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The Consumptive Use of Water in Milford Valley, Utah

Terrel R. Tovey

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THE CONSUMPTIVE USE OF WATER
IN MILFORD VALLEY, UTAH

by

Terrel R. Tovey

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Agricultural Engineering

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1952

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I am indeed grateful to Dr. O. W. Israelsen, Head of the Irrigation and Drainage Department and chairman of my graduate committee, and his office staff, for their constructive criticism of the thesis.

Special thanks goes to the farmers in the Milford Valley for their cooperation during the summer of 1951 when the data were gathered.

Terrel R. Tovey

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INTRODUCTION

Definition of consumptive use

Consumptive use, as used in this thesis, is defined as 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 growing season or a 12-month period, the consumptive use is expressed as acre-feet per acre or depth in feet or inches.

Project 304

On June 1, 1948, the Utah Agricultural Experiment Station Project 304 was initiated jointly by the Experiment Station, the Irrigation Division of Soil Conservation Service, and the Utah State Engineer's office to obtain basic information regarding the consumptive use of water by crops and other vegetation in the upper Colorado River Basin. This information will be used to estimate the water supply needs for individual irrigation and reclamation projects which may be proposed (9). A 3 year study was conducted in the Ferron and Vernal areas, Utah, and many data were collected, including climatological, evapo-transpiration, soil-moisture depletion, surface runoff, ground-water, and cropped areas. A final report of the investigations in the upper Colorado River Basin has been prepared by the Soil Conservation Service office. A report was prepared on each year's work by a graduate engineering student at Utah State Agricultural College as a Master's Thesis.

In 1951 the project was transferred from the upper Colorado River Basin to the Bonneville Basin of Utah (fig.1). Because of the lack of funds and personnel, data were collected only on soil moisture depletion, water inflow and outflow, and land classification. Climatological data were available from the weather station located at the Milford airport. This thesis presents the analysis of the soil moisture depletion and climatological data and the author's attempt to apply the results in determining the consumptive use of water by the cultivated crops in Milford Valley, Utah. The inflow and outflow data were received from the U. S. Geological Survey too late for an analysis to be made.

Purpose of the study

It is a well known fact that there is a shortage of water in Utah. The Utah Water and Power Board (13) reports that of the 2,400,000 acres of arable land in the Bonneville Basin there is an adequate water supply for only 338,000 acres, with the total acres irrigated equal to 864,000. This means that approximately two-thirds of the arable land of the Bonneville Basin has no water, and more than one-half of that irrigated has only a partial supply. A fact that is not so well known is that in the Bonneville Basin there are 220,000 acres of arable land that need drainage (6).

A knowledge of the consumptive use of water by individual areas is important in alleviating both the water shortage and the drainage problems. Carelessness in water application is one of the reasons for over-irrigation, which is one of the man-made factors in the development of the need for drainage. If the farmers in an area had reliable information on how much water the various crops used per day or per week, they could better tell how often to irrigate and how much water to apply per irrigation, providing they knew the available water-holding capacity of the root-zone soil. Thus, the water-application efficiency could be increased which would in effect increase the water supply and decrease the need for drainage (7).

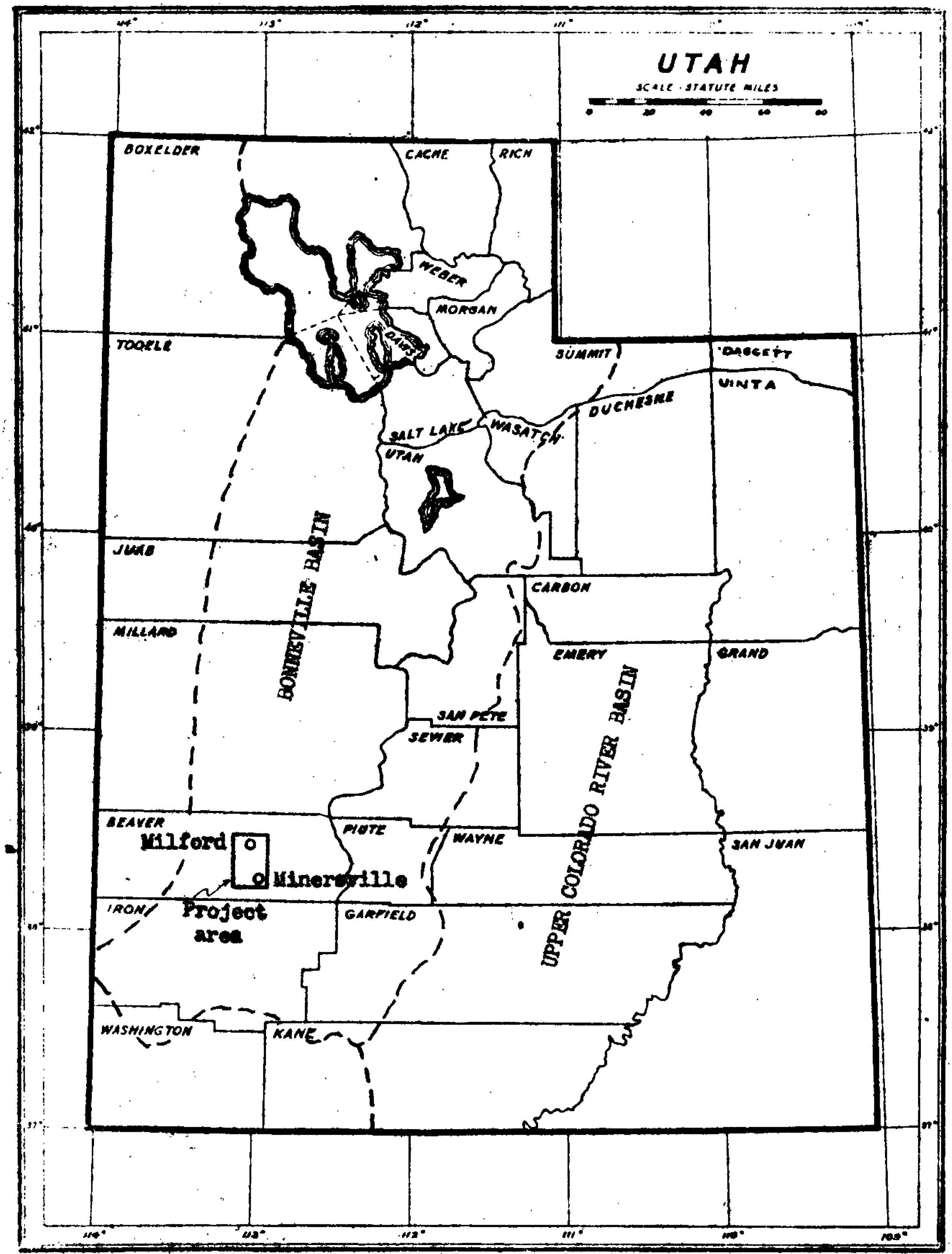


Figure 1. Map of Utah showing the Upper Colorado River and Bonneville Basins and the project area in Milford Valley, Beaver County

THE INFLUENCE OF VARIOUS FACTORS ON CONSUMPTIVE USE

The present concepts regarding the influence of various factors on consumptive use are summarized by Blaney and Criddle (2).

The following factors operate singly or in combination to influence the amounts of water consumed by plants. Their effects are not necessarily constant but may differ with locality and fluctuate from year to year.

Precipitation

Since the water evaporated from intercepted precipitation is considered as being consumptively used, frequent light showers during the hot summer tend to increase the consumptive use unless they raise the relative humidity sufficiently to slow down the rate of transpiration by the plants. Some of the precipitation of heavy storms may be lost by surface runoff. This also tends to increase the consumptive use unless a correction is made for the runoff.

Available irrigation water supply

There can be no consumptive use unless water is available from some source — precipitation, natural ground water, or irrigation. In the arid and semi-arid West where the major source of water is irrigation, both the quantity and seasonal distribution of the available supply will usually affect consumptive use. Where water is plentiful there is a tendency for farmers to over-irrigate in both frequency and depth of application. If the soil surface is frequently wet the resulting evaporation is high. Deep percolation tends to raise the water table and water is wastefully consumed by native vegetation.

Temperature

Temperature probably affects the rate of consumptive use of water by crops more than any other factor. Abnormally low temperatures may retard plant growth, and unusually high temperatures may produce dormancy. Since transpiration is influenced by the area of leaf surface and the physiologic needs of the plant as well as by temperature, consumptive use may vary widely in years for which there are deviations from the normal seasonal distribution even though the accumulated temperatures may be average or above.

Humidity

Consumptive use of water is greater if the average relative humidity percentage is low during the growing season. Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity.

Wind movement

Hot, dry winds and other conditions that produce movement of the air around the plants and over the soil surface will increase the amount of water consumptively used. They tend to carry away the moisture transpired by the plants and evaporated from the surfaces, thus keeping the relative humidity low.

Growing season

The growing season has a major effect on the consumptive use of water by plants because it is tied rather closely to temperature. It may be used as a guide for computing consumptive use, but actual data on dates of planting and harvesting of the crops should be used where available. For a more complete discussion of the effects of the growing season on consumptive use see the final progress report on consumptive water use and requirements of the Colorado River area, Utah, by Barrett and Milligan (1).

Latitude

Latitude has a considerable influence on the rate of consumptive use of water by various plants because the hours of daylight during the summer increase with distance from the equator. Longer days 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.

Soil fertility

Crop yields may be expected to increase with an increase in soil fertility. Although the accompanying increase in water consumptively used is not directly proportional to the increase in yield (11), there is an increase in water used.

Plant pests and diseases

Consumptive use may be lowered materially in those years when plant pests and diseases seriously affect the natural growth of the plants.

SOIL-MOISTURE DEPLETION METHOD OF DETERMINING CONSUMPTIVE USE

Determining the general area

In April 1951, representatives from the Irrigation Division of the Soil Conservation Service, the U. S. Geological Survey, the State Engineer's office, and the Utah Agricultural Experiment Station made a trip through the Sevier River Drainage Basin looking for a satisfactory area on which to make consumptive use investigations.

A satisfactory area is one in which a large proportion of land is cultivated and has soils that are susceptible to sampling. The water table must be at a sufficient depth below the root zone to insure that the ground water is not used by the growing plants. The growing season must be long enough to insure crop maturity. All inflow, outflow, and ground-water storage or depletion must be measurable.

Because of the available records on ground water, which are probably the most expensive to obtain, the cooperative agencies concerned chose the Milford Area in the Bonneville Basin (fig. 1) to make the consumptive use investigations (10). The area is not ideal for several reasons, one being that the cultivated land is less than 5 percent of the arable land. Another is that the ground-water inflow and outflow are difficult to determine.

Selection of plots to be sampled

The 5 most important factors to be considered in selecting plots to be sampled are:

1. Soil Properties: The soil must be of such texture and structure that it can be sampled with relative ease. The best soil samples are usually

obtained from plots that are easy to sample, and if the sampling is easy the sampler is more apt to duplicate samples about which he is uncertain.

2. Crops Grown: The crop growing on the plot should be normal or better in all respects: good stand, popular variety, and disease and insect free. Where time and money are to be spent determining the consumptive use of various crops neither should be wasted by sampling plots on which the growth is not average or above. It is easier and cheaper to sample a few good plots and estimate the consumptive use on a percentage basis to obtain the average for the total area, than to try to sample enough plots to get an average. It is also desirable to know what the maximum use could be if proper farming practices were followed.

3. Water Supply: The plot should have an adequate water supply. For reasons given above it is desirable to choose plots on the farms where the more promising irrigation practices are followed. In 1951 most of the plots sampled were not irrigated according to a regular schedule. Most of the water used was pumped and it was easy for the farmer to irrigate when he felt irrigation was necessary.

4. Accessibility of Plot: The plot should be easily accessible. If several plots are to be sampled properly throughout the growing period, time wasted opening and shutting gates and carrying equipment long distances is not justified unless other factors about the plot are very desirable.

5. Farmers' Cooperation: The attitude of the farmer who owns the land should be good. Without the advice and cooperation of the individual farmers in an area, reliable information is much more difficult to obtain.

In selecting plots in an area the first investigators should sample on several more plots than they plan to sample throughout the season. As time passes, the better plots, judged from the above requirements, are selected and sampled during the entire season. Some plots on which work is started have to be discontinued because of undesirable soil characteristics, insufficient water, disease or insect damage to the crop, or for other reasons. When repeated investigations are carried on, the area is gradually typed and in 2 or 3 years the investigators know where they can sample successfully and where they cannot.

In the Milford Valley during 1951 many plots were sampled (fig. 2). Some of these plots were begun as late as July. Several others were discontinued and some of those sampled should have been discontinued because they were difficult to sample. The investigations in 1952 should run more smoothly because the most desirable sampling areas are better known after the 1951 work.

Soil-Moisture depletion determinations

By making soil-moisture depletion determinations in the crop root-zone soils at appropriate intervals throughout the growing period, and by taking account of the rainfall, irrigations, soil moisture changes, and ground-water contribution, the total consumptive use may be determined.

Rainfall can be measured and irrigations counted, but it is very difficult to make accurate soil-moisture determinations, especially in a new area where the apparent specific gravity of the soil is not known.

For this reasen the King soil tube was used to obtain the samples because with it cores of known volume can be taken from which the equivalent inches of moisture in the soil can be determined without directly finding the apparent specific gravity of the soil. This is done by using Henrie's direct method of computing the equivalent depth of water in soil column (5). A brief description of the method follows. His correction will be described later in this paper.

Direct method of computing equivalent depth of water in a soil column. Since 1 gram of water has a volume of 1 cubic centimeter, the weight of the moisture in the soil column in grams is numerically equal to the volume of water in cubic centimeters. Dividing this value by the area of the cutter of the soil sampler in square centimeters gives the height of moisture in the column in centimeters. Dividing this by 2.54, the number of centimeters in an inch, gives the equivalent inches of water in the soil column. These conversion factors can be combined into the formula:

$$\text{Inches of water} = \frac{\text{Weight of water in grams}}{\pi \frac{D^2}{4} \times 2.54} = \frac{\text{Weight of water in grams}}{2D^2}$$

where D = the inside diameter of the cutter of the soil sampler in centimeters. Or, letting $C = 1/2\ D^2$, the equivalent height of water in inches equals C x weight of water in grams in the soil sample.

By using this simple formula it is necessary to obtain only the weight of the moisture in the sample, the diameter of the cutter with which the sample was taken, and the length of sample. Since the tube diameter is constant for each tube, by taking samples of known length, the only variable is the weight of the moisture which can easily be determined by weighing the soil when wet and dry.

Obtaining soil samples. To obtain the samples of known diameter and length from which the moisture was determined, 1-foot increments of core were taken until the desired depth was reached. The tube was driven down to the 1-foot mark with the driving hammer. It was then twisted to break off the core and was slowly pulled out. The tube was inverted and the core dumped out into a numbered sample can. If any soil remained in the tube it was cleaned out and placed in the can and an air-tight lid was placed on the can. The outside of the tube was then cleaned and the inside more thoroughly cleaned before it was placed back in the hole.

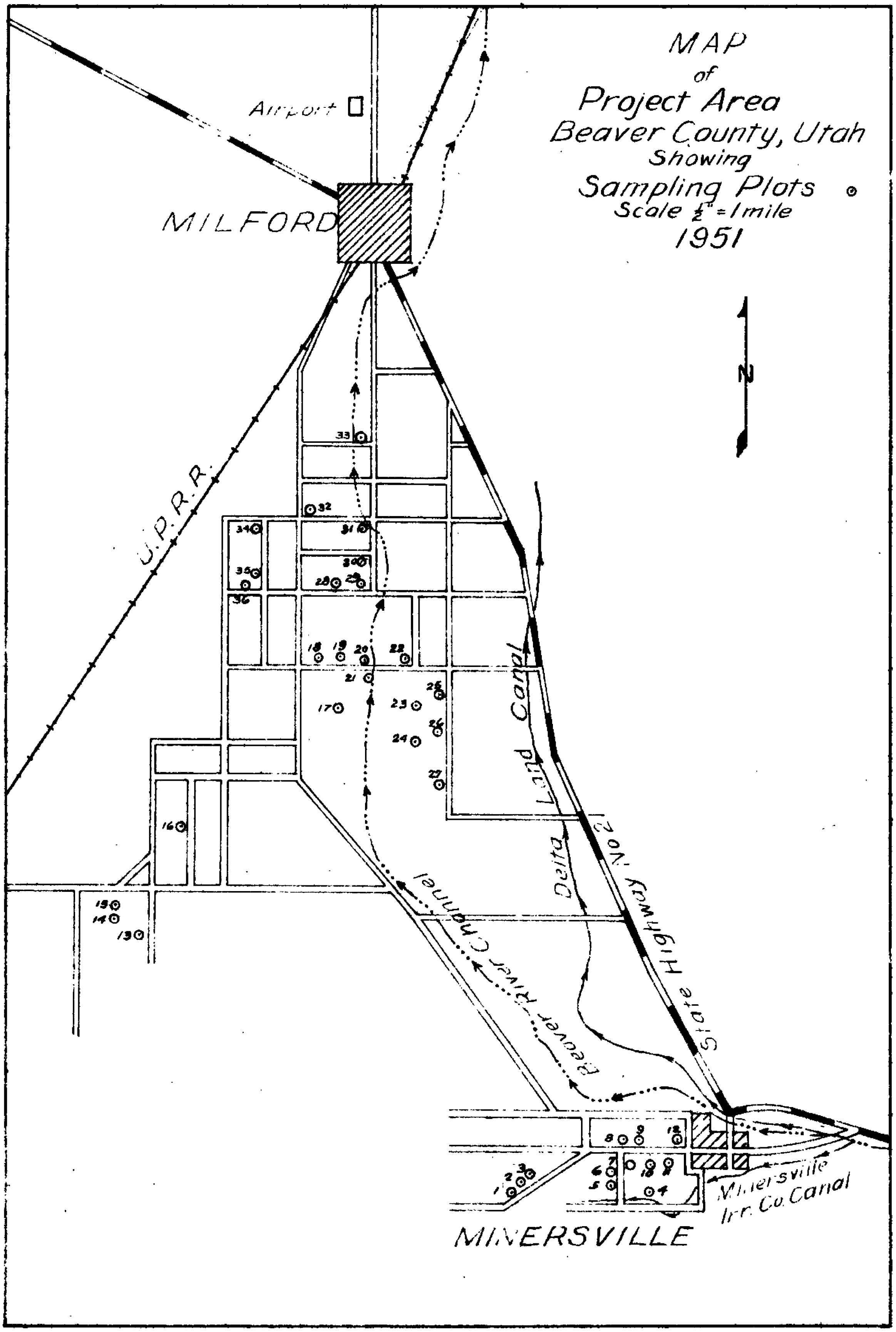


Figure 2. Map of the project area in Milford Valley, Beaver County, Utah, showing sampling plots.

Table 1. Sample data sheet on which field and laboratory data were recorded.

Field Data, Computations, and Corrections of Moisture Content

Date: 8/14/51 Farm: Larson

Area: Milford Crop: Alfalfa

Tube Number: 5 Tube Constant, C, $\frac{1}{2D^2}$: 0.1275

	0-1	1-2	2-3	3-4	4-5	5-6	6-7	Total
(1) Can number	61	62	63	64	65	66	67	
(2) Weight of wet soil + can	179.5	166.5	167.0	176.0	179.0	192.0	192.0	1252.0
(3) Weight of dry soil + can	161.5	149.5	141.0	163.0	157.5	165.5	169.0	1107.0
(4) Weight of moisture (2)-(3)	18.0	17.0	26.0	13.0	21.5	26.5	23.0	145.0
(5) Inches of water (4) x C	2.29	2.17	3.31	1.66	2.74	3.38	2.93	18.48
(6) Weight of dry soil + can	161.5	149.5	141.0	163.0	157.5	165.5	169.0	1107.0
(7) Weight of can	46.0	45.0	43.5	43.0	43.5	42.0	42.0	305.0
(8) Dry weight of soil (6)-(7)	115.5	104.5	97.5	120.0	114.0	123.5	127.0	802.0
(9) Average dry weight of core	115.3	104.1	95.4	112.0	117.9	117.4	128.6	790.7
(10) Correct inches of water (9)/(8) x (5)	2.30	2.15	3.24	1.55	2.83	3.21	2.99	18.27

Field Notes: (Irrigations, moisture conditions, changes in sampling procedure, loss of core, etc.)

Good Samples and Sampling
Water fair - getting dry tho.
3rd Crop starting slowly

It was then driven down to the next foot mark and the procedure repeated. When the desired number of samples was obtained the can numbers were recorded on the data sheet (table 1) and appropriate notes were made concerning the plot, sampling, etc.

Sampling problems. The above procedure is simple if everything goes as explained. However, in pulling out the tube it is easy to lose some of the soil core, especially under excessively wet or dry soil conditions. If dry, some soils do not hold together and when the tube is pulled out of the hole part of the core drops out; if wet, some soils adhere to the tube and a vacuum is formed around the end of the tube, pulling a length of core equal to the length of the shoulder of the cutter out before the vacuum is broken. Sometimes these increments of lost core are picked up in the next sample and the overall moisture content is not greatly affected if a notation is made and the data are carefully checked during the analysis.

When the soil was dumped out of the tube it was often apparent that the sample was short, although the end of the core showed the conical fracture plane caused by twisting the tube. Such samples are hard to explain and should be discarded. Sometimes in driving the tube it can be determined when unnatural conditions are encountered. The presence of roots or rodent holes or the lateral movement of soil are possible reasons for shortage of core.

In sandy soil it is common for the hole to cave in from above. In some instances these holes can be cleaned out, but more accurate results will be obtained if a new set of samples is taken. In all cases the investigator must use his judgment in deciding what to do about samples that look unnatural. In the 1951 work there was very little duplication, and, as a result, unreliable data were obtained. The number of plots should be restricted to a small number so that every plot can be sampled twice or more, if necessary, on each sampling data. If a small scale is taken into the field to use for a check, more reliable data can be obtained.

There is more to the sampling procedure than obtaining the desired soil samples. The plot is usually chosen near the head of a field to insure an adequate water supply but far enough from the head ditch to prevent seepage effects. If it is on the side of a field it is still desirable to go out in the field a few feet. This necessitates walking into the field and tramping down some of the plants. Even when extreme care is taken, some injury to the plants results which affects the consumptive use of the plot. This is more serious in some crops than others and should be remembered when starting onto the plot. It is also desirable to sample a short distance from the last sample hole to eliminate the effects of evaporation or unnatural recharge of the soil moisture if the plot was irrigated. Samples should be taken parallel to the direction of the irrigation run to eliminate as much as possible the effects of uneven water application. To prevent traveling too far in one direction lateral movements can be made on the first sample after an irrigation.

<u>Time to sample.</u> ——Samples should be taken before growth starts in the spring and as often as possible throughout the growing season. It helps to know the irrigation dates in advance because it is desirable to obtain samples just before the irrigation and as soon after as the gravitational water has drained out of the root zone soil. To determine the number of days required for the gravitational water to drain out of the soil, samplings should be made every day after the irrigation for a period long

enough to determine when the depletion rate slows down and appears reasonable. However, it is difficult to sample when the soil is wet, and satisfactory results can be obtained for most soils if they are sampled 3 or 4 days after irrigation. When most soils are dry enough to sample satisfactorily they are at field capacity or below.

If it is felt that reliable samples are being obtained, sampling once every week or 10 days is probably often enough, providing 3 or more samples are taken between irrigations. Thus the irrigation practices will regulate the sampling dates. For crops that are irrigated often the sampling dates should be closer together.

In the 1951 work few of the irrigation dates were known in advance and quite often only 2 sets of samples were obtained between irrigation dates. Several times only 1 set of samples was obtained. This is another disadvantage of having a large number of plots. A few plots with complete, reliable data are worth much more than a large number of plots with incomplete, questionable data.

Depth to sample. If the total soil-moisture depletion is to be found, samples should be taken throughout the soil profile to a depth below the root zone. In this study the root zone for alfalfa was assumed to be 7 feet, and small grains, corn, and potatoes 5 feet. These depths were used because the same depths were used in previous years. No check was made to determine if this depth was adequate, because the plots varied so much that each would have had to be checked to be sure. Bowen (3) found that only 3 percent of the total water used by alfalfa was taken from the 6-foot depth, 6 percent of the total water used by potatoes was taken from the 4-foot depth, and 9 percent of the total water used by oats was taken from the 4-foot depth. Therefore, in the author's opinion, except in rare cases, the moisture used from below the 7th foot of soil in alfalfa and the 5th foot in corn, small grains, and potatoes is negligible considering the present accuracy obtained in determining the moisture content of soil.

Determining equivalent depths of water in each sample. In determining the moisture in a soil column each sample was weighed, dried, and weighed again. The dry weight was subtracted from the wet weight, giving the weight of the moisture, which, when multiplied by the tube constant, C, yields the inches of water in the sample. The depths of water for each foot sampled were totaled, giving the total inches of water in the soil column.

Corrections essential. No matter how careful the person sampling the soil is, he does not get exactly the 1 foot of core that has been assumed in the computations. Therefore, corrections are necessary to obtain reasonable results. Henrie suggests correcting the equivalent inches of water in the core by the ratio of the average dry weight of core to the dry weight of the core for which the moisture is being corrected. His correction is based on the belief that the dry weight of the core in each foot sampled should remain constant when repeated samples are taken from the same plot. If all of the dry weights of the cores in the same foot, taken from the same plots, are averaged, excluding any extremely high or low values which indicate a definite gain or loss of core, this is assumed to be the correct average dry weight of the foot of core.

The dry weights of the samples for the plot from which the data of table 1 were taken are shown with the averages in table 2. All samples were corrected whether they appeared to be questionable or not. However,

Table 2. Sample sheet for determining the average dry weight of core.

DRY WEIGHT OF CORES

Farm: Larson
Converted to tube No. 5
Crop: Alfalfa
Date: 12/23/52

Date Sampled	Tube No. Used	Converted Dry Weight of Core							
		0–1	1–2	2–3	3–4	4–5	5–6	6–7	Total
5/3/51	5	115.2	103.4	103.5	116.3	118.7	123.0	121.2	801.6
5/12/51	4 5	116.5	101.0	96.0	106.5	115.5	132.8	120.1	788.4
6/8/51	4 5	119.5	101.5	89.5	104.0	112.0	111.5	132.0	770.0
6/19/51	5	115.0	96.5	90.5	104.0	113.5	121.5	121.0	762.0
6/25/51	5	107.5	107.0	100.0	113.5	125.5	118.5	129.5	801.6
7/11/51	5	116.5	113.0	98.0	113.0	125.5	129.0	130.0	825.0
7/21/51	5	121.5	104.5	94.0	121.5	125.0	104.5	130.5	801.5
7/28/51	5	112.5	106.0	93.0	113.5	121.0	109.5	139.0	794.5
8/6/51	5	116.5	99.0	98.0	123.0	119.5	119.0	132.5	807.5
8/14/51	5	115.5	104.5	97.5	120.0	114.0	123.5	127.0	802.0
8/24/51	5	94.0	104.5	88.5	102.5	119.0	119.5	123.0	751.0
9/4/51	5	126.5	112.5	97.5	108.5	118.0	116.5	128.5	808.0
9/12/51	5	120.5	101.0	94.0	118.5	111.5	128.0	105.5	779.0
9/24/51	5	113.0	101.0	96.0	105.0	120.0	100.5	148.5	784.0
11/9/51	5	119.5	105.5	95.5	110.5	111.5	104.0	140.5	787.0
Average	5	115.3	104.1	95.4	112.0	117.9	117.4	128.6	790.7

it is the author's opionion that the average dry weights tend to be short because there is always some core lost due to soil sticking to the tube, small losses in transferring the soil from the tube to the can, etc. Therefore, the moisture was not all accounted for; however, this did not seriously affect the consumptive use because all values were corrected and depletion would not change. The total corrected inches of water in the soil column were used in determining the soil-moisture depletion.

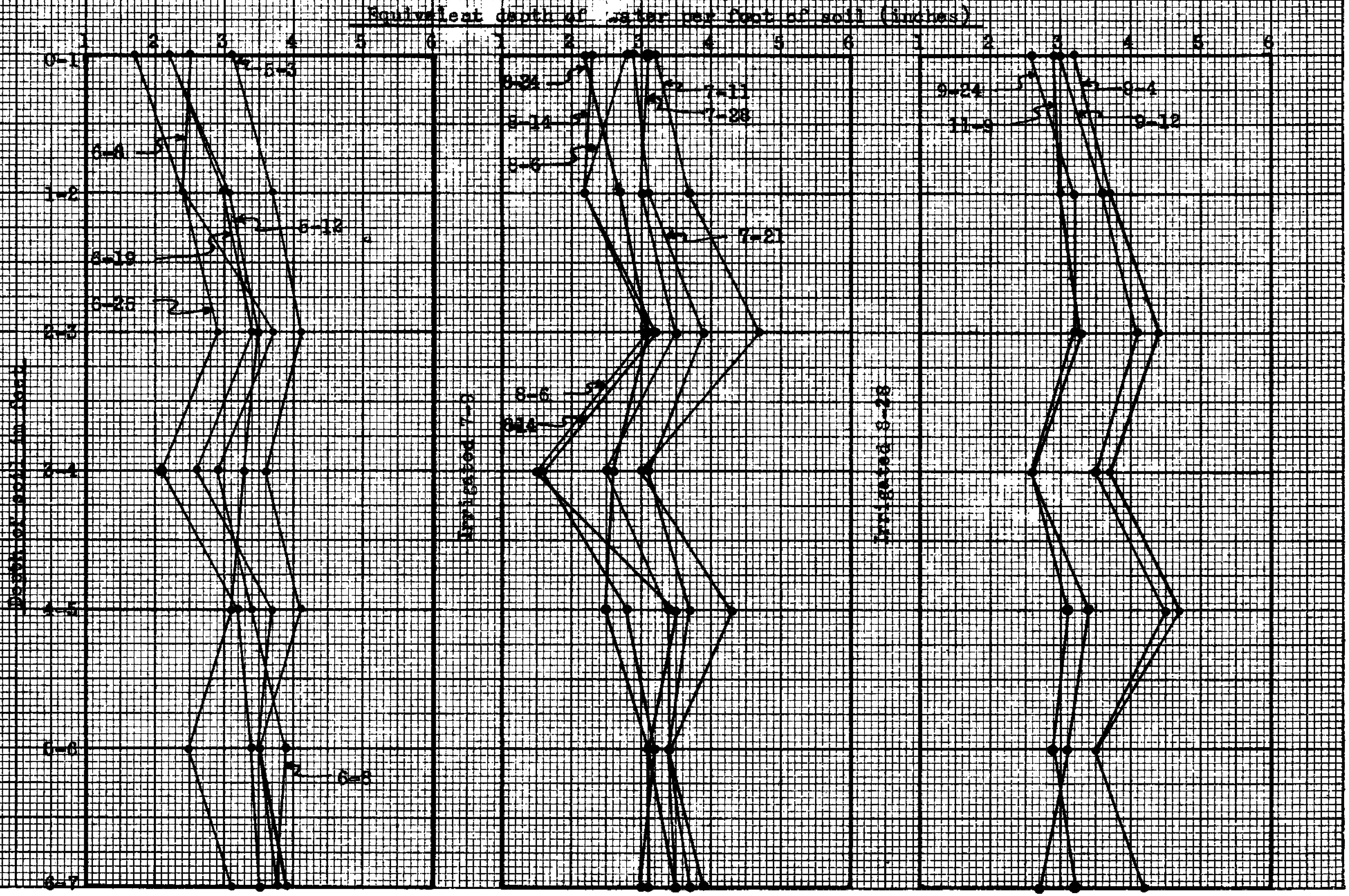
To obtain a visual picture of the moisture distribution, the equivalent inches of water per foot of soil was plotted against depth as shown in Figure 3.

Effects of rainfall and irrigations on soil moisture depletion

The consumptive use for a sampling period, as determined by the soil-moisture depletion method, is the summation of the soil moisture depletion plus any water that is added to the plot between sampling dates. If it is known how much water is added, even though the depletion may be negative the use can be determined by the algebraic addition of the depletion and the added water. Since it is difficult to determine the equivalent depth of water added to the root-zone soil in an irrigation, the depletion for a sampling period in which there was an irrigation was assumed, using the depletion rates before and after the irrigation as the basis for the assumption. The irrigation dates were recorded on the data sheets. Therefore, the water added by rainfall was all that was added to the soil-moisture depletion to obtain the consumptive use between irrigation dates.

In Milford Valley the weather bureau collected rainfall data at Minersville and at the airport, one mile north of Milford (12). There were many convection storms during the summer of 1951, and the data collected at the 2 stations do not give a true picture of the precipitation

Figure 3. Distribution of moisture in the soil on the Larson alfalfa plot at different dates



for each plot. However, since there are neither data available, the precipitation recorded at Minersville was assumed to have fallen on all of the plots in Minersville and the precipitation recorded at the Milford airport was assumed to have fallen on each of the other plots. The Minersville data are not complete, and, where there are data missing, the precipitation recorded at the Milford airport was assumed to have fallen in Minersville also. The mass rainfall curves for Milford and Minersville, used in the 1951 analysis, are shown in figures 4 and 5.

Analysis of the soil moisture data[1]

The first step in the analysis of the soil-moisture depletion data was the plotting of the equivalent depth of water in the root-zone soil against time for each sampling plot. Theoretically in this plotting the points should decrease with time until water was added to the plot, or until the crop stopped growing. In the top half of figure 6 is shown a hypothetical example that illustrates how the equivalent depth of water in the root-zone soil should vary with time during the growing period for a crop. Barrett and Milligan (1), Fisher (4), and Henrie (6) have all used this method of analysis with favorable results. However, when the data collected in 1951 were plotted it was apparent that something was wrong. For most of the plots there was a tendency for the equivalent depth of water in the root-zone soil to decrease with time, but there were so many sampling periods that either showed excessive uses or an addition of water when there had been no water added, that the consumptive use could not be determined for each plot. In the bottom half of figure 6 is shown the root-zone soil-moisture depletion rates as determined by the 1951 determinations. In the actual analysis the effective rain for each sampling period was calculated and added to the depletion.

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[1] All calculations made in the analysis of these data are on file in the Irrigation and Drainage Department, Utah State Agricultural College.

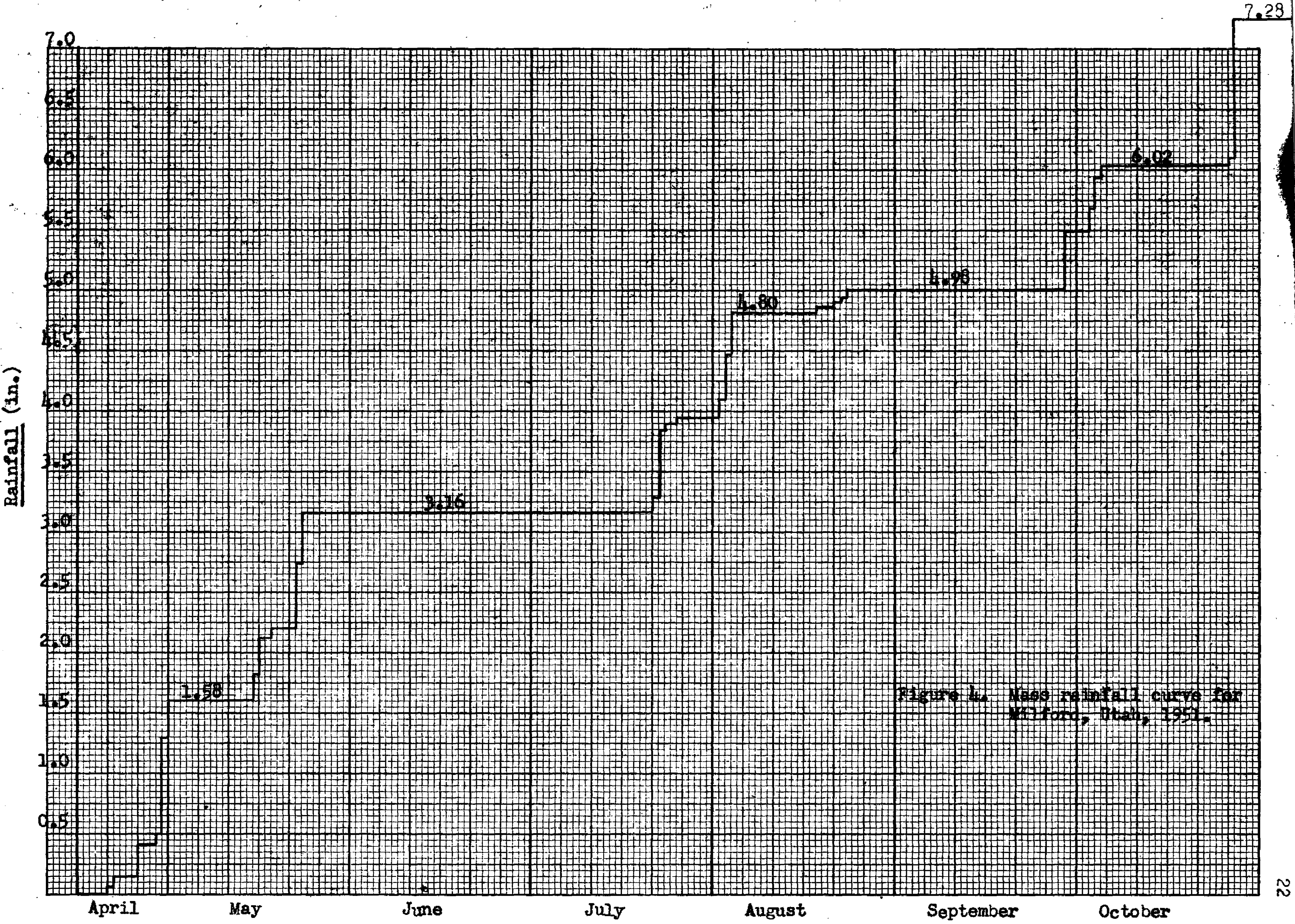

Figure 4. Mass rainfall curve for Milford, Utah, 1951.

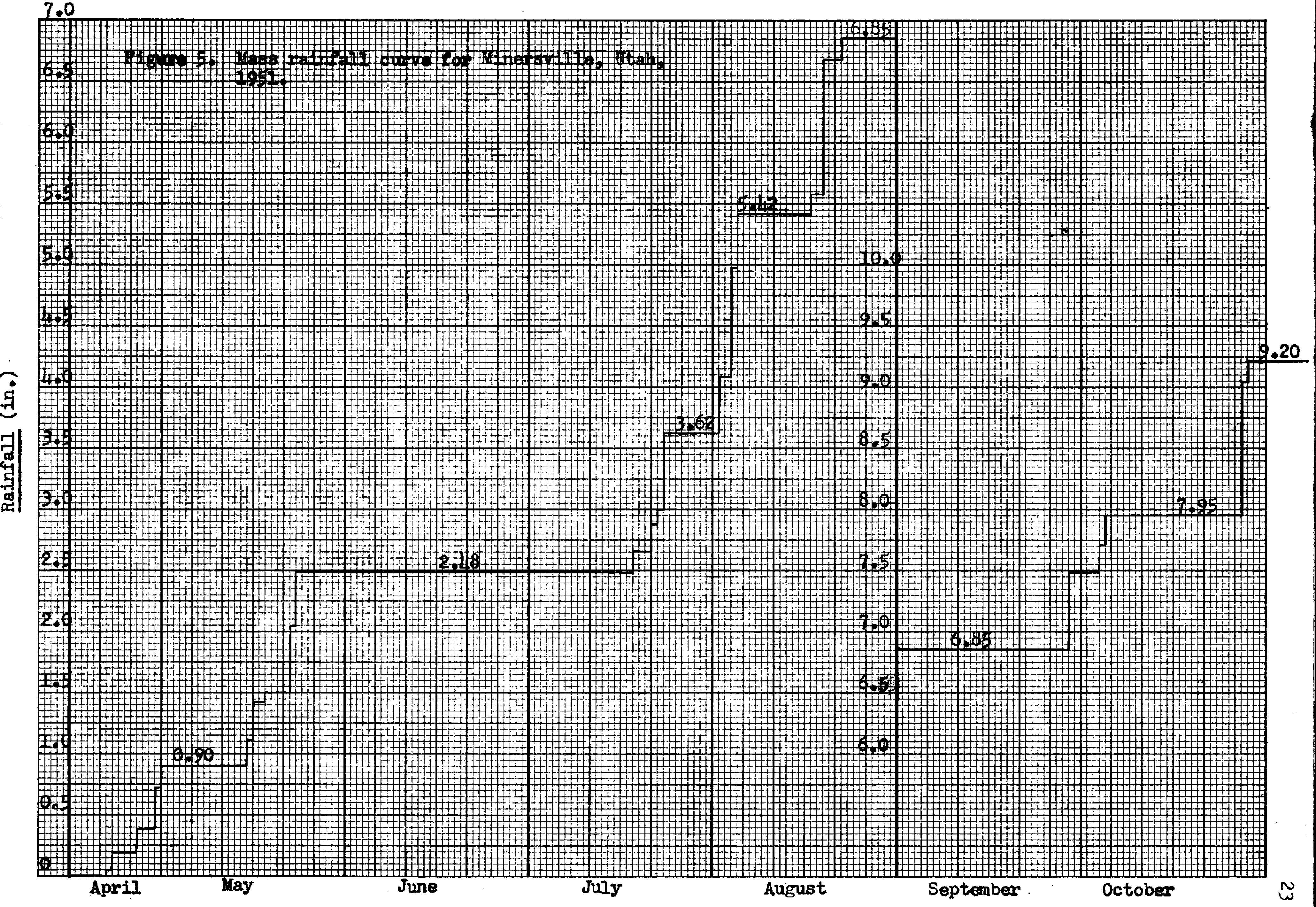
Figure 5. Mass rainfall curve for Minersville, Utah, 1951.

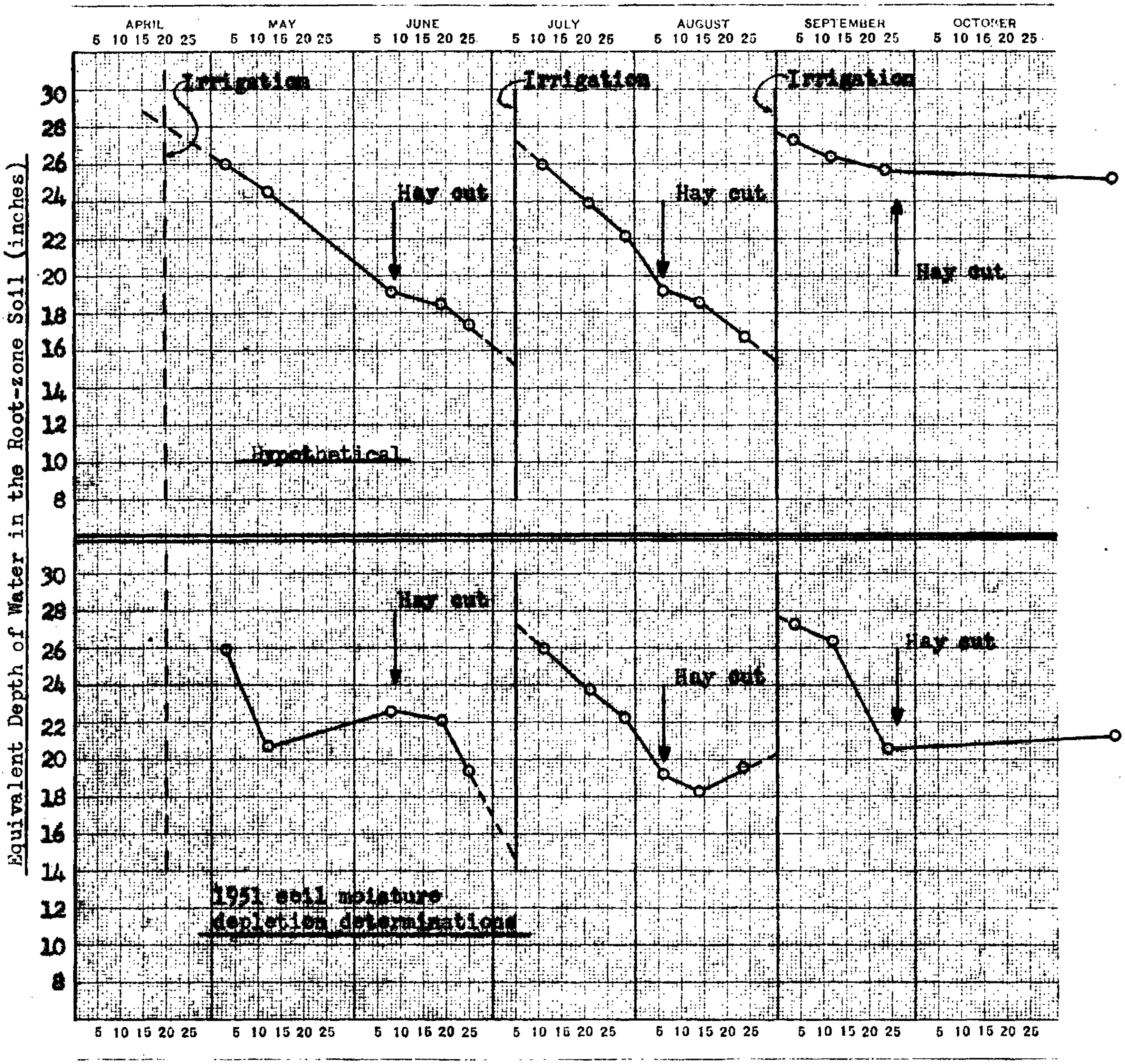

Figure 6. Equivalent depth of water in the root zone soil on each sampling date. Above; Hypothetical depletion rates, Below: Depletion rates as determined by the 1951 soil moisture depletion determinations on the Larson alfalfa plot

Next, the average daily consumptive use for each sampling period was calculated by adding the rain that fell during the period to the depletion during the period and dividing by the number of days in the period. It was suggested that by plotting all of the average daily consumptive uses for all of the plots of a particular crop against time, that a best fit curve could be drawn through the points and would represent the average daily consumptive use for that crop. However, the uses fluctuated so much that the best fit curve was difficult to determine and would not have been reliable if it could have been found, because there were too many uses included that were absurd. Figure 7 shows the uses for all of the alfalfa plots plotted against time.

At this stage in the analysis it was apparent that the data were not too reliable and any statistical analysis was not practical. Therefore, the reasonable uses from all of the plots of each crop were used to obtain an average daily use for the crop[2]. The data were so variable that even by doing this there were periods for which there were no reasonable data and the uses were assumed, using the stage of crop maturity and other influencing factors as a basis for the assumptions.

Results

Data on corn are complete, and the summation of the daily uses equals 22 inches.

Data on alfalfa are complete from May 12, and the summation of the daily uses equals 33 inches. If 3 inches is assumed to have been used

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[2] To determine the reasonable uses, the daily consumptive use factors which are explained later in this thesis under the Blaney and Criddle empirical method, were calculated (figure 8). Any values that fell within from 0.5 to 1.5 times the consumptive use factor, as shown in figure 8, were considered reasonable.

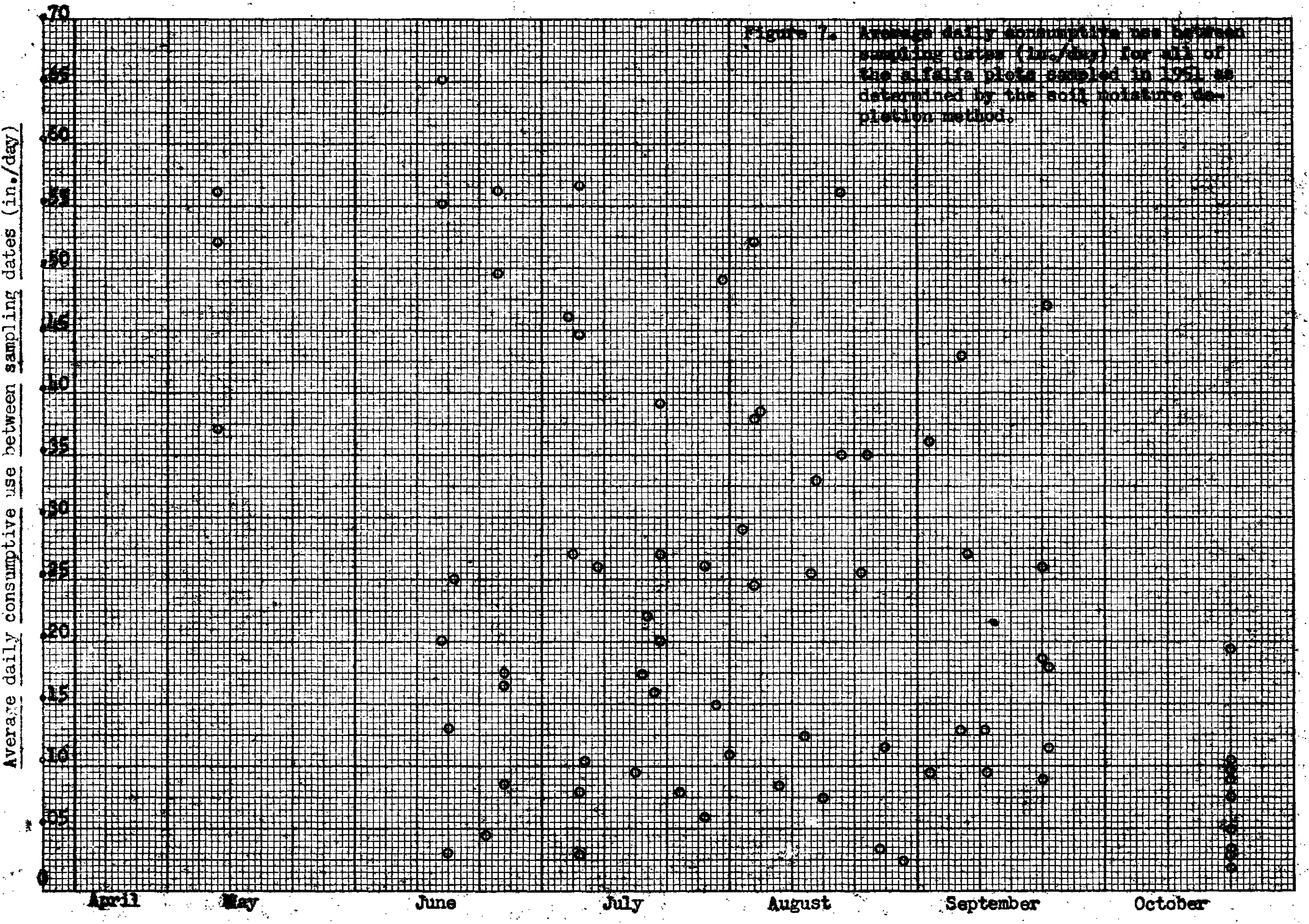

Figure 7. Average daily consumptive use between sampling dates (in./day) for all of the alfalfa plots sampled in 1951 as determined by the soil moisture depletion method.

before May 12 the consumptive use for alfalfa is approximately 36 inches per season.

Although there were several plots of fall grain the growing period for small grains was assumed to be from May 15 to August 15. The data were complete from June 19, and it was assumed that the measured 11 inches represent two-thirds of the seasonal use. On this basis, the consumptive use for small grains is 17 inches for the season.

The potato consumptive use data were so variable that no attempt was made to determine the seasonal consumptive use.

Discussion and conclusions

The field and laboratory experiences of 1951, and the attempted analysis of the data collected, seem to support the following conclusions:

1. Too many plots were sampled. At the end of the season there were 11 alfalfa, 10 grain, 5 corn, and 11 potato plots that were sampled through the season. The alfalfa, grain, and corn could have been handled easily; but because the potatoes were irrigated so often they were sampled as often as every other day. Each plot was sampled in 2 adjacent rows and the hill between - - making as much work as the other 3 crops combined. As a result duplicate samples were seldom taken, except in potatoes which were irrigated so often that the soil was close to field capacity most of the time.

2. More cans were needed. The author had only 162 cans to use in the sampling work. These cans were full most of the time and as a result the drying procedure was rushed and it is possible that some of the samples may have been weighed out of the oven before they were thoroughly dry. The oven would hold a maximum of 131 cans. Although it was checked several times, the 24 hours assumed may not have been sufficient to dry all of

this soil, especially when a large percentage was heavy, holding as much as 5 inches of water per foot.

3. Better cans are essential because the cans were old, badly rusted, and bent. Some moisture could have been lost before the wet weight of the soil was determined. Often it was 10 or 12 hours after they were taken from the ground before the first sample taken were weighed.

4. Too many short cores were accepted. Many times, because of the difficulty of obtaining a full core, a half or third of a core was accepted without a duplication. One short core out of 10 samples can be corrected for, but 5 short cores out of 10 leaves the average dry weight of core questionable.

5. More complete field computations should be required. The calculations were not carried through completely in the field. The inches of water were determined and the dry weight of the soil found, but no correction was attempted on all of the data. One or 2 plots were checked and it could be seen that the dry weights were varying considerably but it was assumed that the correction would take care of it.

6. Close and frequent examination is essential to progress. The project leader visited the area in August. A day was spent going through the regular sampling procedure. General comments and suggestions were made, but nothing was said that indicated proper techniques were not being used. He suggested sampling deeper in the potatoes and encouraged close observation of conditions in general. He examined the data collected up to date but did not make any comments that were discouraging. It was assumed that the data were good, and without a close examination it would have been hard for anyone to believe differently.

7. Early and comprehensive studies are helpful. Henrie's thesis

(7) and other recent articles on consumptive-use determinations by the soil moisture depletion method had not been read by the author. Henrie gave some good recommendations and suggestions that would have helped considerably in the field work.

8. The data collected have some value. The author salvaged several use rates from each plot, put them together, and with a few assumptions obtained values that appear to be reasonable for the consumptive use of alfalfa, corn, and small grain, even though statistical analyses were not practical.

More reliable information could be obtained from the data if apparent specific gravity determinations were to be made during 1952. The moisture percentages of the samples can easily be calculated from the data.

THE BLANEY AND CRIDDLE EMPIRICAL METHOD OF DETERMINING CONSUMPTIVE USE

Consumptive use of water

It was planned that the empirical method of determining consumptive use as outlined by Blaney and Criddle would be used as a check on the soil-moisture depletion method. The method they used was developed from the following reasoning.

> As previously indicated, consumptive use of water is affected by numerous independent and related variables; and of the climatic factors affecting plant growth, temperature and precipitation undoubtedly have the greatest influence. Furthermore, records of temperature and precipitation are far more universally available throughout the western States than are data for other factors. The actual hours of sunshine also play an important part in the rate at which plants grow and consume water, but sunshine records are not generally available. The theoretical daytime hours for each day are available for all the latitudes (14) and may be used in place of the actual data. Although it is recognized that these may be misleading in areas where heavy fog or stormy weather exists during a large part of the year, temperatures tend to correct for such a condition. Humidity records, if available, may also be used as a correction. (2)

Consumptive-use formula

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

$$U = KF = \sum (kf) = u$$

U = Consumptive use of crop in inches for any period.

F = Sum of the time unit consumptive-use factors for the period.

K = Empirical consumptive-use coefficient for the period.

t = Mean time unit temperature, in degrees Fahrenheit.

p = Time unit percent of daytime hours of the year.

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

k = Time unit consumptive-use coefficient.

u = kf = time unit consumptive use in inches.

Blaney and Criddle used the month as the time unit. This is convenient because the mean monthly temperatures can be taken directly from climatological data for many areas. However, the daily temperatures are also given in the climatological data and the sunshine Tables have the daily percent of daytime hours for the year. Therefore, it is possible to break the period down into time units of less than a month where conditions warrant it.

Consumptive use factor. In this study the author determined the daily consumptive-use factor for Milford in the hope that it could be used as a basis for making assumptions for the soil-moisture depletion analysis (figure 8).

The minimum and maximum values of the daily consumptive-use factor during the assumed growing period, April 15 to October 20, are 0.112 inches per day on October 5, and 0.269 inches per day on July 19. It is interesting to note the relationship shown in Figure 8 between the hours of possible sunshine per day and the average daily consumptive-use factor.

Consumptive-use coefficient (K). Blaney and Criddle have summarized the consumptive-use values (U) for the important crops in various localities of the West as determined by investigations, and the calculated consumptive-use factor (F) and the crop coefficients (K) for the areas studied. These data have been correlated with temperature and the growing season, and the consumptive-use coefficient (K) has been computed by the formula $K = \frac{U}{F}$. The computed coefficients varied somewhat because of the diverse

366 days × 250 (10 per unit) divisions.
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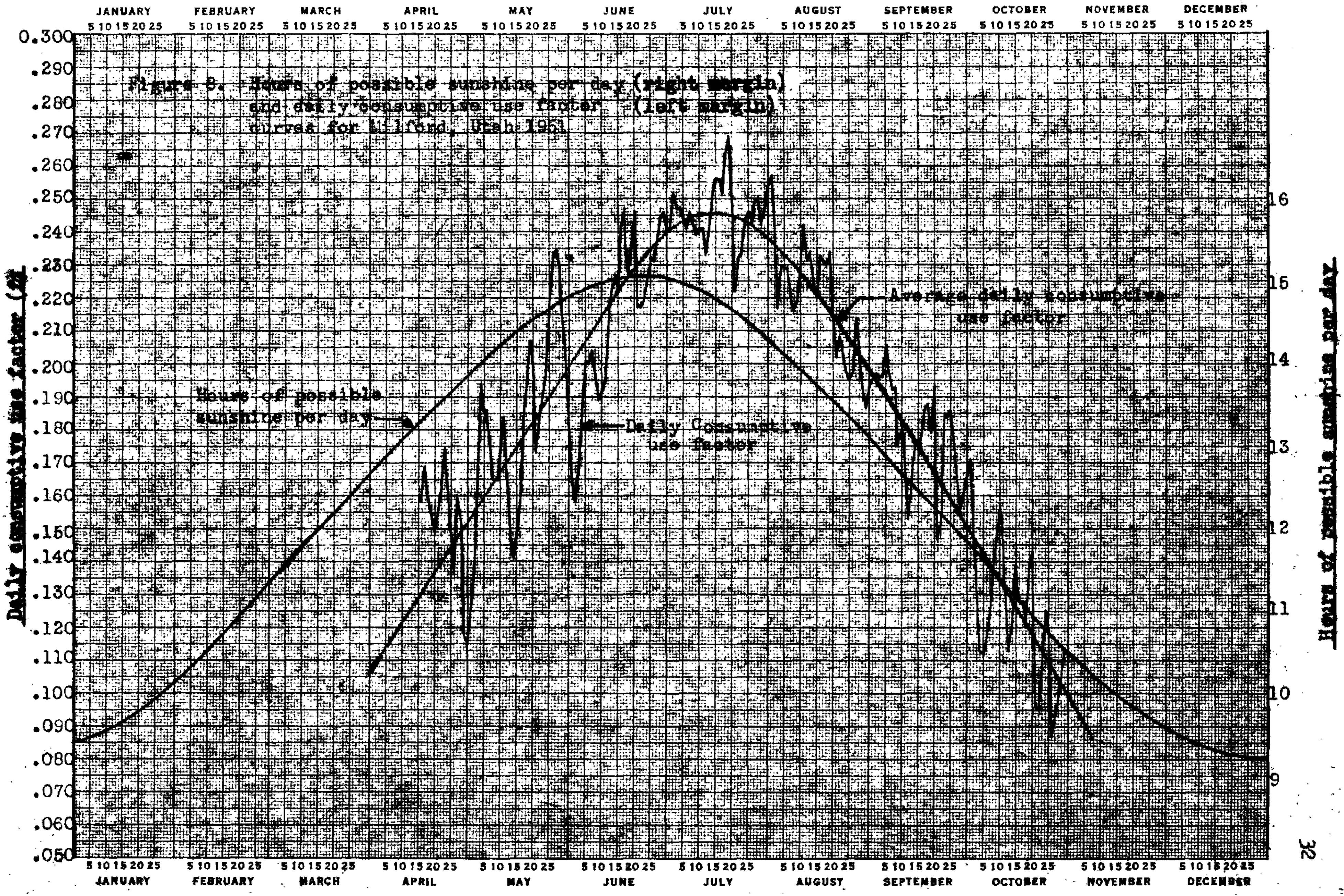

Figure 8. Hours of possible sunshine per day (right margin) and daily consumptive use factor (left margin) curves for Milford, Utah 1951

conditions (such as soils, water supply, and methods) under which the studies were conducted. These coefficients were adjusted, where necessary, after the data were analysed. The resulting coefficients for alfalfa, grain, corn, and potatoes, believe to be suitable for normal conditions in Milford, are presented in Table 3. These coefficients are for the total period and are most useful in determining the total consumptive-use for the period.

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

Crop	Length of growing season or period	Consumptive-use coefficient (K)
Alfalfa	Between frosts	0.85
Corn	4 months	0.85
Grains, small	3 months	0.85
Potatoes	3½ months	0.75

Henrie (6) divided the total period into 3 units and showed that the coefficients were different for each unit.

Israelsen (7) gives monthly coefficients for alfalfa for Upper Salinas Valley, California, that vary from 0.60 in April to 0.85 in July, August, and September, and then back to 0.70 for October.

It is possible that within each month the daily coefficient might vary from 0.5 to 2.0, depending upon the crop, available water, plant nutrients, and other factors that influence the consumptive-use. If limits could be determined for each individual area on a short-time basis, the use rate per day could be more accurately estimated. In the author's opinion this will some day be considered valuable information by the farmers and they will use it to increase irrigation efficiencies and crop growth rates.

Consumptive-use determinations. Consumptive-use factors for the crops grown in Milford Valley are shown in table 4. The consumptive use as determined by the empirical formula is found in table 5, a tabulation of results. The coefficients used were taken from table 3. The growing period for alfalfa and potatoes was extended beyond the frost-free period because there was considerable growth before and after the last and first frosts.

The empirical method of determining consumptive use is an easy, fast way to approximate the consumptive use for an area for which there are temperature and precipitation data available. As more consumptive use data are obtained by measurement, empirical coefficients can be further verified or revised so that they can be used throughout the West with confidence.

Table 4. Calculated consumptive-use factors for Milford, Utah, 1951.

Month	Mean temperature (t)	Percent daytime hours (p)	Consumptive use factor (f)	Alfalfa 4-5/10-20	Corn 6-1/9-10	Grain 5-5/8-15 (small)	Potatoes 6-15/10-1
	°F.						
April	48.3	8.90	4.30	2.15			
May	56.9	9.92	5.65	5.65		2.83	
June	64.5	9.95	6.42	6.42	6.42	6.42	3.21
July	75.4	10.10	8.28	8.28	8.28	8.28	8.28
Aug.	71.3	9.47	6.75	6.75	6.57	3.38	6.75
Sept.	64.1	8.38	5.37	5.37	1.79		5.37
Oct.	48.8	7.80	3.81	2.54			3.81
Total				37.16	23.24	20.91	27.42

Table 5. Calculated consumptive-use for crops in Milford, Utah, and tabulation of results.

Crop	Growing season	Consumptive use factor (F)	Assumed consumptive use coefficient (K)	Consumptive-use		Ratio of depletion to empirical	$\frac{Exa}{K}$
				Empirical (U)	Depletion (U)		
Alfalfa	4-15/10-20	37.16	0.85	32	36	1.125	.968
Corn	6-1/9-10	23.24	0.85	20	22	1.100	.947
Small Grain	5-15/8-15	20.91	0.85	18	17	0.994	.81
Potatoes	6-15/10-1	27.42	-.75	21	-	- - -	

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