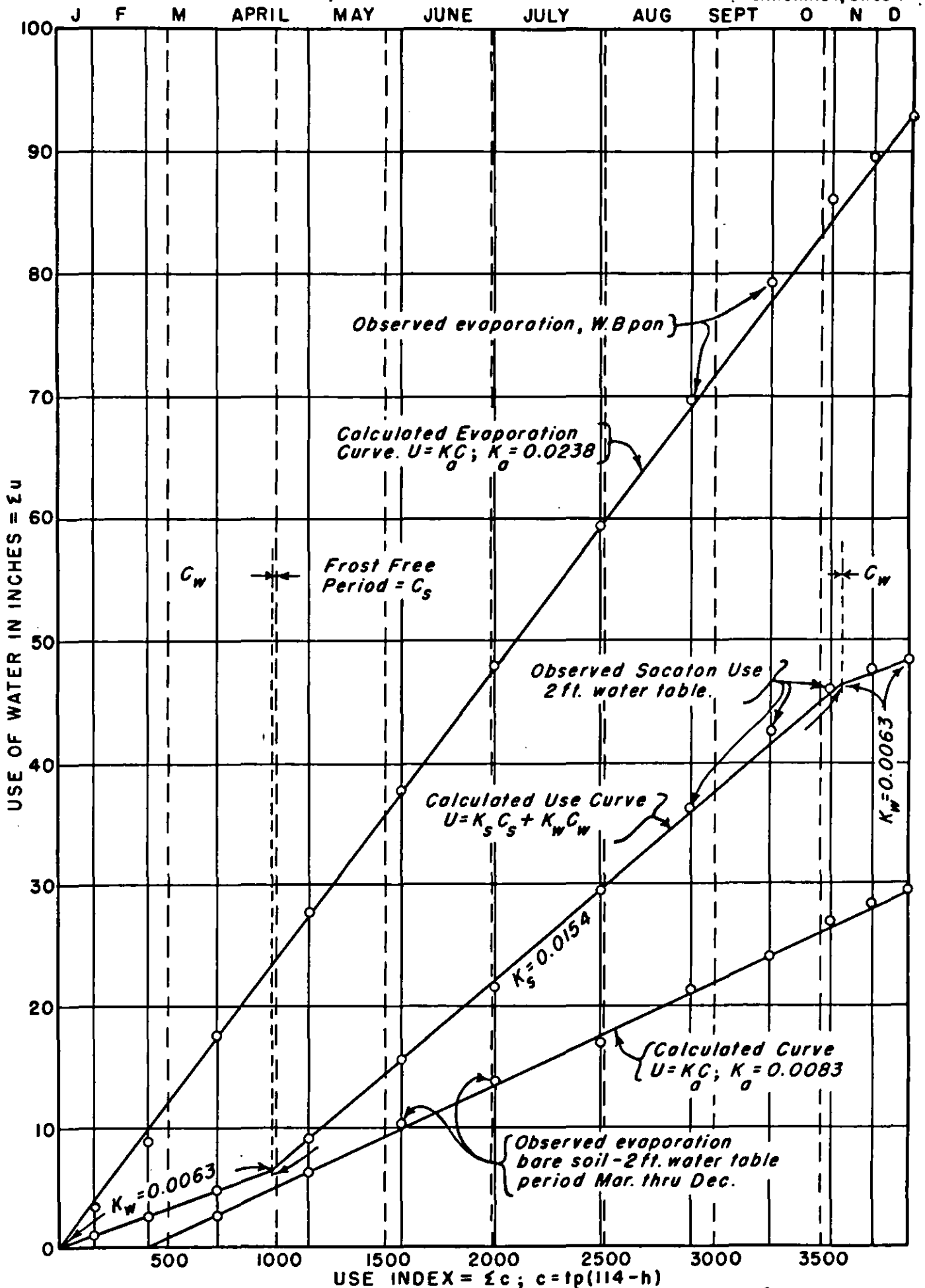


FIGURE I. Observed and calculated use of water curves for Weather Bureau pan, bare soil tank & sacaton tank, Carlsbad, N. Mex., 1940.

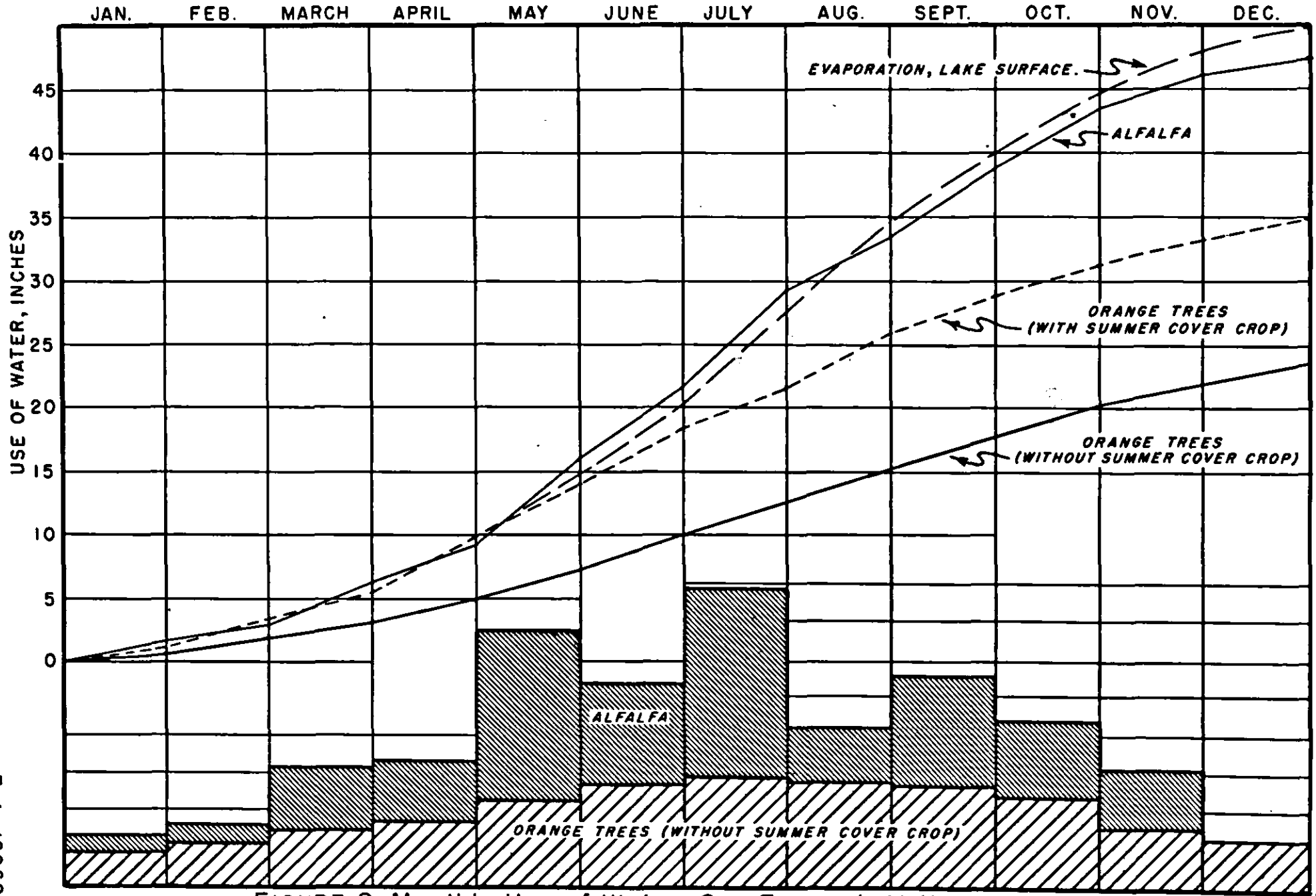


FIGURE 2. Monthly Use of Water, San Fernando Valley, California.

Table 2.- Seasonal consumptive use of water by various irrigated crops as determined by field experiments in several western states.

Location and Crop	Year	Growing season or period	Consumptive use of water	Authority
			Inches	
<u>ALFALFA</u>				
Bonnors Ferry, Idaho	1940-47	5/5 - 9/25	24.0	Marr and Criddle
Carlsbad, New Mex.	1940	4/18-11/10	38.6	Blaney
Davis, California	1939	4/1 - 9/30	30.4	Veihmeyer
Fort Stockton, Texas	1940	4/13-11/11	40.5	Blaney and Bloodgood
Logan, Utah	1902-29	5/7 -10/11	25.0	Pittman and Stewart
San Fernando, Calif.	1940	4/1 -10/31	37.4	Blaney and Stockwell
<u>CORN</u>				
Davis, California	--	6/1 - 9/30	12.0	Veihmeyer
Logan, Utah	1902-29	6/1 - 9/30	25.0	Pittman and Stewart
Vernal, Utah	1948	6/10- 9/20	19.4	Criddle and Peterson
<u>COTTON</u>				
Bakersfield, Calif.	1927-30	4/1 -10/31	29.2	Beckett and Dunshee
Fort Stockton, Texas	1940	4/13-11/11	28.9	Blaney and Bloodgood
Los Banos, Calif.	1932	5/1 -11/30	25.5	Adams and Veihmeyer
Mesa, Arizona	1935	4/1 -10/31	30.9	Harris and Hawkins
<u>SMALL GRAINS</u>				
Bonnors Ferry, Idaho	1930-47	5/5 - 8/5	17.5	Marr and Criddle
Logan, Utah	1902-29	5/10- 8/10	17.5	Pittman and Stewart
San Luis Valley, Colo.	1936	6/1 - 8/31	14.05	Blaney
Scottsbluff, Nebr.	1932-33	4/20- 7/25	14.72	Bowen
<u>ORCHARD-ORANGES</u>				
Azusa, California	1929	4/1 -10/31	21.8	Blaney and Taylor
Mesa, Arizona	1931-34	3/1 -10/31	32.4	Harris and Kinnison
Tustin, California	1929	4/1 -10/31	20.9	Beckett and Pillsbury
<u>ORCHARD-WALNUTS</u>				
Tustin, California	1928	4/1 - 9/30	26.30	Beckett
Tustin, California	1929	4/1 - 9/30	27.43	Beckett
<u>ORCHARD-DECIDUOUS</u>				
Albuquerque, New Mex.	1936	5/1 - 9/31	19.5	Blaney
Davis, California	--	3/1 -11/30	26.4	Veihmeyer
Wenatchee, Wash.	1908	4/15-10/22	23.0	Fortier
Ontario, California	1928	4/1 - 9/30	28.4	Blaney and Taylor

Table 2.- Seasonal consumptive use of water by various irrigated crops as determined by field experiments in several western states. (Cont'd.)

Location and Crop	Year	Growing season or period	Consumptive use of water	Authority
			Inches	
<u>POTATOES</u>				
Bonnars Ferry, Idaho	1947	5/8 - 9/27	22.95	Marr and Criddle
Logan, Utah	1902-29	5/20- 9/15	15.0	Pittman and Stewart
Ontario, Oregon	1941-42	4/20- 8/31	17.9	Sanford and Criddle
San Luis Valley, Colo.	1936	6/1 - 9/30	19.89	Blaney
<u>SUGAR BEETS</u>				
Davis, California	--	4/1 - 9/30	25.20	Veihmeyer
Logan, Utah	1902-29	4/15-10/15	25.0	Pittman and Stewart
Scottsbluff, Nebr.	1932-36	4/20-10/15	24.0	Bowen
<u>TOMATOES</u>				
Davis, California	1933-35	6/1 -10/31	22.8	Veihmeyer
Mercedes, Texas	1918-20	3/25- 6/30	17.0	Rockwell
<u>TRUCK</u>				
Stockton, California	1925-28	5/1 - 9/30	21.4	Stout
Stockton, California	1925-28	4/1 -10/31	24.6	Stout

Table 3.- Annual or seasonal consumptive use of water as determined by tanks and soil moisture studies in valley areas of several western states.

Type of vegetation	Locality	Depth to water table <u>Inches</u>	Period From : To		Number of months	Con- sumptive use <u>Inches</u>	Authority
<u>Native grass</u>							
	San Bernardino, Calif.	1/	Oct. 1928	Sept. 1929	12	10.0	Blaney and Taylor (5)
	Ontario, Calif.	1/	Oct. 1927	Sept. 1928	12	13.4	Blaney and Taylor (5)
	Anaheim, Calif.	1/	Oct. 1927	Sept. 1928	12	12.6	Blaney and Taylor (5)
	Cucamonga, Calif.	1/	Oct. 1929	Sept. 1930	12	15.0	Blaney and Taylor (5)
<u>Native brush</u>							
	San Bernardino, Calif.	1/	Oct. 1927	Sept. 1930	12	21.6	Blaney and Taylor (5)
	Muscoy, Calif.	1/	Oct. 1927	Sept. 1928	12	17.7	Blaney and Taylor (5)
	Palmer Canyon, Calif.	1/	Oct. 1929	Sept. 1930	12	19.6	Blaney and Taylor (5)
<u>Salt grass</u>							
	Owens Valley, Calif.	18	Jan. 1911	Dec. 1911	12	48.8	Lee (8)
	Owens Valley, Calif.	35	Jan. 1911	Dec. 1911	12	40.2	Lee (8)
	Owens Valley, Calif.	59	Jan. 1911	Dec. 1911	12	13.4	Lee (8)
	Santa Ana, Calif.	12	May 1931	Apr. 1932	12	42.8	Blaney and Taylor (16)
	Santa Ana, Calif.	24	May 1931	Apr. 1932	12	35.3	Blaney and Taylor (16)
	Santa Ana, Calif.	36	June 1931	Apr. 1932	11	23.8	Blaney and Taylor (16)
	Santa Ana, Calif.	48	May 1931	Apr. 1932	12	13.4	Blaney and Taylor (16)
	San Luis Valley, Colo.	14	Apr. 1928	Oct. 1928	7	17.8	Tipton and Hart (1)
	San Luis Valley, Colo.	24	Apr. 1928	Oct. 1928	7	15.6	Tipton and Hart (1)
	Los Griegos, New Mex.	14	Oct. 1926	Sept. 1927	12	33.2	Elder (1)
	Los Griegos, New Mex.	26	Oct. 1927	Sept. 1928	12	22.7	Elder (1)
	Isleta, New Mex.	8	June 1936	May 1937	12	31.5	Blaney and Morin (1)
	Mesilla Valley, New Mex.	14	July 1936	June 1937	12	39.8	Blaney (1)
	Escalante Valley, Utah	23	May 1927	Oct. 1927	6	22.6	White (17)
	Escalante Valley, Utah	26	May 1927	Oct. 1927	6	17.9	White (17)

Table 3.- Annual or seasonal consumptive use of water as determined by tanks and soil moisture studies in valley areas of several western states (Cont'd.)

Type of vegetation :	Locality :	Depth to water table :	Period :		* Number of months :	Con- sumptive use :	Authority :
		Inches	From	To		Inches	
<u>Trees</u>							
Cottonwood, )	San Luis Rey, Calif.	48	Apr. 1941	Mar. 1943	12	62.5	Muckel and Blaney
Willows and )	Safford Valley, Ariz.	84	Oct. 1943	Sept. 1944	12	91.7	Gatewood and Robinson(18)
grass )							
Tamarisk	Safford Valley, Ariz.	83.6	Oct. 1943	Sept. 1944	12	87.8	Gatewood and Robinson(18)
Tamarisk	Safford Valley, Ariz.	24	May 1940	Dec. 1940	8	61.1	Turner and Halpenny
Tamarisk	Safford Valley, Ariz.	48	May 1940	Dec. 1940	8	47.9	Turner and Halpenny
Tamarisk	Carlsbad, New Mex.	36	Jan. 1940	Dec. 1940	12	57.3	Blaney and Morin (3)
Mesquite	Safford Valley, Ariz.	120	Oct. 1943	Sept. 1944	12	32.5	Gatewood and Robinson(18)
<u>Miscellaneous</u>							
Baccharis	Safford Valley, Ariz.	24	May 1940	Dec. 1940	8	52.0	Turner and Halpenny
Baccharis	Safford Valley, Ariz.	48	May 1940	Dec. 1940	8	39.7	Turner and Halpenny
Baccharis	Safford Valley, Ariz.	72	Oct. 1943	Sept. 1944	12	54.2	Gatewood and Robinson(18)
Grease wood	Escalante Valley, Utah	26	May 1927	Oct. 1927	6	25.2	White (17)
Meadow grass	San Luis Valley, Colo.	0	June 1936	Nov. 1936	6	36.3	Blaney and Morin (3)
Sacaton	Carlsbad, New Mex.	36	Jan. 1940	Dec. 1940	12	44.8	Blaney and Morin (3)
Bermuda grass	San Bernardino, Calif.	24	May 1929	Apr. 1931	12	34.4	Blaney and Young (16)
Sedge grass	Fort Collins, Colo.	6	May 1930	Oct. 1930	6	60.2	Parshall (19)
Sedge grass	Fort Collins, Colo.	18	May 1930	Oct. 1930	6	53.6	Parshall (19)
Sedge grass	Isleta, New Mex.	3	June 1936	May 1937	12	76.9	Blaney and Morin (1)
Wire rush	Santa Ana, Calif.	24	Aug. 1930	July 1931	12	78.9	Blaney and Young (16)
Rushes	Fort Collins, Colo.	--	July 1931	Oct. 1931	4	52.6	Parshall (19)
Tules	Victorville, Calif.	0	Jan. 1931	Dec. 1932	12	78.4	Blaney and Taylor (16)
Tules	San Luis Valley, Colo.	0	June 1936	Nov. 1936	6	38.8	Blaney (1)

1/ Determined by soil sampling. No high water table.

## METHODS OF DETERMINING WATER USE

Scientists have tried various ways to determine the amount of water transpired by plants (8). One of the earliest methods consists of weighing freshly cut leaves, twigs, or stalks of growing plants immediately after cutting and at short intervals thereafter, during a period of hours or days, or until wilting commences. Experimenters have grown thousands of individual plants in small pots, weighing them periodically to determine the transpiration or evapo-transpiration losses. Most of these methods are artificial, and it is questionable whether the results can be extended to field conditions.

Various methods have been used by engineers to determine consumptive use by agricultural crops and natural vegetation under field conditions (20). Regardless of the method, the problems encountered are numerous. The source of water used by plant life, whether from precipitation alone, irrigation plus rainfall, or ground water plus precipitation, is a factor in selecting a method. Those most widely used in engineering investigations are: (a) soil-moisture studies on plots, (b) tank or lysimeter experiments, (c) ground-water fluctuations, (d) inflow-outflow measurements (e) integration, (f) effective heat, (g) correlation of water use, climatological and other data, and (h) analysis of irrigation and precipitation records.

### Soil-moisture Studies on Plots

This method is usually employed for irrigated field plots where the soil is fairly uniform and the depth to ground water is such that it will not influence the soil-moisture fluctuations within the root zone. Soil samples are taken by means of a standard soil tube before and after each irrigation, with some samples between irrigations in 6-inch sections for the first foot and thereafter in one-foot sections in the major root zone. Usually a great number of soil samples must be taken.

Standard laboratory practices are used in determining the moisture content of the soil samples. The samples are weighed and dried in an electric oven at 110° C. and the dry weights determined. The water content of a sample is expressed as percentage of the oven-dry weight of the soil. From the moisture percentage thus obtained, the quantity of water in acre-inches per acre (inches) removed by evaporation and transpiration from each foot of soil is computed by using the formula  $D = \frac{PVd}{100}$  where P represents the moisture percentage by weight, V the apparent specific gravity (or volume weight) of the soil, d the depth of soil in inches, and D the equivalent depth of water lost by the soil in inches (acre-inches per acre).

The total number of acre-inches of water extracted by evapo-transpiration from the soil is computed for each period and later reduced to equivalent losses in acre-inches or inches for a thirty-day period. The thirty-day period losses may then be plotted and a use-of-water curve for the season obtained. The average use of water for each month is taken direct from the curve. (See figure 1).



In 1925 this method was improved by Beckett and Blaney, and it is described in detail in a report on irrigation water requirement studies in San Diego County, California (21). Later the method was used to measure monthly use of water by alfalfa, cotton and other crops by Blaney (5), Harris (22), and other investigators. Examples of monthly consumptive use of water determination made by this method are shown in table 4 for several crops.

Table 4.- Monthly consumptive use by orange trees, peach trees, alfalfa, cotton, beets, and potatoes, as determined by soil moisture studies.

Month	Consumptive use of water, in inches							
	Oranges	Peaches	Alfalfa	Cotton	Beets	Potatoes		
	1/	2/	1/ 3/	4/ 5/	2/	3/		
April	2.2	1.0	3.3	--	0.8	1.1		
May	2.2	3.5	6.7	4.0	1.1	2.2	1.9	
June	3.1	6.7	5.4	7.0	3.3	3.6	3.3	--
July	3.4	8.0	7.8	7.1	5.6	6.0	5.2	3.4
August	3.7	6.5	4.2	6.4	7.7	8.8	6.9	5.8
September	3.1	2.7	5.6	--	6.4	7.2	5.8	4.4
October	2.9	1.4	4.4		3.6	2.9	1.1	
Total for Season	20.6	29.8	37.4	--	28.5	31.8	24.2	--

1/ Los Angeles, Calif. (15); 2/ Ontario, Calif. (5); 3/ Scottsbluff, Neb.; 4/ Bakersfield, Calif.; 5/ Mesa, Ariz. (22).

#### Tank and Lysimeter Experiments

One of the more common methods of determining use of water by individual agricultural crops and natural vegetation is to grow the plants in tanks or lysimeters and measure the quantity of water necessary to maintain the growth satisfactorily. Tanks as large as 10 feet in diameter and 10 feet deep have been tried. However, in most consumptive-use studies, the tanks are about two to three feet in diameter and six feet deep (5) (19).

The practicability of determining consumptive use by means of tanks or lysimeters is dependent on reproduction of natural conditions. In addition to environment, artificial conditions are caused by the limitations of soil, size of tank, or regulation of water supply.

Weighing is the precise means of determining the consumptive use from tanks. This method was used by the Division of Irrigation, United States Department of Agriculture as early as 1903 in cooperation with the University of California (13). However, conditions and facilities will not always permit the weighing of tanks.

Tanks should be placed in surroundings of natural growth of the same species — that is, in their natural environment — so that consumptive use of water will presumably be the same as for similar growth outside the tank.

It has been found that all tank vegetation must be protected from the elements by surrounding growth of the same species.

Soil tanks equipped with Mariotte supply tanks have been used successfully in evapo-transpiration measurements from water tables at various depths. This equipment was recommended by the National Resources Committee. Tanks best adapted are the double type with an annular space between the inner and outer shells (5).

The Mariotte supply system furnished water as needed to maintain a fixed water level in the annular space in the soil tank. The amount of water withdrawn is determined by differences in daily or weekly readings of the glass gage attached to the supply tank (5) (19).

Lee employed tanks to measure the use of water by natural vegetation in Owens Valley, California, in 1911 (8). Since 1919 the writer has employed this method in California, Colorado, and New Mexico (1) (3) (5).

#### Ground-water Fluctuations

Evapo-transpiration losses are indicated by daily rise and fall of the water table. Diurnal measurements of ground-water table fluctuations provide a basis for computing consumptive use of water by overlying vegetation. It has been successfully used by the U. S. Geological Survey in Escalante Valley, Utah; Santa Ana Valley, California; Gila Valley, Arizona, and other areas (17) (16) (18). The procedure is to install observation wells equipped with water-stage registers at representative locations in the area under consideration and obtain graphic records of the ground-water fluctuations. The specific yield of the soil is determined by standard methods. The diurnal cycle, as indicated by the ground-water table, represents a curve showing the relation of consumptive use to ground-water discharge or recharge. White (17), in his report on Escalante Valley, Utah, described briefly the method of determining the ground water discharged by plants as follows:

" . . . The records obtained from observation wells show that during the growing season there is a marked daily fluctuation of the water table nearly everywhere in the fields of ground-water plants. . . . The maximum daily drawdown observed during the investigation amounted to about  $1\frac{1}{2}$  inches in greasewood and shad scale,  $2\frac{1}{2}$  inches in alfalfa,  $3\text{--}3\frac{3}{4}$  inches in salt grass, and  $4\frac{1}{2}$  inches in sedges and associated marsh grasses. The fluctuations do not occur in plowed fields, cleared lands, tracts of sagebrush, and tracts where the water table is far below the surface. In general they begin with the appearance of foliage in the spring and cease after killing frosts. They cease or are materially reduced after the plants are cut. The water table rises sharply almost immediately after a rain in fields of ground-water plants during the growing season, even though the rain is light and affords no ground-water recharge. There is little or no rise of the water table after rains in clear lands at any time or in fields of ground-water plants when plant life is dormant.

" . . .Cylinders were driven near observation wells so as to inclose columns of undisturbed soil in the zone in which the fluctuations take place, and the rise and fall of the water table in the inclosed columns after the addition or subtraction of measured amounts of water were carefully noted. From these experiments the specific yield of the soils was determined. The amount of ground water discharged daily by the plants was then computed by the formula  $q = y (24r \pm s)$ , in which  $q$  is the depth of ground water withdrawn, in inches,  $y$  is the specific yield of the soil in which the daily fluctuation of the water table takes place,  $r$  is the hourly rate of rise of the water table, in inches, from midnight to 4 a.m., (when it was determined that transpiration and evaporation were practically nil) and  $s$  is the net fall or rise of the water during the 24-hour period in inches. In field experiments the quantities on the right-hand side of the formula except the specific yield can be readily determined from the automatic records of water-table fluctuations . . . ."

#### Inflow-Outflow Measurements

Consumptive use of water by cottonwoods, willows, tules, and other riparian vegetation common to small streams may be determined by measuring the inflow to and the outflow from a selected area by means of flow recorders located on bed-rock controls (5) (16).

In the Upper Rio Grande (1), the Pecos River (3), and other (23) investigations, engineers have used the inflow-outflow method to determine the valley consumptive use in irrigated valleys containing as much as 400,000 acres.

In the Upper Rio Grande investigation the inflow-outflow method was considered to be the measurement of the amount of water flowing into and out of a given area, including precipitation, and change in ground-water storage. Thus, valley consumptive use ( $U$ ) is equal to the amount of water that flows into the valley during a 12-month year ( $I$ ), plus the yearly precipitation on the valley floor ( $P$ ), plus the water in ground storage at the beginning of the year ( $G_s$ ), minus the amount of water in ground storage at the end of the year ( $G_e$ ), minus the yearly outflow ( $O$ ); all amounts measured in acre-feet. This relation may be expressed by the equation  $U = (I + P) + (G_s - G_e) - O$ . The difference between the storage of capillary water at the beginning of the year and at the end of the year is considered negligible. It is also assumed that stream measurements are made on bed-rock controls and that there is no sub-surface flow or that it is relatively small. The quantity ( $G_s - G_e$ ) is considered as a unit so that absolute evaluation of either  $G_s$  or  $G_e$  is unnecessary — the difference only being needed. This is the product of the difference in the average depth of water table in January of one year to January of the following year, measured in feet and multiplied by the specific yield of the soil and area of the valley floor. The quantity  $P$  is obtained by multiplying the average annual precipitation in feet by the area of the valley floor in acres. The unit consumptive use of the entire valley in acre-feet per acre is obtained by dividing the total consumptive use by the area of the valley floor. Results of inflow-outflow measurement in several areas are given in table 5.

Table 5.- Examples of valley consumptive use of water determinations by inflow-outflow method.

Location	Year	Area	Annual consumptive use		Authority
			Total	Average	
		Acres	Acre-feet	Feet	
San Luis Valley, Colo.	1925-35	400,000	664,900	1.66	Blaney-Rohwer (1)
San Luis Valley, Colo.	1936	400,000	685,423	1.71	Blaney-Rohwer (1)
San Luis Valley, Colo.	1930-32	17,300	26,215	1.52	Tipton-Hart (1)
Isleta-Belen, N. Mex.	1936	17,500	38,700	2.28	Blaney-Morin (1)
Mesilla Valley, N. Mex.	1919-35	109,000	297,756	2.73	Blaney-Israelson (1)
Mesilla Valley, N. Mex.	1936	110,418	303,683	2.75	Blaney-Israelson (1)
Carlsbad, N. Mex.	1921-39	51,700	129,752	2.51	Blaney-Morin-Criddle (2)
Carlsbad, N. Mex.	1940	51,700	119,898	2.33	Blaney-Morin-Criddle (2)
New Fork, Wyo.	1939-40	25,000	--	1.59	Lowry-Johnson (23)
Michigan-Illinois-Colo.	1938-40	43,000	--	1.50	Lowry-Johnson (23)
Uncompahgre, Colo.	1938-40	137,700	--	2.28	Lowry-Johnson (23)

#### Integration Method

Briefly stated, the integration method is the summation of the products of consumptive use for each crop times its area, plus the consumptive use of natural vegetation times its area, plus water surface evaporation times water surface area, plus evaporation from bare land times its area. This method was used in the Upper Rio Grande Basin (1) and the Pecos River (2) investigation to determine valley consumptive use.

Before the integration method can be successfully used, it is necessary to know unit evapo-transpiration or consumptive use of water and the areas of various classes of agricultural crops, natural vegetation, bare land, and water surfaces. Unit values of the evapo-transpiration can be obtained by soil-moisture, tank, or some of the other methods previously described. By using aerial maps and field surveys, the areas of the various types of vegetative cover and of the land and water surfaces can be determined, and the valley consumptive use computed (1) (2).

#### Effective Heat

Many formulas have been developed in the past for determining evaporation from meteorological observations. Formulas for estimating consumptive use are not so numerous. A few methods for determining consumptive use, based on climatic factors, have been suggested and have been found to give reasonable results. For many years irrigation engineers have used temperature data in estimating valley consumptive use of water in areas of the West (4). Hedke developed the effective heat method on the Rio Grande (4). By this method consumptive use is estimated from a study of the heat units available to the crops of a particular valley. It assumes that there is a linear relation between the amount of water consumed and the quantity

of available heat. From studies of the United States Bureau of Reclamation, Lowry and Johnson (23) in 1941 developed a somewhat similar method, which has been employed by the Bureau in making its estimates of consumptive use. This method assumes a linear relation between consumptive use and accumulated daily maximum temperatures above 32° Fahrenheit during the growing season.

In 1940 in connection with the Pecos River Joint Investigation (3), Blaney and Morin of the Soil Conservation Service developed a method of estimating consumptive use by natural ground-water vegetation and by irrigated crops having access to an ample water supply, by correlating the relationship between evapo-transpiration, evaporation, temperature, percent of daytime hours, length of growing season and humidity (24). In 1945 this method was modified so that estimates of consumptive use may be made for areas where humidity records are not available (25). This method has been used by the Soil Conservation Service and other agencies in estimating rates of water consumption in many areas.

#### Correlation of Water Use, Climatological and other Data

Actual measurements of consumptive use under each of the various physical and climatological conditions of any large area are expensive and time consuming. Therefore, some rapid method of transferring the results of careful measurements made in several areas to other areas of similar conditions is needed. Several years ago the Soil Conservation Service developed such a method to estimate rates of water consumption (26) (27). Briefly, the procedure is to correlate existing consumptive-use data with monthly temperature, percent of daytime hours, precipitation, frost-free (growing) period, or irrigation season. The coefficients so developed for different crops are used to translocate or transpose consumptive-use data from one section to other areas where only climatological data are available.

Although it is recognized that consumptive use of water is affected by numerous independent and related variables, records of temperatures and precipitation are by far the most universally available throughout the Western States. Research studies indicate that of all the climatic factors, these elements, together with daylight, undoubtedly have the greatest influence on plant growth.

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

U = Consumptive use of crop (or evaporation) in inches for any period.

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

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

- t = Mean monthly temperature in degrees Fahrenheit.  
 p = Monthly percent of daytime hours of the year.  
 $f = \frac{t \times p}{100}$  = monthly consumptive use factor.  
 k = Monthly consumptive use coefficient.  
 u = kf = monthly consumptive use in inches.

The consumptive-use factor (F) for any period may be computed for areas where monthly temperature records are available. Then by knowing the consumptive use coefficient (K) for a particular crop in some locality, an estimate of the use by the same crop in some other area may be made by application of the formula  $U = KF$ .

The consumptive-use coefficients (K) for the more important irrigated crops grown under normal conditions in the West and natural vegetation are shown in table 6. These coefficients were developed from actual measurements of consumptive use in tank and soil moisture field studies and inflow-outflow measurements made throughout the West over a period of years by the Division of Irrigation and Water Conservation and other agencies. These coefficients are based on the assumption that the plants or trees receive a full water supply throughout the growing season or frost-free period. Figure 3 shows the relation of consumptive use (U), consumptive use factor (F), and coefficient (K) for various kinds of natural vegetation and agricultural crops in the West. Monthly percent of annual daytime hours computed from Sunshine tables (28) are shown in table 7 and figure 4.

Table 6.- Tentative normal consumptive-use coefficients for the more important irrigated crops and natural vegetation of the West

Crop	: Length of : growing season : : or period :	: Consumptive use : coefficient (K)
<u>Irrigated Land</u>		
Alfalfa	Frost-free	0.85
Beans	3 months	.65
Corn	4 months	.75
Cotton	7 months	.62
Citrus orchard	7 months	.55
Deciduous orchard	Frost-free	.65
Pasture, grass	Frost-free	.75
Potatoes	3 months	.70
Small grains	3 months	.75
Sorghum	5 months	.70
Sugar beets	5½ months	.70
<u>Natural Vegetation</u> <sup>1/</sup>		
Very dense	Frost-free	1.30
Dense	Frost-free	1.20
Medium	Frost-free	1.00
Light	Frost-free	.80

<sup>1/</sup> Ample moisture available from ground water or water table.

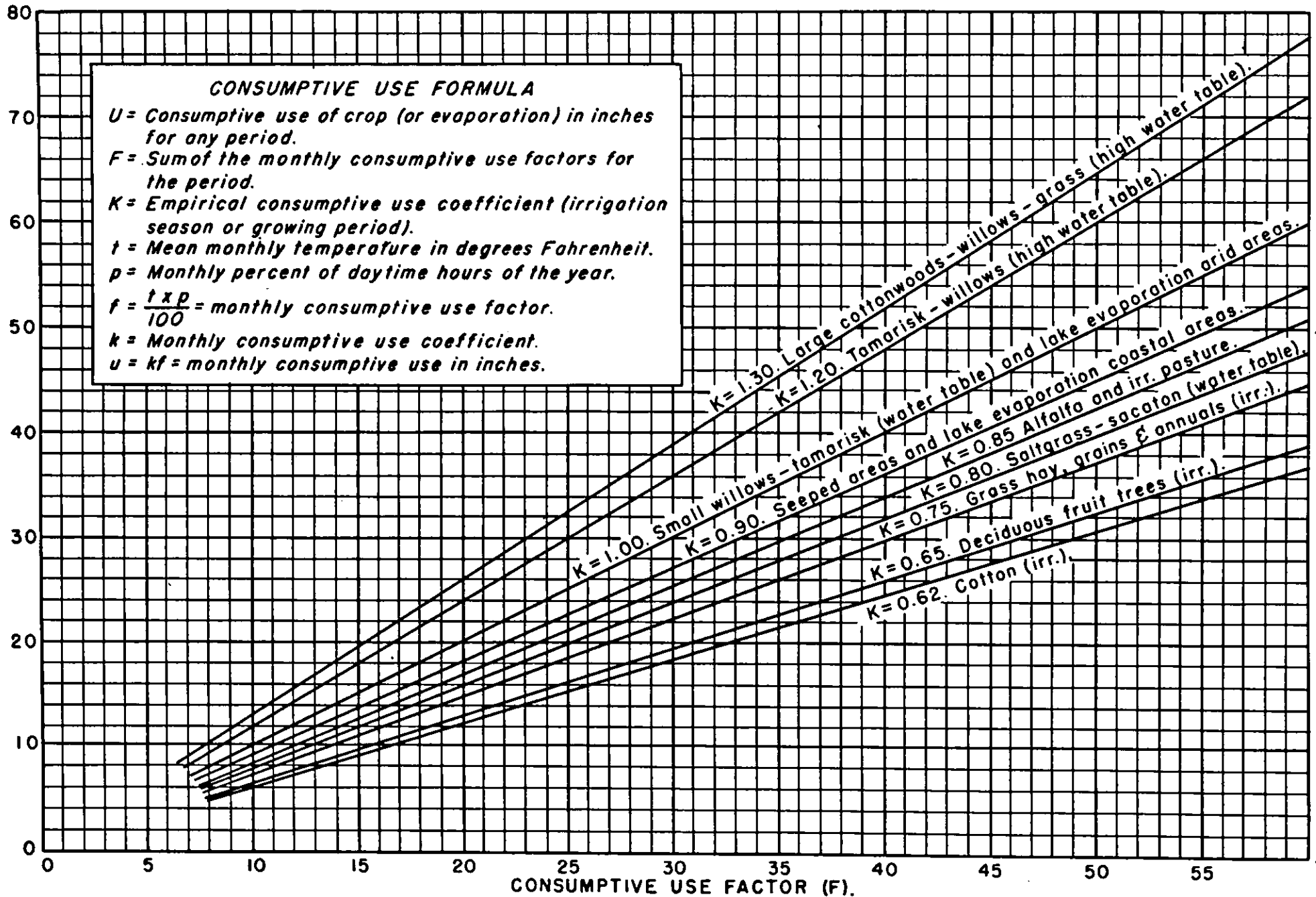


FIGURE 3. Relation of Consumptive Use to Temperature and Percent of Daytime Hours.

Table 7.- Monthly percent of daytime hours of the year for latitudes 24 to 50 degrees north of the equator. (28) 1/

Month	Latitudes in degrees north of equator													
	24	26	28	30	32	34	36	38	40	42	44	46	48	50
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Perce.
January	7.58	7.49	7.40	7.30	7.20	7.10	6.99	6.87	6.76	6.62	6.49	6.33	6.17	5.98
February	7.17	7.12	7.07	7.03	6.97	6.91	6.86	6.79	6.73	6.65	6.58	6.50	6.42	6.32
March	8.40	8.40	8.39	8.38	8.37	8.36	8.35	8.34	8.33	8.31	8.30	8.29	8.27	8.25
April	8.60	8.64	8.68	8.72	8.75	8.80	8.85	8.90	8.95	9.00	9.05	9.12	9.13	9.25
May	9.30	9.38	9.46	9.53	9.63	9.72	9.81	9.92	10.02	10.14	10.26	10.39	10.53	10.69
June	9.20	9.30	9.38	9.49	9.60	9.70	9.83	9.95	10.08	10.21	10.38	10.54	10.71	10.93
July	9.41	9.49	9.58	9.67	9.77	9.88	9.99	10.10	10.22	10.35	10.49	10.64	10.80	10.99
August	9.05	9.10	9.16	9.22	9.28	9.33	9.40	9.47	9.54	9.62	9.70	9.79	9.89	10.00
September	8.31	8.31	8.32	8.34	8.34	8.36	8.36	8.38	8.38	8.40	8.41	8.42	8.44	8.44
October	8.09	8.06	8.02	7.99	7.93	7.90	7.85	7.80	7.75	7.70	7.63	7.58	7.51	7.43
November	7.43	7.36	7.27	7.19	7.11	7.02	6.92	6.82	6.72	6.62	6.49	6.36	6.22	6.07
December	7.46	7.35	7.27	7.14	7.05	6.92	6.79	6.66	6.52	6.38	6.22	6.04	5.86	5.65
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

1/ Computed from "Sunshine Tables", U. S. Weather Bureau Bulletin No. 805, Edition of 1905.



Examples of rates of consumptive use in the Upper Colorado River Basin (2) computed by the above method are shown in table 8.

Table 8.- Estimates of normal unit consumptive use rates for irrigated crops during the irrigation period for several localities in the Upper Colorado River Basin (2). 1/

Location	Normal rate consumptive use, in inches			
	Alfalfa	Pasture	Grains	Corn
Chinle, Arizona	28.3	24.2	15.4	20.1
Eagle, Colorado	18.5	16.2	11.6	11.6
Cortez, Colorado	24.5	21.5	14.6	18.9
Durango, Colorado	22.9	20.1	14.0	17.1
Farmington, New Mexico	32.1	28.4	15.3	20.4
Green River, Utah	32.5	28.6	16.2	21.7
Price, Utah	26.7	23.5	15.4	19.9
Eden, Wyoming	17.2	15.1	13.4	--
Pinedale, Wyoming	14.8	13.0	--	--

1/ Values used in the formula  $U = KF$  are as follows:

Alfalfa, 0.85; pasture, 0.75; grain, 0.75; and, corn, 0.75.

The consumptive-use coefficients shown in table 6 are for average conditions in the semi-arid areas of the West. Studies are now being made to develop correction factors for humid conditions in eastern states. It is anticipated that humidity or solar radiation records can be used for this purpose until measured consumptive use data are available. Basic solar radiation data are now available at many stations throughout the United States.

#### Analysis of Irrigation and Precipitation Records

In the consumptive-use studies conducted by the Division of Irrigation, Soil Conservation Service, in cooperation with the National Resources Planning Board on the Pecos River in 1940, the writer developed a method of determining unit consumptive use for various agricultural crops from irrigation and precipitation (3). This method has been successfully employed in several areas in California in cooperation with the State Engineer (26). It consists of estimating evaporation and transpiration losses during the irrigation season and winter period based on data available as to the number of irrigations and depth of water applied, farm duty of water, and efficiency of irrigation water application for various crops and soils; and precipitation and evaporation from free water surface. Precipitation may be a large factor in winter consumptive use.

A field survey of conditions through the valley area was made. Water superintendents of irrigation district and water companies, engineers, county farm advisors, and farmers were interviewed to ascertain the quantity of irrigation water supplied to various crops, both for the growing season and the winter period. Precipitation, irrigation and other records were collected and estimated. made of the efficiency of irrigation for various crops

in the different areas. The latter data were supplemented by water-application efficiency studies made on typical farms by measuring the quantity of water applied and taking soil samples before and after irrigation to determine the proportion of soil moisture available for crop transpiration use within the root zone. These data were analyzed and the unit rate of water consumption for each crop computed. The total consumptive use in acre-feet may be computed by multiplying unit values of consumptive use for each crop by its area. An example of results of normal valley consumptive use in Salinas Valley, California, estimated by this method is given in table 9.

Table 9.- Estimated normal valley consumptive use of water in the Forebay Area,  
Salinas Valley, California (26)

Classification	Area	Winter consumption 1/		Summer consumption 2/		Annual consumption	
		Unit	Total	Unit	Total	Unit	Total
	Acres	Feet	Acre-feet	Feet	Acre-feet	Feet	Acre-feet
<u>IRRIGATED CROPS</u>							
Alfalfa	5,208	0.63	3,281	2.57	13,385	3.20	16,666
Lettuce	2,551	.63	1,607	1.00	2,551	1.63	4,158
Truck	5,146	.63	3,242	1.50	7,719	2.13	10,961
Beans	5,247	.63	3,305	1.14	5,982	1.77	9,287
Beets	1,563	.83	1,297	1.17	1,829	2.00	3,126
Guayule	3,102	.63	1,954	1.13	3,505	1.76	5,459
Orchard	710	.63	447	1.34	951	1.97	1,398
Grain	109	.63	69	.71	77	1.34	146
Sub-total	23,636		15,202		35,999		51,201
<u>IRRIGABLE DRY FARM AND GRASS</u>	4,182	0.40	1,673	0.35	1,464	0.75	3,137
<u>NATIVE VEGETATION (Valley floor)</u>							
Swamp	91	0.91	83	3.74	340	4.65	423
Dense trees-brush-grass	850	.76	646	4.24	3,604	5.00	4,250
Medium brush-trees-grass	2,820	.92	2,594	1.93	5,443	2.85	8,037
Sparse brush-grass	2,610	.63	1,644	1.04	2,714	1.67	4,358
Sub-total	6,371		4,967		12,101		17,063
<u>MISCELLANEOUS</u>							
Water surface	202	0.69	139	3.07	620	3.76	759
River channel	3,335	.46	1,534	1.32	4,402	1.78	5,936
Waste land	326	.25	81	.15	49	.40	130
Town and farmlots	1,060	.50	530	1.50	1,590	2.00	2,120
Roads and railroads	1,261	.25	315	.15	189	.40	504
Sub-total	6,184		2,599		6,850		9,449
<b>TOTALS</b>	<b>40,373</b>		<b>24,441</b>		<b>56,414</b>		<b>80,855</b>

1/ November 1 to March 31.      2/ Irrigation season, April 1 to October 31.

REFERENCES

- (1) WATER UTILIZATION, UPPER RIO GRANDE BASIN, by Harry F. Blaney, Paul A. Ewing, O. W. Israelsen, Carl Rohwer, and F. C. Scobey. National Resources Committee, Part III. February 1938.
- (2) CONSUMPTIVE USE OF WATER IN 1941 IRRIGATED AREAS OF THE UPPER COLORADO RIVER BASIN, by Harry F. Blaney and Wayne D. Criddle. Division of Irrigation and Water Conservation, Soil Conservation Service, U. S. Dept. of Agriculture. (Mimeo.) April 1949.
- (3) CONSUMPTIVE WATER USE AND REQUIREMENTS, by Harry F. Blaney, Paul A. Ewing, Karl V. Morin, and Wayne D. Criddle. Report of the Participating Agencies, Pecos River Joint Investigation. National Resources Planning Board. June 1942.
- (4) CONSUMPTIVE USE OF WATER IN IRRIGATION, by S. T. Harding, O. W. Israelsen, et al. Paper No. 176C. Reprinted from Trans. Amer. Soc. C. E., Vol. 94. 1930.
- (5) RAINFALL PENETRATION AND CONSUMPTIVE USE OF WATER IN SANTA ANA RIVER VALLEY AND COASTAL FLAIN, by Harry F. Blaney, C. A. Taylor, and A. A. Young. Calif. State Bulletin No. 35, Dept. Pub. Works, Div. Water Resources. 1930.
- (6) TRANSACTION OF THE AMERICAN GEOPHYSICAL UNION. National Research Council. Part II. 1934.
- (7) LETTER SYMBOLS AND GLOSSARY FOR HYDRAULICS. Manual No. 11. Amer. Soc. C. E. 1935.
- (8) TRANSPIRATION AND TOTAL EVAPORATION, by Charles H. Lee. Physics of the Earth-IX-Hydrology. McGraw-Hill Book Co. 1942.
- (9) HYDROLOGY HANDBOOK. Manual No. 28, Chapter 4, Evaporation and Transpiration. Hydraulic Division. Amer. Soc. C. E. 1949.
- (10) A FIRST REPORT ON THE RELATIONS BETWEEN CLIMATES AND CROPS, by Cleveland Abbe. U. S. Dept. Agr. Weather Bureau Bul. 36. 1905.
- (11) DAILY TRANSPIRATION DURING THE NORMAL GROWTH PERIOD AND ITS CORRELATION WITH THE WEATHER, by L. J. Briggs and H. L. Briggs. Journal of Agricultural Research, Vol. 7. 1916.
- (12) THE WATER REQUIREMENTS OF PLANTS, by Lyman L. Briggs and H. L. Shantz. Bulletin No. 284. Bureau of Plant Industry, U. S. Dept. of Agr. 1915.
- (13) EVAPORATION LOSSES IN IRRIGATION AND WATER REQUIREMENTS OF CROPS, by Samuel Fortier. U. S. Dept. Agr., Office Experiment Stations. Irrigation Investigations. Bul. 177. 1907.

REFERENCES (Continued)

- (14) PROGRESS REPORT ON EVAPORATION AND USE OF WATER STUDIES AT DENVER IRRIGATION FIELD LABORATORY, COLORADO, by Harry F. Blaney, Division of Irrigation, U. S. Dept. of Agriculture. 1920.(Unpublished)
- (15) PROGRESS REPORT ON COOPERATIVE RESEARCH STUDIES ON WATER UTILIZATION, SAN FERNANDO VALLEY, CALIFORNIA, IRRIGATION SEASON OF 1940, by Harry F. Blaney and Homer J. Stockwell, Jr. Division of Irrigation, Soil Conservation Service, U. S. Dept. of Agri. June 1941. (Unpublished)
- (16) WATER LOSSES UNDER NATURAL CONDITIONS FROM WET AREAS IN SOUTHERN CALIFORNIA. Calif. State Bul. No. 44, Part I, by Harry F. Blaney, C. A. Taylor, and A. A. Young. Part II by Harold Troxell. 1933.
- (17) A METHOD OF ESTIMATING GROUND-WATER SUPPLIES BASED ON DISCHARGE OF PLANTS AND EVAPORATION FROM SOIL, by W. N. White. Results of Investigations in Escalante Valley, Utah. U. S. Geol. Survey Water-Supply Paper 59-a. 1932.
- (18) USE OF WATER BY BOTTOM-LAID VEGETATION IN LOWER SAFFORD VALLEY, ARIZONA, by J. S. Gatewood, T. W. Robinson, B. E. Colby, J. D. Ham, and L. C. Halpenny. Geological Survey, U. S. Dept. of Interior. (Unpublished manuscript) 1949.
- (19) USE OF WATER BY NATIVE VEGETATION, by Arthur A. Young and Harry F. Blaney. Bulletin No. 50. California State Division of Water Resources. 1942.
- (20) FIELD METHODS OF DETERMINING CONSULPTIVE USE OF WATER, by Harry F. Blaney. Division of Irrigation, U. S. Dept. of Agr. 1938. (Mimeographed)
- (21) IRRIGATION WATER REQUIREMENT STUDIES OF CITRUS AND AVOCADO TREES IN SAN DIEGO COUNTY, CALIFORNIA, 1926 and 1927, by S. H. Beckett, Harry F. Blaney, and C. A. Taylor. Univ. of Calif., College of Agr., Agr. Expt. Sta. Bul. 489. 1930.
- (22) IRRIGATION STUDIES IN ARIZONA, by Karl Harris. Division of Irrigation and Water Conservation, Soil Conservation Service, U. S. Dept. of Agriculture. (Unpublished)
- (23) CONSULPTIVE USE OF WATER FOR AGRICULTURE, by Robert L. Lowry, Jr. and Arthur F. Johnson. Transactions of Amer. Soc. Civ. Engrs. Vol. 107. 1942.
- (24) EVAPORATION AND CONSULPTIVE USE OF WATER EMPIRICAL FORMULAE, by Harry F. Blaney and Karl V. Horin, Part I, Transactions Amer. Geo. Union. 1942.