Funding for WRDS and the creation of this electronic document was provided by the Wyoming Water Development Commission (http://wwdc.state.wy.us)

THE UNIVERSITY OF WYOMING

WATER RESOURCES RESEARCH INSTITUTE

P. O. BOX 3038, UNIVERSITY STATION

LARAMIE, WYOMING 82070

TELEPHONE: 766-2143
AREA CODE: 307

Water Resources Series No. 29

CONSUMPTIVE USE BY IRRIGATED HIGH MOUNTAIN MEADOWS IN SOUTHERN WYOMING

by

Theodore J. Swartz
Robert D. Burman
Paul A. Rechard

May 1972

Abstract

An area along the Medicine Bow River in south central Wyoming was instrumented to obtain estimates of consumptive use (evapotranspiration) from irrigated high mountain meadows. Four basic methods were employed: non-weighing tank lysimeters, the hydrologic budget, the Modified Jensen-Haise method, and an adaptation of the Blaney-Criddle method.

A description of the instrumentation required to secure the necessary data for these methods, the results of the application of these methods, and comparisons of the results are presented.

Analysis revealed that estimates by the Blaney-Criddle method were consistently less than the values obtained by any of the other methods. Estimates by the Jensen-Haise method compared favorably, on a weekly basis, with the evapotranspiration measured from the tank lysimeters. Comparisons also showed that estimates by the Modified Jensen-Haise method produced the least discrepancy from the seasonal consumptive use determined by the hydrologic budget.

KEY WORDS: Evapotranspiration/ Lysimeter/ Hydrologic budget/ Wetlands/ Streamflow/ Consumptive use/

ACKNOWLEDGMENTS

The cooperation of the landowners is recognized for their permission and cooperation during the installation and maintenance of the instrumentation sites necessary for this study.

Research on which this report is based was supported in part by the Office of Water Resources Research under the Water Resource Research Act of 1964 and the Wyoming Water Planning Program, Office of the State Engineer, both acting through the Wyoming Water Resources Research Institute.

TABLE OF CONTENTS

LIST OF TABLES

TABLE | | Page

LIST OF FIGURES

Figure | Page

Figure Page

CHAPTER I. INTRODUCTION

Greater demands for agricultural, municipal, and industrial water are arising continuously throughout the country. In view of these increasing demands, it is imperative that more information regarding the availability and usage of water be obtained, so that planners and administrators can better distinguish or distribute their needs with reference to what is available or what is already being used.

The concept of usage and availability of water is quite frequently the basis of negotiation of interstate compacts as well as the division of waters within a state.

Considerable investigation has been conducted concerning the consumptive use of agricultural land. Veihmeyer (21)[1] presents a resume including 158 references on determining consumptive use and since the time of release of his publication, many more publications have been presented. The majority of these publications consider lands at elevations less than 5000 feet. Limited research on lands above 5000 feet has been conducted. It is hypothesized that the coefficients for determining consumptive use by lands at less than 5000 feet elevation, may not be applicable to lands above 5000 feet (15).

---

[1]Number in parentheses refers to the number entry in the list of cited literature.

In view of this belief, an area including substantial irrigated mountain meadows of mean elevation near 7500 feet was selected in southern Wyoming along the Medicine Bow River for extensive investigation to determine the consumptive use. The primary objectives of this study were: 1) to determine the valley consumptive use by the hydrologic budget, 2) to observe the consumptive use by means of tank lysimeters, and 3) to compare the measured consumptive use from the tank lysimeters to the evapotranspiration estimates obtained from the Blaney-Criddle and the Modified Jensen-Haise methods. The terms "consumptive use" and "evapotranspiration" will be used interchangeably throughout this report.

There exists among researchers in the field of evapotranspiration considerable disagreement concerning the definition of "potential evapotranspiration". For this study "potential evapotranspiration" will be defined as the amount of water that could be consumptively used when plant constituents and available moisture are not limiting factors. The Blaney-Criddle method of estimating consumptive use assumes that potential evapotranspiration is the product of the crop coefficients and the consumptive use factor, where as in the Modified Jensen-Haise method "potential" is assumed without application of crop coefficients.

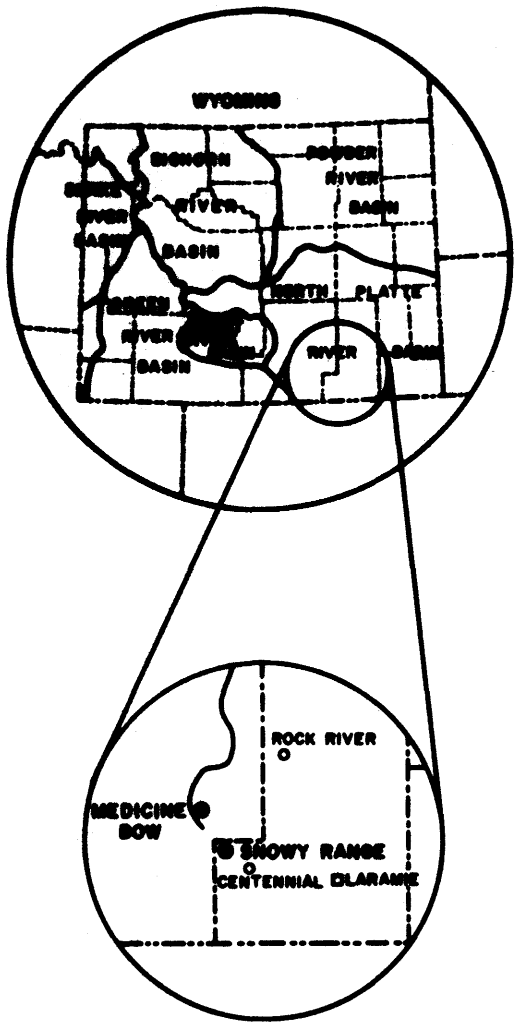
The area selected for study is predominantly mountain valley terrain. Due to low spring and fall temperatures, the operation of the tank lysimeters in this area is limited to nearly a twelve week period during the summer months. Comparisons will be presented for the period of operation of the lysimeters and for an estimated growing season. An attempt will also be made to determine the portion of yearly evapotranspiration as determined by the hydrologic budget that occurs during the estimated growing season.

CHAPTER II. GENERAL DESCRIPTION OF THE AREA

Location

The study site is located on the eastern side of Carbon County in south central Wyoming along approximately 16 miles of the Medicine Bow River (Figure 1). The study area is bounded on the south by the Medicine Bow National Forest boundary, on the east by the hydrologic divide with Wagonhound Creek, and on the west by the hydrologic divides with Pass Creek and Fish Creek. The northern boundary is a high bluff extending in an east-west direction. Figure 2 shows an outline of the specific study area. The study area contains 37590 acres of land, of which 14550 acres are irrigated or riparian. The irrigated and riparian areas will be referred to as "wetlands" and are outlined in Figure 3.

The Medicine Bow River heads on the north side of Medicine Bow Peak in the Snowy Range of the Medicine Bow National Forest between Laramie, Wyoming, and Rawlins, Wyoming. It flows in a northerly direction through the study area to the town of Elk Mountain, Wyoming, then in a northeasterly direction to the town of Medicine Bow, Wyoming. It then flows in a northwesterly direction to its confluence with the North Platte River at Seminoe Reservoir. The total reach of the river is approximately 195 miles (13) and its drainage



LOCATION MAP

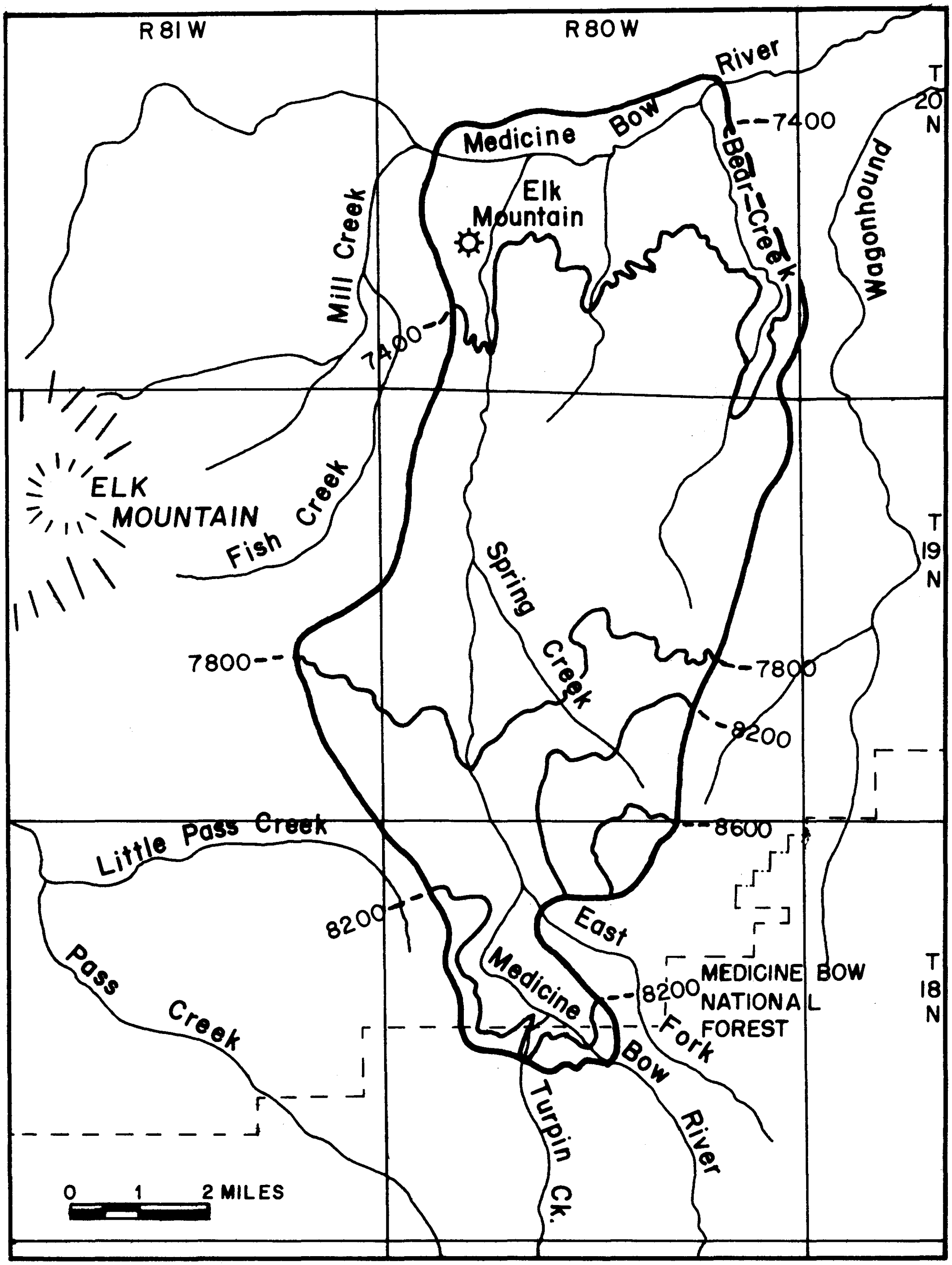
W.R.R.I.

SNOWY RANGE and MEDICINE BOW

RESEARCH AREAS

UNIVERSITY of WYOMING

Figure 1



BOUNDARY OF SPECIFIC STUDY AREA

Figure 2

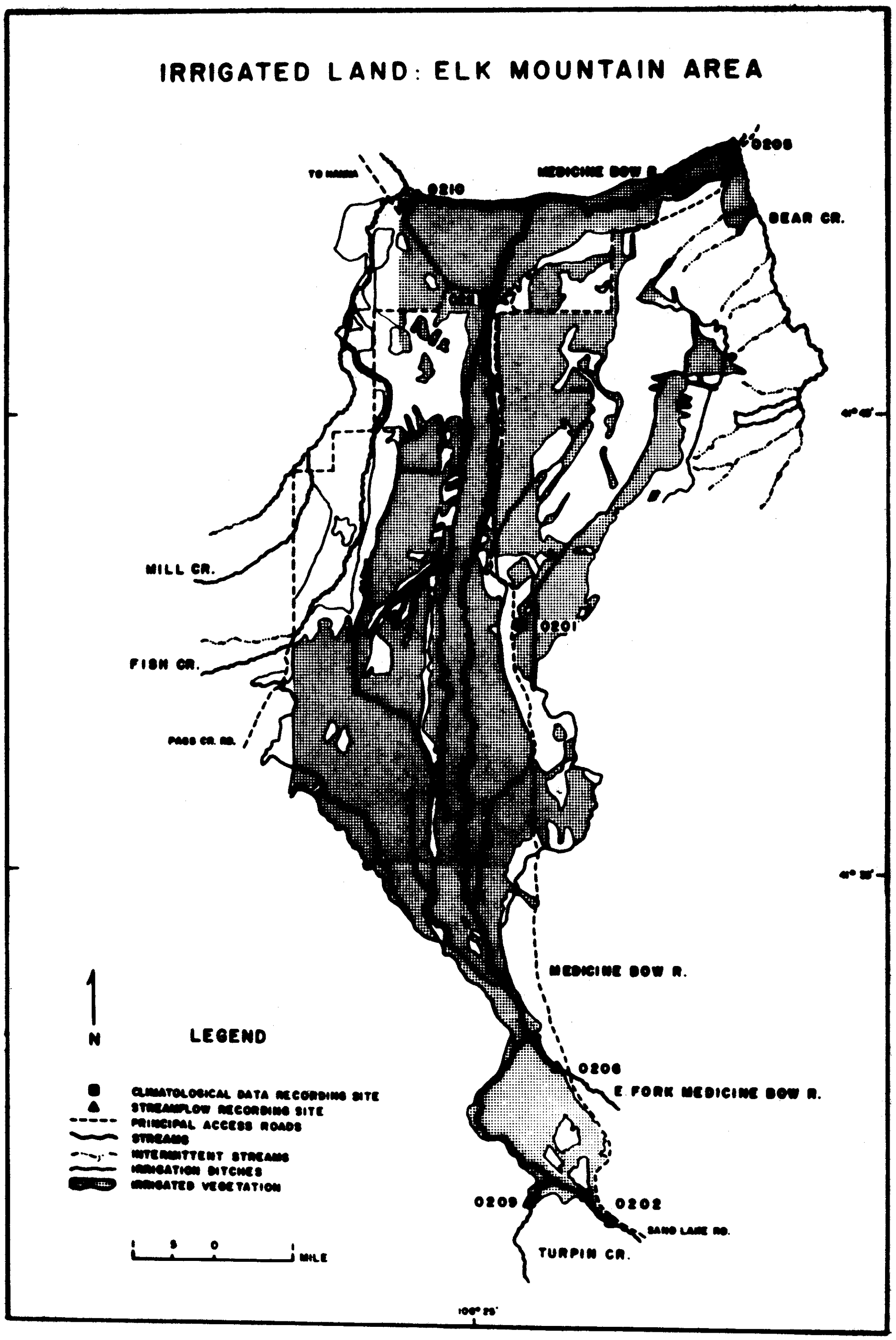

IRRIGATED LAND: ELK MOUNTAIN AREA
0208
MEDICINE BOW R.
0210
BEAR CR.
MILL CR.
FISH CR.
0201
MEDICINE BOW R.
LEGEND
N
CLIMATOLOGICAL DATA RECORDING SITE
STREAMFLOW RECORDING SITE
PRINCIPAL ACCESS ROADS
STREAMS
INTERMITTENT STREAMS
IRRIGATION DITCHES
IRRIGATED VEGETATION
0206
E. FORK MEDICINE BOW R.
0209
0202
TURPIN CR.
MILE

Figure 3

basin contains 2338 square miles of which 396 square miles are probably noncontributing (19).

Elevation and Climate

The study area is located in a valley with Elk Mountain rising 11162 feet above sea level on the west and a hydrologic divide on the east with an elevation between 7200 and 10000 feet. The study area varies in elevation from 7000 feet at the northern boundary to 8500 feet at the Medicine Bow National Forest boundary on the south and has an average elevation of approximately 7500 feet above mean sea level.

Reichenbaugh (11) describes the climate of the area as being predominantly Continental in classification due to the area's high elevation and cool temperatures. He also indicated that the distribution of precipitation in the area is of an orographic nature and illustrates the "altitude effect" or the increase of precipitation with the increase in elevation.

At the town of Elk Mountain, Wyoming, located in the northwestern corner of the area, twenty year climatological records (1951 through 1970) at the United States National Weather Service substation reveal a normal annual precipitation of 11.73 inches and an average annual temperature of 41.3 degrees Fahrenheit. In addition, the extreme temperatures for the 20 year period at this location were 95 degrees

Fahrenheit and -42 degrees Fahrenheit, both occurring during 1963.

Land Use and Vegetation

Reichenbaugh (11) describes the area as being composed of dry land range suitable for livestock grazing and irrigated native and introduced grass hay meadows that normally produce one cutting per year. After the hay crop has been removed, the meadows are grazed for the remainder of the year. Intermingled among the irrigated and dry lands, evergreen and other perennial trees and shrubs cover the area.

CHAPTER III. INSTRUMENTATION

When consumptive use estimates are to be made within a specific area, certain climatological and hydrological data must be acquired. Beginning in 1965, the Water Resource Research Institute established a network of stations as part of the Snowy Range Water Resource Observatory (Figure 4). A tabulation of the instrumentation at the stations within the study area is included in Table 1.

Streamflow

The streamflow network was established in 1965 and expanded in 1968 to the present network consisting of streamflow gages at six locations along the Medicine Bow River and its tributaries. Data from only five of these stations were used for this study. These five stations then define the boundary of the actual study area.

The surface outflow of the basin was measured on the Medicine Bow River at Orton's Ranch (Station 0205) by a Stevens[2] A-35 stage recorder in conjunction with a Stevens Manometer-Servo unit. In addition, at this station one 18-inch and one 24-inch Parshall flume recorded the outflow of two small diversions that bypassed the main gaging station.

---

[2]Company names and trade names presented within do not imply preferential treatment or endorsement and are included for the benefit of the reader only.

SNOWY RANGE WATER RESOURCE OBSERVATORY

W.R.R.I. INSTRUMENTATION

NOTE: LARGE NUMBERS WITHIN THE BOUNDARY REPRESENT DATA COLLECTION SITES.

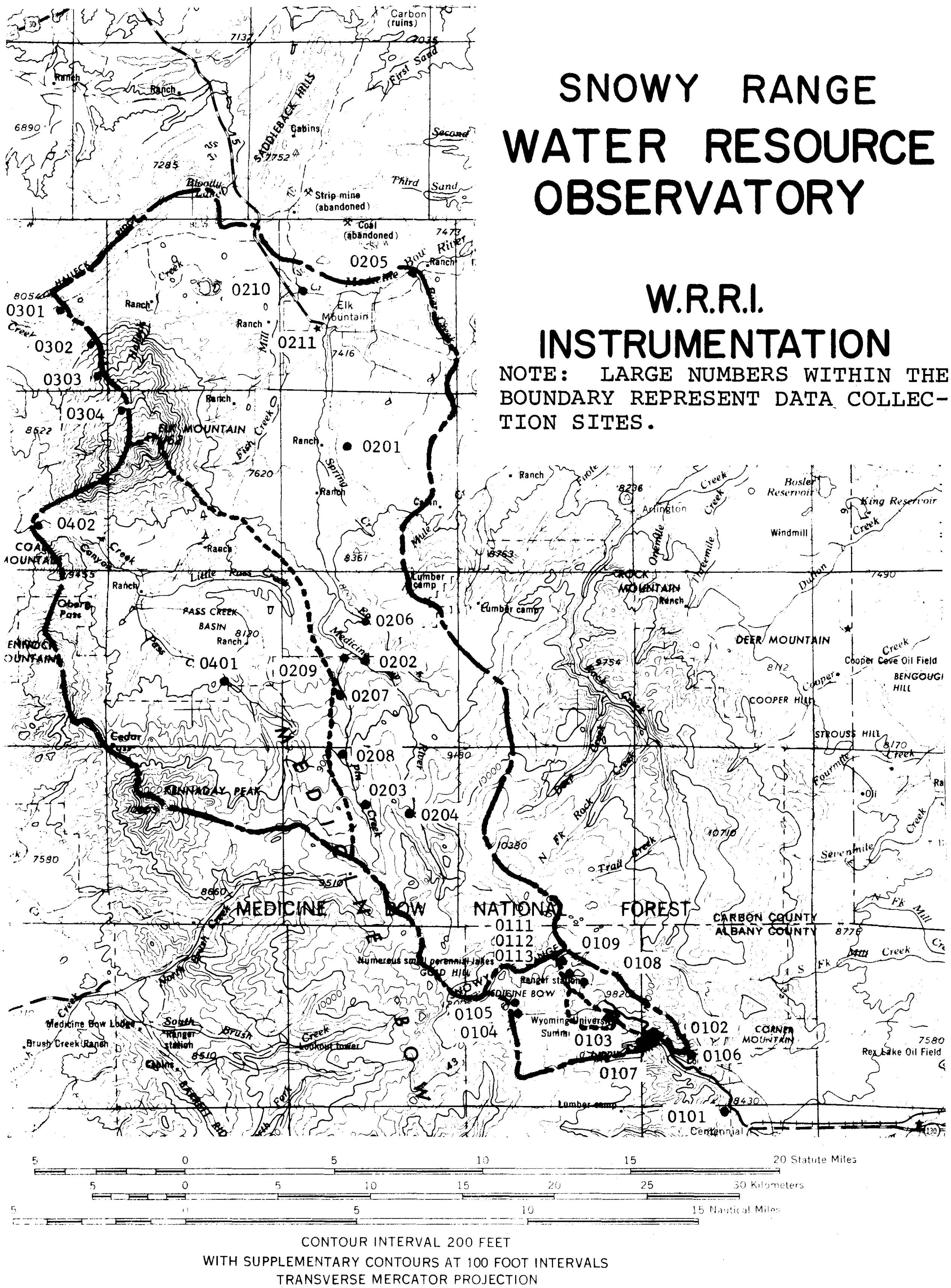


Figure 4

TABLE 1
WRRI INSTRUMENTATION IN UPPER MEDICINE BOW STUDY AREA

SITE AND DESCRIPTION			INSTRUMENTATION	
NUMBER	NAME AND DESCRIPTION	ELEVATION	TYPE	MANUFACTURER
0211	Elk Mountain Town	7270	U.S. Dept. of Commerce, Nat'l. Weather Service	
0210	Mill Creek at Larson Ranch Section 18 T20N R80W	7220	Streamflow Lysimeter Hygrothermograph Anemometer - Totalizing Precipitation Gage Accumulating	Stevens A-35 Recorder Kahlsico WE-24-01 Belfort
0209	Turpin Creek at Mouth Section 20 T18N R80W	8260	Streamflow	Stevens Manometer-Servo Model 63 Stevens A-35 Recorder
0206	East Fork Medicine Bow River Section 9 T18N R80W	8000	Streamflow	Stevens Manometer-Servo Model 63 Stevens A-35 Recorder

TABLE 1 (Continued)
WRRI INSTRUMENTATION IN UPPER MEDICINE BOW STUDY AREA

SITE AND DESCRIPTION			INSTRUMENTATION	
NUMBER	NAME AND DESCRIPTION	ELEVATION	TYPE	MANUFACTURER
0205	Medicine Bow River at Orton Ranch Section 11 T20N R80W	7060	Streamflow	Stevens Manometer-Servo Model 63 Stevens A-35 Recorder 18" Parshall Flume 24" Parshall Flume 2-Stevens Type F-1 Recorders
0202	Medicine Bow Guard Station Section 21 T18N R80W	8320	Wind Recorder Hygrothermograph Max-Min Thermometer Precipitation Recorder Streamflow	Epic Kahlsico WE-24-01 Science Associates Belfort 5-780 (Cannon Drive) Stevens Manometer-Servo Model 63 Stevens A-35 Recorder
0201	Medicine Bow River Flats Section 8 T19N R80W	7720	Hygrothermograph Max-Min Thermometer Precipitation Recorder Class A Evaporation Pan Pyrheliograph Sol-A-Meter Anemometer-Totalizing	Kahlsico WE-24-01 Science Associates Belfort 5-780 (Cannon Drive) Belfort Yellott Belfort

TABLE 1 (Continued)
WRRI INSTRUMENTATION IN UPPER MEDICINE BOW STUDY AREA

SITE AND DESCRIPTION			INSTRUMENTATION	
NUMBER	NAME AND DESCRIPTION	ELEVATION	TYPE	MANUFACTURER
None Given	McKee Cow Camp Section 21 T18N R80W	8320	2 Lysimeters	

The record from these Parshall flumes was obtained by means of Stevens Type F-1 stage recorders.

The surface inflow was measured near the confluence of each of three major tributaries to the Medicine Bow River and on the Medicine Bow River above the Medicine Bow Guard Station (Station 0202).

The tributaries mentioned above were: Turpin Creek (Station 0209), East Fork of the Medicine Bow River (Station 0206), and Mill Creek (Station 0210). At all of the inflow stations, with the exception of Mill Creek, Stevens A-35 stage recorders connected to Stevens Manometer-Servo units were utilized. At Mill Creek a float activated Stevens A-35 stage recorder was employed.

Each of these streamflow stations was serviced at least once every four weeks. At the time of service, each stream was gaged by a cup-type current meter or by dye dilution techniques. From these instantaneous gagings, rating curves were developed from which the continuous record, developed by the Stevens recorders, was reduced.

Climatological Data

In addition to the streamflow measurement stations, three climatological stations within the study area were utilized. The first of these stations, located at the Medicine Bow National Forest Guard Station, designated by the same station number as the streamflow station (Station

0202), and operated in cooperation with the United States Department of Agriculture, Forest Service, consisted of the following instrumentation: a Belfort 5-780 (Cannon Drive) recording precipitation gage, an Epic wind recorder for recording wind velocity and direction, a Kahlsico WE-24-01 hygrothermograph for continuous recording of ambient temperatures and relative humidity, and a set of Science Associates maximum and minimum thermometers.

The second climatological site was located near the center of the study area and is referred to as Medicine Bow Flats (Station 0201). The instrumentation at this site included a Belfort 5-780 (Cannon Drive) recording precipitation gage, a Kahlisco WE-24-01 hygrothermograph, a set of Science Associates maximum and minimum thermometers, a standard Class A evaporation pan during the summer months, a Belfort totalizing anemometer, and either an accumulating Yellott Sol-A-Meter or a weekly continuous recording Belfort pyrheliograph for an index of solar radiation received within the area. The Yellott Sol-A-Meter was in service during the winter months when all of the climatological stations were serviced only once every four weeks. During the summer months, the station was serviced weekly.

The third climatological site was located in the town of Elk Mountain, Wyoming (Station 0211). This site is a climatological substation of the National Weather Service. The data obtained from this station were used for analysis and consumptive use estimates for the northern part of the study area. In conjunction with this site, an accumulating precipitation gage and a Belfort totalizing anemometer were installed at Mill Creek (Station 0210). Data from Station 0211 are not available during the period of October 1970 through June 1971, as this station was not in service. During this period, a Kahlisco WE-24-01 hygrothermograph was installed at Mill Creek (Station 0210).

Each of these climatological stations was serviced at least once every four weeks during the year and weekly during the summer months. At the time of servicing each station, the relative humidity was obtained by means of a sling psycrometer to obtain a continuous check on the operation of the hygrothermograph.

Lysimeters

Reichenbaugh (11) suggested that lysimeters should be installed within the area to supplement the already operational data collection system. He also indicated that this would be a means of measuring consumptive use and yield data against which some of the accepted methods of estimating could be compared.

As a result of this suggestion, four small non-weighing tank lysimeters, patterned after Grable, et al. (5), were installed in irrigated fields within the study area. Two were installed near the Mill Creek site (Station 0210) and two were installed north of the Medicine Bow Guard Station (Station 0202), at a site referred to as the "McKee Cow Camp." No station number was ever assigned to the McKee Cow Camp. These lysimeters have yielded two seasons of data.

CHAPTER IV. METHODS OF DETERMINING CONSUMPTIVE USE

Several methods are presently being used or investigated for the determination or estimation of evapotranspiration. These methods include empirical estimates, energy balance approaches and direct measurements.

Some of the empirical methods of estimating consumptive use are the Blaney-Criddle (2), the Thornthwaite (17), and the Lowry-Johnson (8). All three of these methods use temperature as the basis for estimation.

Three relations for estimating evapotranspiration are the Modified Jensen-Haise (7), based on energy balance; and the Penman (9) and the van Bavel (20) methods, based on energy balance and aerodynamic approaches. A few of the parameters used in these relations are solar radiation, albedo, mean or maximum and minimum temperature, aerodynamic roughness of the crop, saturation and actual vapor pressures and soil surface temperatures. Not all of these procedures use the same parameters.

Direct measurements of consumptive use can be obtained through the use of soil moisture investigations, tanks or lysimeters, and the hydrologic budget (Inflow-Outflow). The hydrologic budget is applicable predominantly to larger drainage basins, where the lysimetry and soil moisture studies can be utilized for small field applications.

As a means of determining and estimating consumptive use in the Medicine Bow River Study Area, one empirical method - Blaney-Criddle, one energy budget analysis - the Modified Jensen-Haise, and two direct measurement methods - the hydrologic budget and lysimetry, were employed.

Blaney-Criddle Estimate

Blaney and Criddle (2) developed a simple method of estimating consumptive use in arid areas and Criddle (4) later modified the method for short term use. The parameters involved in the Blaney-Criddle method are the mean monthly temperature (t), the percent of daytime hours of the year for each month (p), and an empirically or experimentally determined crop coefficient (k). The factors are related mathematically by:

$$u = \frac{k \times t \times p}{100} = k \times f \qquad [1]$$

where u = monthly consumptive use in inches, and

f = the consumptive use factor defined as $t \times p/100$.

For a seasonal basis the equation becomes:

$$K = KF \qquad [2]$$

where $F = \Sigma(f)$ [2a]

K = seasonal crop coefficient.

For the purpose of this study an attempt was made to utilize this method on a daily basis. A computer program presented by Trelease, et al. (18) was modified from a monthly basis to a daily basis for the Medicine Bow study area. Calculations were conducted on several 14-day periods utilizing the mean temperature for the period, the percent of possible daytime hours for the 14-day period and the crop coefficient as average for the period.

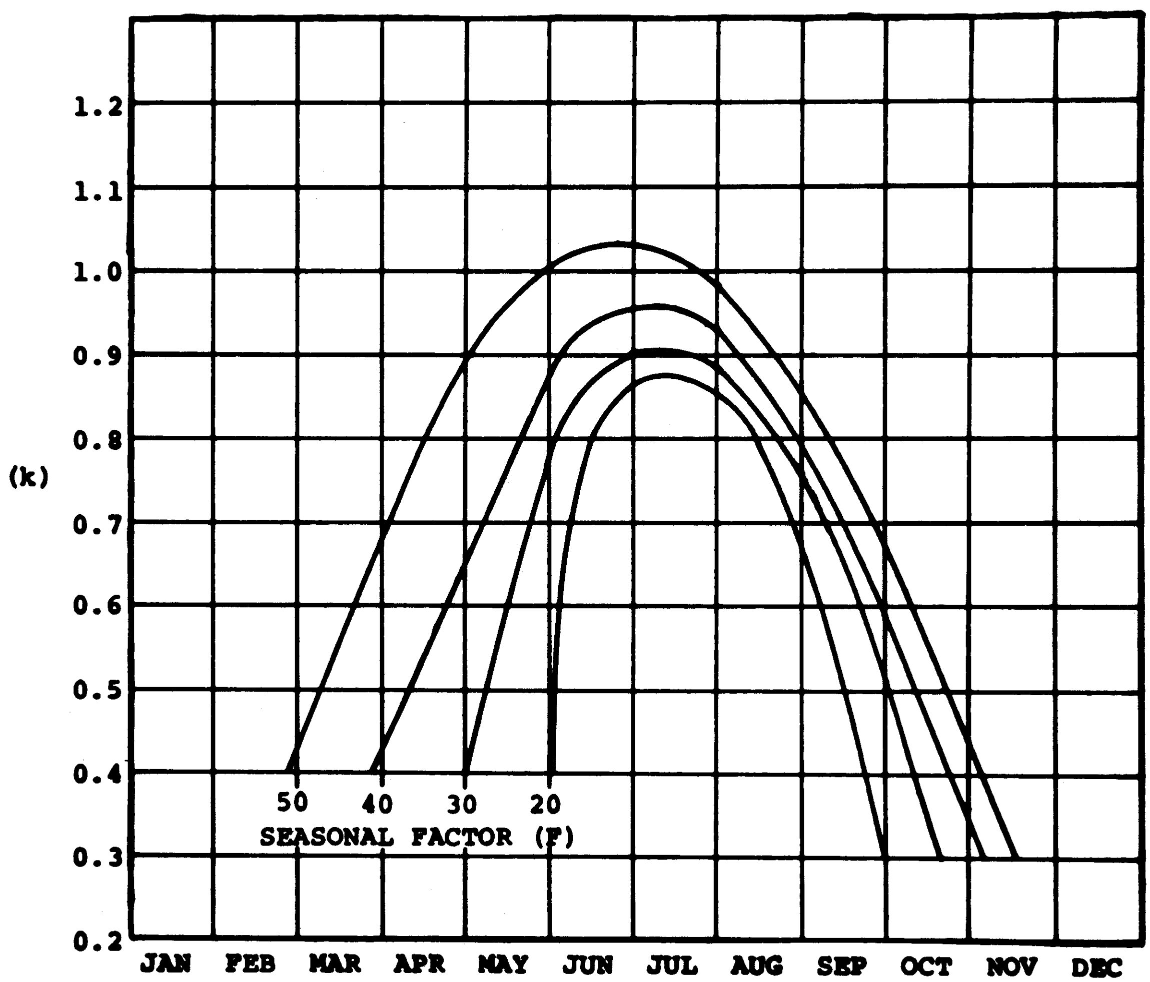
The period calculations compared reasonably well with the sums of the daily values for the same 14-day period. Criddle (4) suggests computing short term consumptive use by using portions of monthly values rather than the procedure used herein.

A copy of the computer program and the output of daily computation is available on request to the Water Resources Research Institute.

In order to adapt the monthly computer program presented by Trelease, et al., to a daily program, two major adjustments had to be made. The first adjustment was to secure a daily percent of daytime hours from a monthly percent of daytime hours for a latitude of 42°00' North Latitude. The second adjustment involved multiple correlation and regression procedures to develop equations for the family of crop coefficient curves for improved pasture to obtain daily coefficients for this crop (Figure 5). Equations developed for seasonal factors of 20, 30 and 40 for the family of curves are included below the figure of the family of crop coefficient curves.

During the execution of the program, the mean daily

BLANEY-CRIDDLE CROP COEFFICIENTS
FOR IMPROVED PASTURE*



CROP COEFFICIENT EQUATIONS FOR:

$$F = 20;\ k = -3.760 + 4.615(10^{-2})(X) - 1.147(10^{-5})(X^2)$$

$$F = 30;\ k = -1.944 + 2.859(10^{-2})(X) - 7.164(10^{-5})(X^2)$$

$$F = 40;\ k = -.873 + 1.885(10^{-2})(X) - 4.886(10^{-5})(X^2)$$

where k is the daily crop coefficient, and

(X) is the day number beginning with January 1 as day number 1 and neglecting February 29.

*After Figure 1, Criddle (4)

Figure 5

temperature (MT), the percent of possible daytime hours for that day (DH), and a crop identification code (NCR) were read. The computer then calculated a seasonal factor (SFA) from the previously presented equation 2a. For seasonal factors occurring between the factors for which the equations were developed, a vertical straight line interpolation was assumed. The daily crop coefficient obtained through this operation was then multiplied by the consumptive use factor (FA) for that day to determine the potential consumptive use. The period of daily values used included April 15 through September 27 for 1969, 1970 and 1971 for each of the three temperature recording stations within the area. Missing temperature data at any of the three sites were reconstructed by correlation and regression procedures.

The next procedure conducted by the computer was to sum the daily consumptive use estimates over consecutive seven day periods beginning on April 20. These weekly or seven day period values were then compared with similar results obtained by other methods.

Modified Jensen-Haise Method

The second method of estimating consumptive use adapted to this study area was a method developed by Jensen and Haise and later modified by Jensen (7). This method, referred to as the Modified Jensen-Haise, takes the form of an energy budget analysis, incorporating elevation adjustments, and climatic and energy components. The components or parameters include mean daily temperature, daily solar radiation, saturation vapor pressure for the mean maximum temperature for the warmest month and for the mean minimum temperature occurring in the same month. These parameters are related by the following mathematical expression:

$$ET = C_T \ (T-T_X) \ R_S \tag{3}$$

where ET = daily potential consumptive use in inches,

T = mean daily temperature in degrees Fahrenheit,

R_S = daily solar radiation in the area in inches,

C_T = air temperature coefficient in degrees^{-1}, and

T_X = temperature intercept defined in Equation 7.

The air temperature coefficient (C_T) is determined by the expression:

$$C_T = 1/(C_1 + C_2 \ C_H) \tag{4}$$

where C_1 and C_2 are experimentally or empirically determined constants for an area and are dependent upon the elevation above sea level of the area and the aerodynamic roughness of the crop.

Forthe study area discussed herein, C_1 is equal to 41 determined from the expression:

$$C_1 = 68 - \frac{3.6 \text{ x elevation}}{1000} \tag{5}$$

and C_2 is equal to 13 (14). The other component C_H, in equation 4 is defined as a humidity index and may be determined from the equation:

$$C_H = 50 \text{ mb}/(E_2 - E_1) \tag{6}$$

where E_2 and E_1 are the saturation vapor pressures in millibars for the mean maximum temperature and the mean minimum temperature for the hottest month respectively.

The last parameter in Equation 3, T_X, is a temperature intercept in degrees Fahrenheit determined and adjusted for elevation by the expression:

$$T_X = 27.5°F - .25(E_2 - E_1)\ °F/mb - elevation/1000\ °F \quad [7]$$

where E_2 and E_1 are the saturation vapor pressures as defined previously (14).

The Modified Jensen-Haise method has crop coefficients for different types of crops to be multiplied by the potential consumptive use to acquire estimated consumptive use. For this study these crop coefficients were neglected and analysis was conducted on potential consumptive use only.

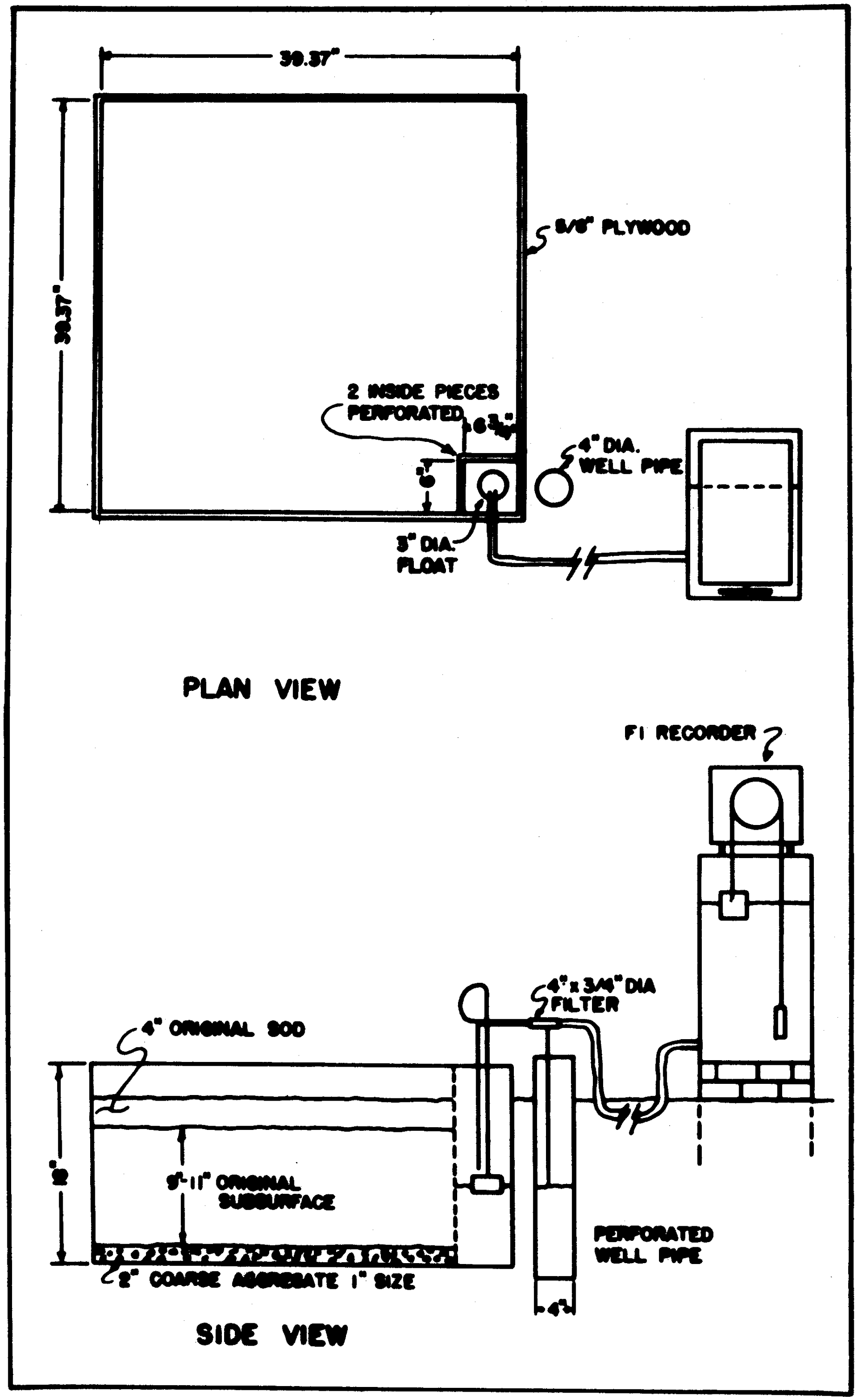
To employ this method of estimating consumptive use, a computer program similar to the Blaney-Criddle program discussed earlier, was developed. The Jensen-Haise program calculated a daily consumptive use estimate. Solar radiation obtained from Medicine Bow River Flats (Station 0201) entered the program for all three sites located within the area. Occassionally, the solar radiation data from this site were incomplete. On these occassions linear correlation and regression procedures between the Medicine Bow River Flats and the National Weather Service Climatological Station at Laramie, Wyoming, were exercised to reconstruct the missing data. By similar means, any temperature data voids were reconstructed. A copy of the computer program and output for the Jensen-Haise method is available on request to the Water Resources Research Institute.

The daily values of consumptive use calculated by the computer were then summed over consecutive seven day periods beginning on April 20 for the three stations for the three year period.

Lysimeters

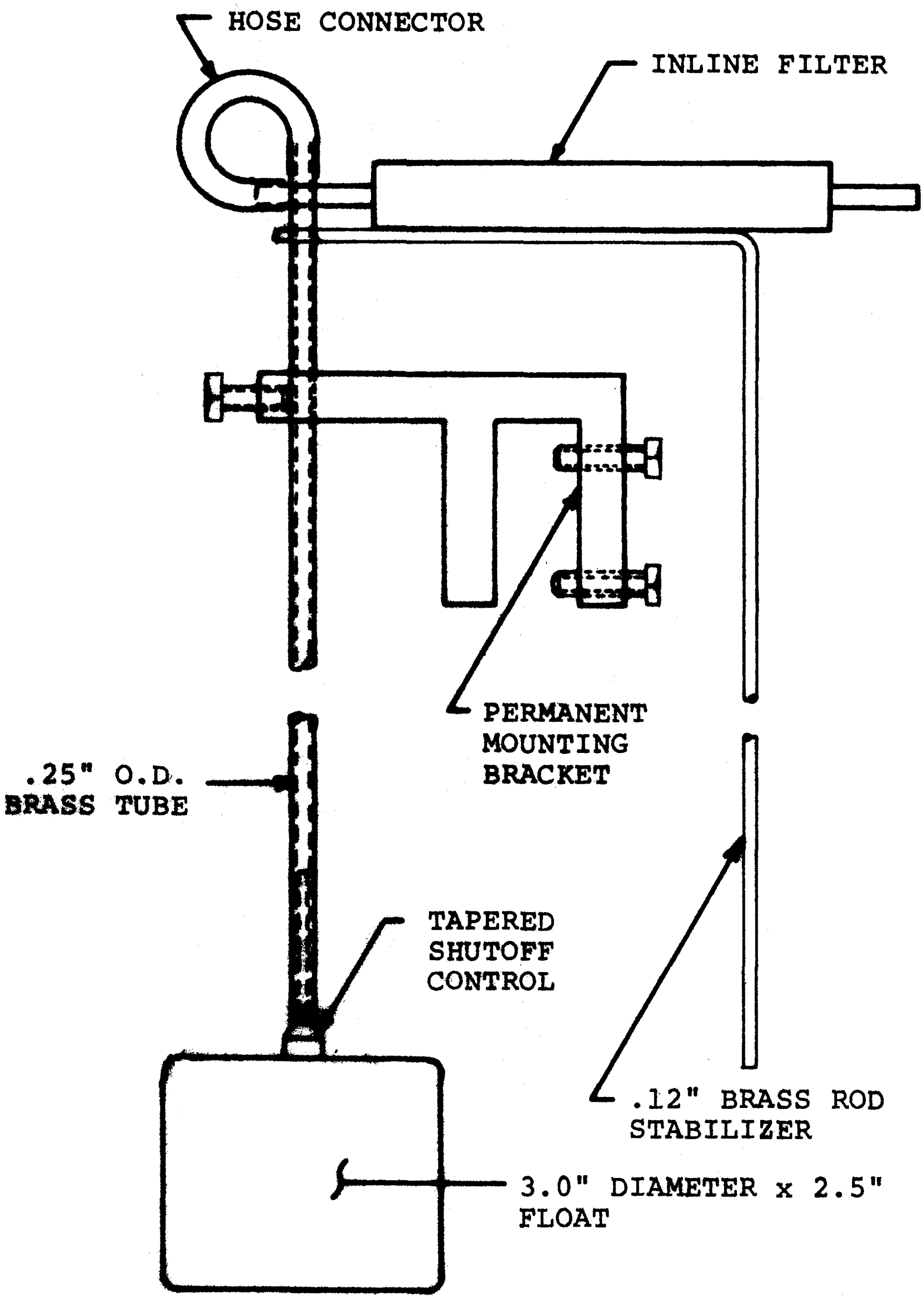
To obtain the direct consumptive use values, two small non-weighing tank lysimeters were installed at the McKee Cow Camp and two at Mill Creek (Station 0210). At each of these locations, the lysimeters were located 200 to 300 feet apart. Figure 6 indicates the configuration and construction of the tank lysimeter units, and Figure 7 is a schematic diagram of the inflow control mechanism installed within the tank.

These tanks were constructed of 5/8 inch plywood, 39.37 inches on a side and 18 inches in depth. They were coated with a fiber glass epoxy solution and then lined with a butyl rubber material to prevent leakage. The inside evaporative soil surface area of the tanks was 1550 square inches (1 square meter) including 16 square inches lost due to the water inflow control mechanism. This produced an effective soil surface area for consumptive use of 1534 square inches.



SCHEMATIC DIAGRAM OF TANK LYSIMETER UNITS

Figure 6



SCHEMATIC DIAGRAM OF THE FLOW CONTROL MECHANISM,
DESIGNED BY JAVID JAFARI.

Figure 7

During installation, these tanks were filled from the bottom with two to three inches of graded coarse aggregate of one inch diameter. Eleven to twelve inches of the original subsurface were then placed in the tank in as much of an undisturbed manner as possible. To complete the installation four inches of the original sod were replaced in an undisturbed condition.

Being non-weighing tank lysimeters, water storage tanks had to be installed for supply and recording purposes. These storage tanks were constructed of light gage, galvanized steel one foot on a side and four feet in height, and installed for gravity feed to the tank lysimeters. Stevens Type F-1 stage recorders were mounted on the top of the storage tanks to record the change in water level per unit of time.

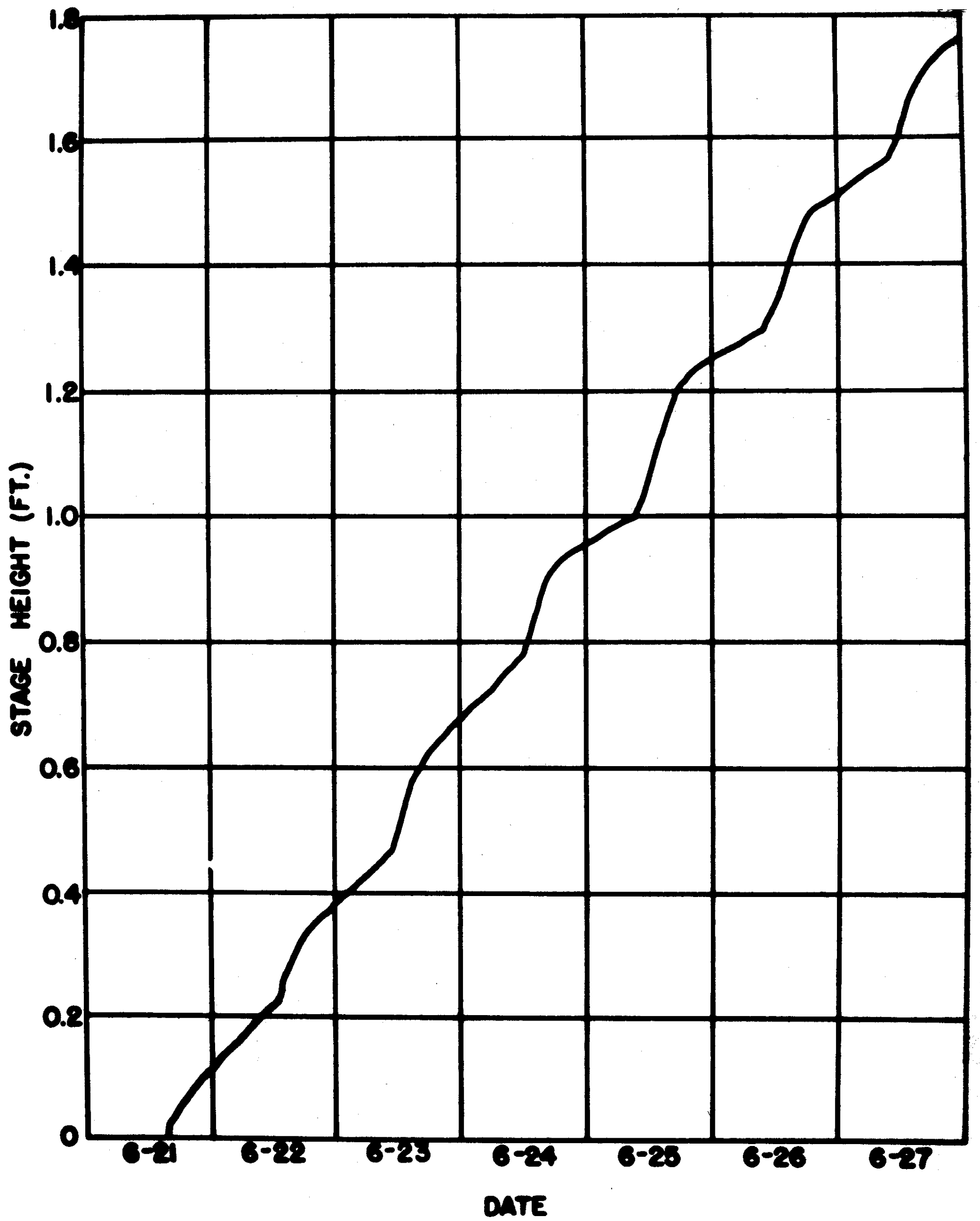
The lysimeters were then supplied water from the storage tanks by means of 1/4 inch outside diameter copper tubing to a filter and then to the flow control mechanism inside the lysimeter. The water level inside the lysimeter was maintained at the same level as the water table outside the lysimeter whenever possible. The water table was determined by a four inch diameter perforated well pipe installed just outside the lysimeter tanks. Occassionally the water table depth receded below the depth obtained by the perforated well pipe. On these occassions, the water level within the tank lysimeter was maintained in the aggregate material in the bottom of the tank.

The surface area ratio of the water surface in the storage tank to the soil surface of the lysimeter is .094, indicating that for every one-tenth of a foot (1.2 inches) decrease of water level in the storage tank, .0094 feet (.112 inches) of water was lost due to consumptive use from the plant surfaces and soil in the lysimeter.

These lysimeters were serviced at least once weekly during the period from the first part of June through the end of August for the 1970 and 1971 seasons. A representative curve of the water use for a six day period obtained from the Stevens Type F-1 stage recorder is presented in Figure 8.

Data from the Stevens Type F-1 stage recorders were reduced on a daily basis for each of the four lysimeters. The daily values were then summed for a seven day period to obtain a weekly value of consumptive use. For the two lysimeters at each site, Mill Creek and the McKee Cow Camp, the weekly values were averaged. Then, to the averaged water use values the precipitation recorded for the same week near the site was added to obtain an actual consumptive use value for the area.

On occassion, one or both of the lysimeters were inoperative on a daily basis for periods of two or more days. Usually when this occurred, the total volume of water used per total time elapsed was recorded by the stage recorders.



REPRESENTATIVE WATER USE CURVE FROM THE
TANK LYSIMETERS FOR A SIX DAY PERIOD

Figure 8

With this information, an average use per hour was determined and then multiplied by the appropriate number of hours to complete the weekly period.

On other occassions, no record was available from one or the other of the lysimeters at each site, due to leakage in the transmission line between the storage tank and the lysimeter, or due to the failure of the flow metering device. For periods when this occurred, data from the operating lysimeter at the specific site were used directly instead of using an average value.

Hydrologic Budget

Another method of estimating consumptive use is through investigation of the hydrologic budget (Inflow-Outflow). The hydrologic budget utilizes the difference of the inflow and outflow of the basin and is presented by Walton (22) in the form of the following equation:

$$P_a = R_u + ET + U \pm \Delta S_s \pm \Delta S_g \qquad [8]$$

where P_a = the recorded precipitation received within the area,

R_u = the difference in stream flow into and out of the basin,

ET = consumptive use by the basin,

U = the difference in subsurface inflow and outflow of the basin,

ΔS_s = net change in soil moisture,

ΔS_g = net change in ground storage

and all of the units are in second-feet-days or acre-feet.

Rearranging this expression to solve for consumptive use (ET) and making the assumptions that:

1. The net change in soil moisture (ΔS_s) for a yearly period is negligible (6), and
2. The change in ground water storage (ΔS_g) for a yearly period is also negligible,

then yields the following expression:

$$ET = P_a - R_u - U. \qquad [9]$$

Due to the geologic configuration and composition of the basin, Saulnier (12) indicated that any subsurface flow either into or out of the basin was quite unlikely to occur. With the existence of this condition, the hydrologic budget for this basin further simplifies to:

$$ET = P_a - R_u \qquad [10]$$

or

$$ET = P_a - (SO - SI) \qquad [11]$$

where SO = surface stream outflow of the basin, and

SI = surface stream inflow to the basin.

As the study was primarily concerned with determining the consumptive use from the wetland area, the following identities were incorporated. The total consumptive use from the basin (ET) was separated into the sum of the consumptive use from the wetland area and the non-irrigated area. This identity is expressed by the relation that:

$$ET = ET_i + ET_n \qquad [12]$$

where ET_i = consumptive use from the wetland area, and

ET_n = consumptive use from the non-irrigated area.

In addition, the recorded precipitation for the area (P_a) is equal to the sum of the effective precipitation and the portion of the recorded precipitation that contributes to surface runoff, or:

$$P_a = P_e + P_r \qquad [13]$$

where P_e = effective precipitation on the area, and

P_r = the portion of the recorded precipitation contributing to surface runoff.

By dividing the recorded precipitation into its respective components for the wetland and non-irrigated areas, Equation 12 becomes:

$$P_a = P_{ai} + P_{an} = P_{ei} + P_{ri} + P_{en} + P_{rn} \qquad [14]$$

where P_{ai} = recorded precipitation of the wetland area,

P_{an} = recorded precipitation on the non-irrigated area,

P_{ei} = effective precipitation on the wetland area,

P_{ri} = the portion of the recorded precipitation contributing to surface runoff from the wetland area,

P_{en} = effective precipitation on the non-irrigated

P_{rn} = the portion of recorded precipitation contributing to surface runoff from the non-irrigated area.

By employing the condition that on the non-irrigated area, the only source of water for consumptive use occurs in the form of precipitation, then the consumptive use from the non-irrigated area is equal to the effective precipitation received on that area, or:

$$ET_n = P_{en} = P_{an} - P_{rn} \quad [15]$$

By making the necessary substitutions from Equations 11, 12, 13 and 14 into Equation 10 and simplifying the resulting expression, the consumptive use from the wetland area becomes:

$$ET_i = SI + P_{ri} + P_{rn} - SO \quad [16]$$

Precipitation received within the area was recorded at three independent locations as mentioned previously. Monthly records from these sites are presented in Table 2. Any missing records at these sites were reconstructed by means of correlation and linear regression procedures, using data from the sites within the area only. It was assumed that only 25 percent of the precipitation recorded during the winter months (November - March) contributed to the hydrologic budget. As the majority of the precipitation occurring during these winter months occurs in the form of snow it was assumed that 75 percent would sublimate or evaporate during the winter period (10).

During the summer months (April - October) a method used by the United States Department of the Interior to estimate the effective precipitation was employed (2). This method is presented in part in Table 3. It assumes that a major portion of the recorded precipitation is effective for satisfying consumptive use and from Equations 12 and 14, the

TABLE 2. MONTHLY PRECIPITATION DATA AT THE CLIMATOLOGICAL STATIONS IN THE AREA (VALUES IN INCHES)

WATER YEAR 1969	MEDICINE BOW GUARD STATION	MEDICINE BOW RIVER FLATS	MILL CREEK
Oct	1.35	.85	.97
Nov	1.98	.72	.87
Dec	1.61	.38	.29
Jan	1.30	.85	.83
Feb	1.62	.80	1.04
Mar	1.39	.45	.56
Apr	2.42	1.03	.34
May	1.34	1.11	.99
Jun	2.97	2.93	4.28
Jul	.20	.70	.61
Aug	.96	.42	1.04
Sep	.55	.40	.91
TOTAL	17.69	10.65	12.73
1970			
Oct	3.18	2.38	3.05
Nov	1.68	.68	.70
Dec	1.38	1.37	.39
Jan	2.27	.94	.49
Feb	.76	.70	.20
Mar	2.43	3.21	1.24
Apr	3.49	3.29	1.83
May	1.71	.66	.96
Jun	3.27	2.94	2.80
Jul	1.30	.85	.80
Aug	1.24	.74	.74
Sep	1.93	1.73	1.89
TOTAL	24.64	19.49	15.09
1971			
Oct	2.75	1.54	1.37
Nov	3.17	1.85	1.61
Dec	1.57	.36	.44
Jan	1.84	4.64	3.81
Feb	2.30	.85	.83
Mar	3.23	1.14	1.05
Apr	2.24	1.75	1.54
May	3.40	1.90	1.65
Jun	.29	.41	.08
Jul	.80	.44	.08
Aug	1.45	.84	1.50
Sep	1.29	.76	.40
TOTAL	24.33	16.48	14.36

difference between the recorded and effective precipitation contributes to surface runoff.

TABLE 3. METHOD OF ESTIMATING EFFECTIVE PRECIPITATION (ALL VALUES IN INCHES)

Recorded Precipitation (P_a)	Effective Precipitation (P_e)
For:	
$P_a \leq 1.0$,	$P_e = .95\ (P_a)$
$P_a > 1.0$ and ≤ 2.0,	$P_e = .95 + .90\ (P_a)$
$P_a > 2.0$ and ≤ 3.0,	$P_e = 1.85 + .82\ (P_a)$
$P_a > 3.0$ and ≤ 4.0,	$P_e = 2.67 + .65\ (P_a)$
$P_a > 4.0$ and ≤ 5.0,	$P_e = 3.32 + .45\ (P_a)$

Recognizing the division between summer and winter precipitation, the hydrologic budget for the wetland area becomes:

$$ET_i = SI + P_{ai}(\text{Summer}) + P_{rn}(\text{Summer}) + P_r(\text{Winter}) - SO \quad [17]$$

where ET_i = consumptive use from the wetland area,

SI = surface stream inflow,

P_{ai}(Summer) = recorded precipitation on the wetland area during the summer months,

P_{rn}(Summer) = the portion of recorded precipitation contributing to surface runoff from the non-irrigated area during the summer months,

P_r(Winter) = the portion of the recorded precipitation contributing to surface runoff during the winter months from the entire area equal to $.25(P_a)$, and

SO = surface stream flow out of the area.

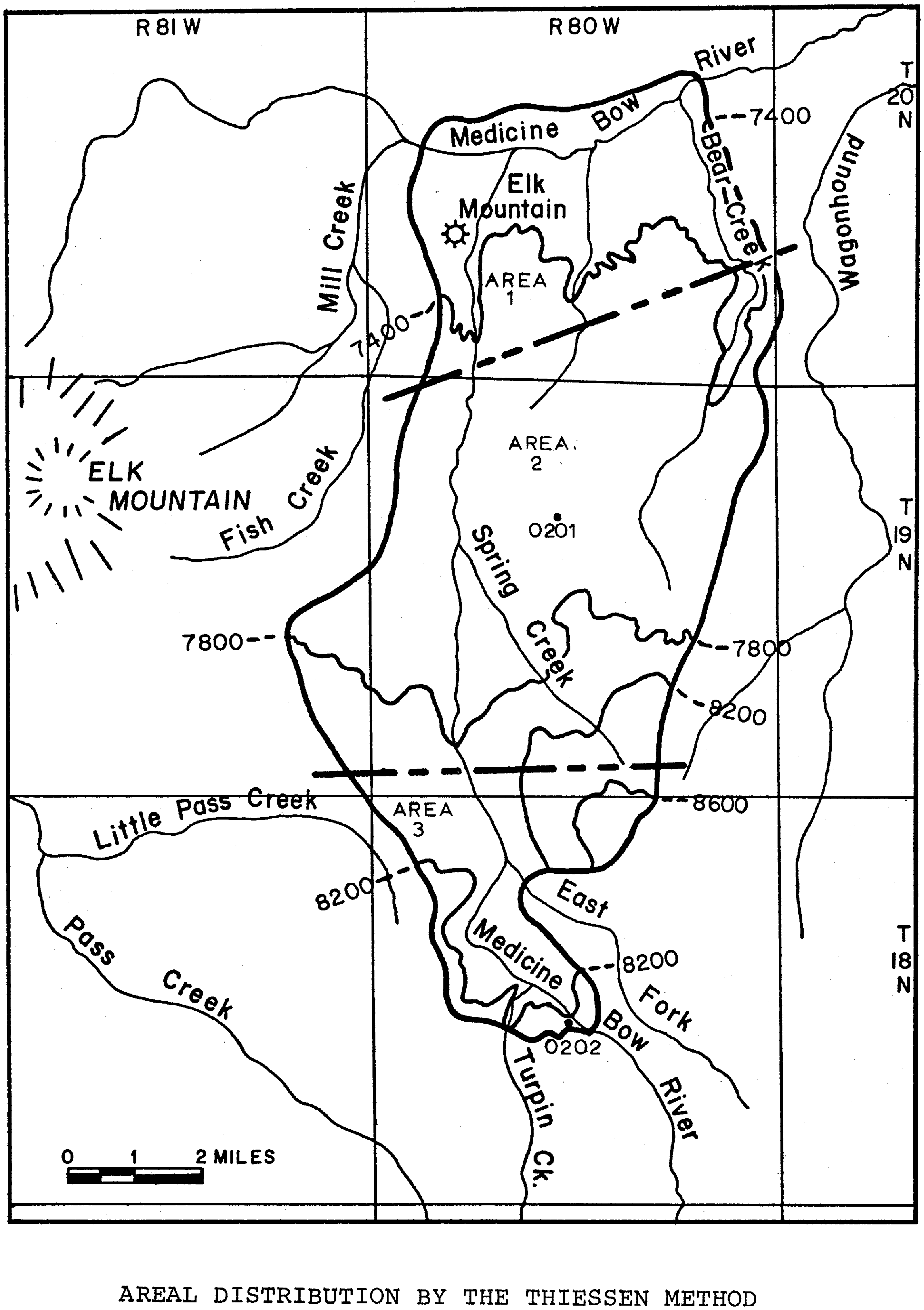
On the basis of the above assumption, Table 4 was developed to present the portion of recorded precipitation that contributes to surface runoff.

To establish the areal distribution of precipitation from the three gaging stations, the area was divided by the Thiessen method (16) shown in Figure 9. In Figure 9, Area 1 contains a total of 10650 acres, 4230 acres of which are wetlands; Area 2 contains 21950 acres of which 8680 acres are wetlands; and Area 3 is composed of 4990 acres of which 1640 acres are wetlands. The total area comprises 37590 acres including 14550 acres of wetland area. The areas from this distribution multiplied by the predetermined precipitation contributing to the hydrologic budget for each of the three recording locations, determined the volume of water entering into the budget from each of the three area. The sum of these three areas then represented the contribution to the hydrologic budget due to precipitation.

TABLE 4. MONTHLY ESTIMATED PRECIPITATION CONTRIBUTING TO SURFACE RUNOFF (VALUES IN INCHES)

Developed with the assumption that for the winter months (Nov.-Mar.) 25% of the precipitation contributed to the hydrologic budget; and for the summer months (Apr.-Oct.) recorded precipitation minus calculated precipitation is equal to the precipitation contributing to runoff.

WATER YEAR	MEDICINE BOW GUARD STATION	MEDICINE BOW RIVER FLATS	MILL CREEK
1969			
Oct	.09	.04	.05
Nov	.50	.18	.22
Dec	.40	.10	.07
Jan	.32	.21	.21
Feb	.40	.20	.26
Mar	.35	.11	.14
Apr	.23	.05	.02
May	.08	.06	.05
Jun	.32	.32	.87
Jul	.01	.04	.03
Aug	.05	.02	.05
Sep	.03	.02	.05
TOTAL	2.78	1.35	2.02
1970			
Oct	.40	.22	.35
Nov	.42	.17	.18
Dec	.34	.34	.10
Jan	.57	.24	.12
Feb	.19	.18	.05
Mar	.61	.80	.31
Apr	.50	.43	.13
May	.12	.03	.05
Jun	.42	.32	.29
Jul	.08	.04	.04
Aug	.07	.04	.04
Sep	.14	.12	.14
TOTAL	3.86	2.93	1.80
1971			
Oct	.29	.04	.09
Nov	.79	.46	.40
Dec	.39	.09	.11
Jan	.46	1.16	.95
Feb	.58	.21	.21
Mar	.81	.28	.26
Apr	.19	.13	.10
May	.47	.14	.12
Jun	.01	.02	.00
Jul	.04	.02	.00
Aug	.10	.04	.10
Sep	.08	.04	.02
TOTAL	4.21	2.68	2.36



AREAL DISTRIBUTION BY THE THIESSEN METHOD

Figure 9

CHAPTER V. RESULTS

The results of the various methods presented indicate considerable variation in estimated values. Table 5 presents weekly consumptive use calculated by the Blaney-Criddle method for the area around the Medicine Bow Guard Station. Weekly consumptive use for 1969 ranged from .28 inches per week in late-April, to 1.21 inches per week in mid-July, to .55 inches per week in late-September. During 1970 the weekly consumptive use ranged from .25 inches per week in late-April, to 1.19 inches per week in mid-July, to .32 inches per week in late-September; and for 1971 the Blaney-Criddle estimates ranged from .24 inches per week in late-April, to 1.23 inches per week in mid-July, to .34 inches per week in late-September.

Estimates by the Modified Jensen-Haise method (Table 6) produced weekly sums at the Medicine Bow Guard Station for 1969 ranging from .67 inches per week in late-April, to 1.83 inches per week in early-July, to 1.18 inches per week in late-September. Similarly, during 1970, the estimated evapotranspiration ranged from .46 inches per week in late-April, to 1.84 in late-June, to .57 inches per week in late-September.

The tank lysimeters located at the McKee Cow Camp

TABLE 5. BLANEY-CRIDDLE CONSUMPTIVE USE CALCULATED WEEKLY

MEDICINE BOW GUARD STATION - NO. 0202

LATITUDE 41-31 LONGITUDE 106-23 ELEVATION 8320

1969		1970		1971	
FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM
04-20-69	.28	04-20-70	.25	04-20-71	.24
04-27-69	.32	04-27-70	.25	04-27-71	.32
05-04-69	.38	05-04-70	.40	05-04-71	.32
05-11-69	.51	05-11-70	.43	05-11-71	.43
05-18-69	.59	05-18-70	.57	05-18-71	.43
05-25-69	.67	05-25-70	.54	05-25-71	.55
06-01-69	.79	06-01-70	.68	06-01-71	.64
06-08-69	.72	06-08-70	.73	06-08-71	.82
06-15-69	.81	06-15-70	.88	06-15-71	1.01
06-22-69	.82	06-22-70	1.15	06-22-71	1.12
06-29-69	1.04	06-29-70	1.08	06-29-71	1.05
07-06-69	1.13	07-06-70	1.16	07-06-71	1.16
07-13-69	1.21	07-13-70	1.19	07-13-71	1.23
07-20-69	1.19	07-20-70	1.14	07-20-71	1.10
07-27-69	1.21	07-27-70	1.15	07-27-71	1.02
08-03-69	1.18	08-03-70	1.14	08-03-71	1.05
08-10-69	1.10	08-10-70	1.05	08-10-71	1.05
08-17-69	1.01	08-17-70	.96	08-17-71	1.01
08-24-69	1.04	08-24-70	.92	08-24-71	.89
08-31-69	.95	08-31-70	.74	08-31-71	.70
09-07-69	.82	09-07-70	.56	09-07-71	.62
09-14-69	.68	09-14-70	.48	09-14-71	.33
09-21-69	.55	09-21-70	.32	09-21-71	.34

TABLE 6. MODIFIED JENSEN-HAISE CONSUMPTIVE USE CALCULATED WEEKLY

MEDICINE BOW GUARD STATION - NO. 0202

LATITUDE 41-31 LONGITUDE 106-23 ELEVATION 8320

1969		1970		1971	
FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM
04-20-69	.67	04-20-70	.46	04-20-71	.36
04-27-69	.75	04-27-70	.44	04-27-71	.80
05-04-69	.65	05-04-70	.80	05-04-71	.50
05-11-69	1.00	05-11-70	.82	05-11-71	.86
05-18-69	1.19	05-18-70	1.14	05-18-71	.64
05-25-69	1.34	05-25-70	.99	05-25-71	1.03
06-01-69	1.22	06-01-70	1.10	06-01-71	.99
06-08-69	.72	06-08-70	.92	06-08-71	1.06
06-15-69	.93	06-15-70	1.31	06-15-71	1.61
06-22-69	.84	06-22-70	1.84	06-22-71	1.82
06-29-69	1.63	06-29-70	1.64	06-29-71	1.39
07-06-69	1.83	07-06-70	1.62	07-06-71	1.58
07-13-69	1.50	07-13-70	1.68	07-13-71	1.72
07-20-69	1.76	07-20-70	1.60	07-20-71	1.35
07-27-69	1.64	07-27-70	1.62	07-27-71	1.21
08-03-69	1.61	08-03-70	1.60	08-03-71	1.35
08-10-69	1.41	08-10-70	1.59	08-10-71	1.40
08-17-69	1.15	08-17-70	1.21	08-17-71	1.28
08-24-69	1.22	08-24-70	1.37	08-24-71	1.08
08-31-69	1.52	08-31-70	1.04	08-31-71	.96
09-07-69	1.42	09-07-70	.95	09-07-71	.97
09-14-69	1.20	09-14-70	.83	09-14-71	.75
09-21-69	1.18	09-21-70	.57	09-21-71	.48

near the Medicine Bow Guard Station, produced measured weekly evapotranspiration values for 1970 ranging from 1.69 inches per week in early-June, to 1.98 in early-July, to .69 inches per week in late-August (Table 7). During the two-week period, June 17 through June 30, 1970, there appears to be a discrepancy in the data. During the week of June 17, the lysimeters indicated a consumptive use of .57 inches per week; and for the week of June 24, the consumptive use was 2.32 inches per week. The variation is much greater than would by expected. Therefore, this two-week period was neglected when comparisons were made. A possible explanation for this discrepancy may be that the large amount of precipitation received in that area during the week of June 10, was not all consumptively used during that week and that a portion may have carried over into the week of June 17. In addition, the consumptive use value from lysimeter No. 5 for the week of June 24 appears in excess of the value determined from lysimeter No. 6. By reducing the excessive value and applying the reduction to the previous week, and incorporating the precipitation adjustment, more appropriate values may be obtained.

For 1971 the tank lysimeter values ranged from 2.49 inches per week in late-June, to 2.75 inches per week in early-August, to 2.07 inches per week in late-August.

Table 8 presents weekly consumptive use calculated by the Blaney-Criddle method for the Mill Creek Area. Weekly

TABLE 7. 1970 AND 1971 WEEKLY LYSIMETER DATA
(ALL VALUES IN INCHES)

DATE	MCKEE COW CAMP CONSUMPTIVE USE				
1970	NO.5	NO.6	AVE	PREC	ET
6/10-6/16	.19	.19	.19	1.50	1.69
6/17-6/23	.47	NR		.10	.57
6/24-6/30	2.84	1.63	2.24	.08	2.32
7/01-7/07	1.52	1.83	1.68		1.68
7/08-7/14	1.92	1.85	1.88	.10	1.98
7/15-7/21	1.70	1.76	1.73	.22	1.95
7/22-7/28	1.07	.36	.71	1.12	1.83
7/29-8/04	1.41	1.61	1.51	.17	1.68
8/05-8/11	1.76	1.68	1.72	.28	2.00
8/12-8/18	1.00	1.52	1.26		1.26
8/19-8/25	NR*	.55		.14	.69
8/26-9/01	NR	NR			--
TOTAL					17.65
AVE/WK					1.60
1971					
6/21-6/27	2.67	2.31	2.49		2.49
6/28-7/04	1.93	1.97	1.95	.16	2.11
7/05-7/11	1.93	1.62	1.78	.04	1.82
7/12-7/18	1.79	1.68	1.74	.11	1.85
7/19-7/25	.98	1.02	1.00	.41	1.41
7/26-8/01	1.76	1.55	1.66	.09	1.75
8/02-8/08	1.97	2.15	2.06	.19	2.25
8/09-8/15	1.84	1.82	1.83		1.83
8/16-8/22	1.89	1.80	1.84		1.84
8/23-8/29	.72	NR		1.35	2.07
TOTAL					19.42
AVE/WK					1.94

*No Record

TABLE 8. BLANEY-CRIDDLE CONSUMPTIVE USE CALCULATED WEEKLY

MILL CREEK AT LARSON RANCH - NO. 0210

LATITUDE 42-30 LONGITUDE 106-26 ELEVATION 7215

1969		1970		1971	
FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM
04-20-69	.41	04-20-70	.29	04-20-71	.29
04-27-69	.44	04-27-70	.34	04-27-71	.37
05-04-69	.52	05-04-70	.55	05-04-71	.41
05-11-69	.69	05-11-70	.57	05-11-71	.54
05-18-69	.79	05-18-70	.76	05-18-71	.54
05-25-69	.97	05-25-70	.80	05-25-71	.68
06-01-69	1.00	06-01-70	.86	06-01-71	.80
06-08-69	.96	06-08-70	.95	06-08-71	.93
06-15-69	1.05	06-15-70	1.09	06-15-71	1.16
06-22-69	1.05	06-22-70	1.32	06-22-71	1.18
06-29-69	1.25	06-29-70	1.29	06-29-71	1.10
07-06-69	1.31	07-06-70	1.35	07-06-71	1.21
07-13-69	1.39	07-13-70	1.37	07-13-71	1.23
07-20-69	1.37	07-20-70	1.29	07-20-71	1.14
07-27-69	1.33	07-27-70	1.30	07-27-71	1.05
08-03-69	1.29	08-03-70	1.28	08-03-71	1.08
08-10-69	1.24	08-10-70	1.18	08-10-71	1.07
08-17-69	1.13	08-17-70	1.07	08-17-71	.98
08-24-69	1.09	08-24-70	1.07	08-24-71	.94
08-31-69	.94	08-31-70	.89	08-31-71	.83
09-07-69	.81	09-07-70	.74	09-07-71	.73
09-14-69	.74	09-14-70	.62	09-14-71	.40
09-21-69	.72	09-21-70	.47	09-21-71	.40

consumptive use for 1969 ranged from .41 inches per week in late-April, to 1.39 inches per week in mid-July, to .72 inches per week in late-September. For 1970, the range was .29 inches per week in late-April, to 1.37 inches per week in mid-July, to .47 inches per week in late-September. During 1971 similar results occurred at Mill Creek in that the Blaney-Criddle method estimated .29 inches per week in late-April, 1.23 inches per week in mid-July, and .40 inches per week in late-September.

Weekly estimates calculated by the Modified Jensen-Haise method for the Mill Creek area (Table 9) ranged from 1.42 inches per week in late-April, to 2.67 inches per week in early-July, to 1.45 inches per week in late-September for 1969. During the 1970 season this method calculated estimates ranging from .80 inches per week in late-April, to 2.56 inches per week in late-June, to 1.03 inches per week in late-September. Similarly, for 1971, this method calculated estimates of .66 inches per week in late-April, to 2.23 inches per week in late-June, to .72 inches per week in late-September.

The tank lysimeters at Mill Creek produced weekly measured consumptive use (Table 10) ranging from 2.12 inches per week in late-June, to .72 inches per week in late-August. For 1971, the consumptive use from the lysimeters ranged from 2.32 inches per week in late-June, to 1.29 inches per week in late-August.

TABLE 9. MODIFIED JENSEN-HAISE CONSUMPTIVE USE CALCULATED WEEKLY

MILL CREEK AT THE LARSON RANCH - NO. 0210

LATITUDE 42-30 LONGITUDE 106-26 ELEVATION 7215

1969		1970		1971	
FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM
04-20-69	1.42	04-20-70	.80	04-20-71	.66
04-27-69	1.43	04-27-70	.91	04-27-71	1.19
05-04-69	1.13	05-04-70	1.33	05-04-71	.78
05-11-69	1.56	05-11-70	1.18	05-11-71	1.22
05-18-69	1.72	05-18-70	1.60	05-18-71	.88
05-25-69	2.01	05-25-70	1.51	05-25-71	1.43
06-01-69	1.86	06-01-70	1.69	06-01-71	1.49
06-08-69	1.17	06-08-70	1.51	06-08-71	1.53
06-15-69	1.58	06-15-70	2.10	06-15-71	2.14
06-22-69	1.42	06-22-70	2.56	06-22-71	2.23
06-29-69	2.51	06-29-70	2.41	06-29-71	1.73
07-06-69	2.67	07-06-70	2.17	07-06-71	1.97
07-13-69	2.15	07-13-70	2.38	07-13-71	2.04
07-20-69	2.46	07-20-70	2.19	07-20-71	1.68
07-27-69	2.23	07-27-70	2.21	07-27-71	1.50
08-03-69	2.15	08-03-70	2.27	08-03-71	1.63
08-10-69	2.11	08-10-70	2.21	08-10-71	1.70
08-17-69	1.59	08-17-70	1.66	08-17-71	1.43
08-24-69	1.55	08-24-70	1.92	08-24-71	1.38
08-31-69	1.73	08-31-70	1.50	08-31-71	1.47
09-07-69	1.58	09-07-70	1.54	09-07-71	1.56
09-14-69	1.40	09-14-70	1.25	09-14-71	.63
09-21-69	1.45	09-21-70	1.03	09-21-71	.72

TABLE 10. 1970 AND 1971 WEEKLY LYSIMETER DATA
(ALL VALUES IN INCHES)

DATE	MILL CREEK CONSUMPTIVE USE				
1970	NO.3	NO.4	AVE	PREC	ET
6/03-6/09	NR*	NR		.11	--
6/10-6/16	NR	NR		2.36	--
6/17-6/23	NR	NR		.18	--
6/24-6/30	2.12	NR		T	2.12
7/01-7/07	1.59	2.20	1.89	.13	2.02
7/08-7/14	1.66	.88	1.27	.05	1.32
7/15-7/21	1.64	1.75	1.69	.07	1.76
7/22-7/28	.99	1.19	1.09	.32	1.41
7/29-8/04	1.44	1.45	1.45	.18	1.63
8/05-8/11	1.43	1.30	1.36	.36	1.72
8/12-8/18	1.18	NR			1.18
8/19-8/25	.86	.88	.87		.87
8/26-9/01	.66	.75	.70	.02	.72
TOTAL					14.75
AVE/WK					1.48
1971					
6/14-6/20	2.12	1.91	2.02		2.02
6/21-6/27	2.49	2.15	2.32		2.32
6/28-7/04	2.09	1.94	2.01	T	2.01
7/05-7/11	2.24	2.09	2.17		2.17
7/12-7/18	2.08	2.04	2.06	.06	2.12
7/19-7/25	1.85	1.38	1.62	.08	1.70
7/26-8/01	1.38	1.72	1.55	.12	1.67
8/02-8/08	1.34	1.31	1.32	.33	1.66
8/09-8/15	1.60	1.41	1.50	.05	1.56
8/16-8/22	1.76	1.39	1.58		1.58
8/23-8/29	1.07	1.22	1.14	.15	1.29
TOTAL					20.10
AVE/WK					1.83

*No Record

For 1969 and 1970, the weekly consumptive use calculated by both the Modified Jensen-Haise and the Blaney-Criddle methods for the Medicine Bow River Flats fell between the values estimated for Mill Creek and for the Medicine Bow Guard Station. This would be expected due to the Medicine Bow River Flats geographic location and elevation with respect to the other two stations. During 1971, the Modified Jensen-Haise method again calculated estimates for the Medicine Bow River Flats area that fell between those calculated at the Medicine Bow Guard Station and at Mill Creek. However, the weekly consumptive use values calculated by the Blaney-Criddle method were slightly higher than the estimates calculated for Mill Creek. This was due to the 1971 mean temperature being higher at the Medicine Bow River Flats than they were at Mill Creek. Since the mean temperature is the only variable climatic component of the Blaney-Criddle method and the Modified Jensen-Haise method uses solar radiation in addition, the Modified Jensen-Haise equation has a greater possibility of reflecting the variations in consumptive use as measured by the tank lysimeters. Tables 11 and 12 present the calculated weekly consumptive use in the Medicine Bow River Flats area for 1969, 1970, and 1971, as determined by the Blaney-Criddle method and the Modified Jensen-Haise method respectively.

TABLE 11. BLANEY-CRIDDLE CONSUMPTIVE USE CALCULATED WEEKLY

MEDICINE BOW RIVER FLATS - NO. 0201

LATITUDE 42-00 LONGITUDE 106-22 ELEVATION 7720

1969		1970		1971	
FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM
04-20-69	.32	04-20-70	.27	04-20-71	.29
04-27-69	.37	04-27-70	.29	04-27-71	.40
05-04-69	.47	05-04-70	.50	05-04-71	.44
05-11-69	.64	05-11-70	.54	05-11-71	.56
05-18-69	.76	05-18-70	.73	05-18-71	.57
05-25-69	.89	05-25-70	.73	05-25-71	.74
06-01-69	.95	06-01-70	.84	06-01-71	.84
06-08-69	.87	06-08-70	.87	06-08-71	.97
06-15-69	.96	06-15-70	1.02	06-15-71	1.19
06-22-69	.95	06-22-70	1.28	06-22-71	1.30
06-29-69	1.20	06-29-70	1.23	06-29-71	1.21
07-06-69	1.30	07-06-70	1.28	07-06-71	1.34
07-13-69	1.36	07-13-70	1.31	07-13-71	1.36
07-20-69	1.32	07-20-70	1.25	07-20-71	1.22
07-27-69	1.29	07-27-70	1.26	07-27-71	1.12
08-03-69	1.30	08-03-70	1.25	08-03-71	1.14
08-10-69	1.21	08-10-70	1.15	08-10-71	1.14
08-17-69	1.10	08-17-70	1.05	08-17-71	1.09
08-24-69	1.05	08-24-70	1.02	08-24-71	.98
08-31-69	.91	08-31-70	.85	08-31-71	.83
09-07-69	.81	09-07-70	.65	09-07-71	.75
09-14-69	.68	09-14-70	.59	09-14-71	.41
09-21-69	.58	09-21-70	.42	09-21-71	.44

TABLE 12. MODIFIED JENSEN-HAISE CONSUMPTIVE USE CALCULATED WEEKLY

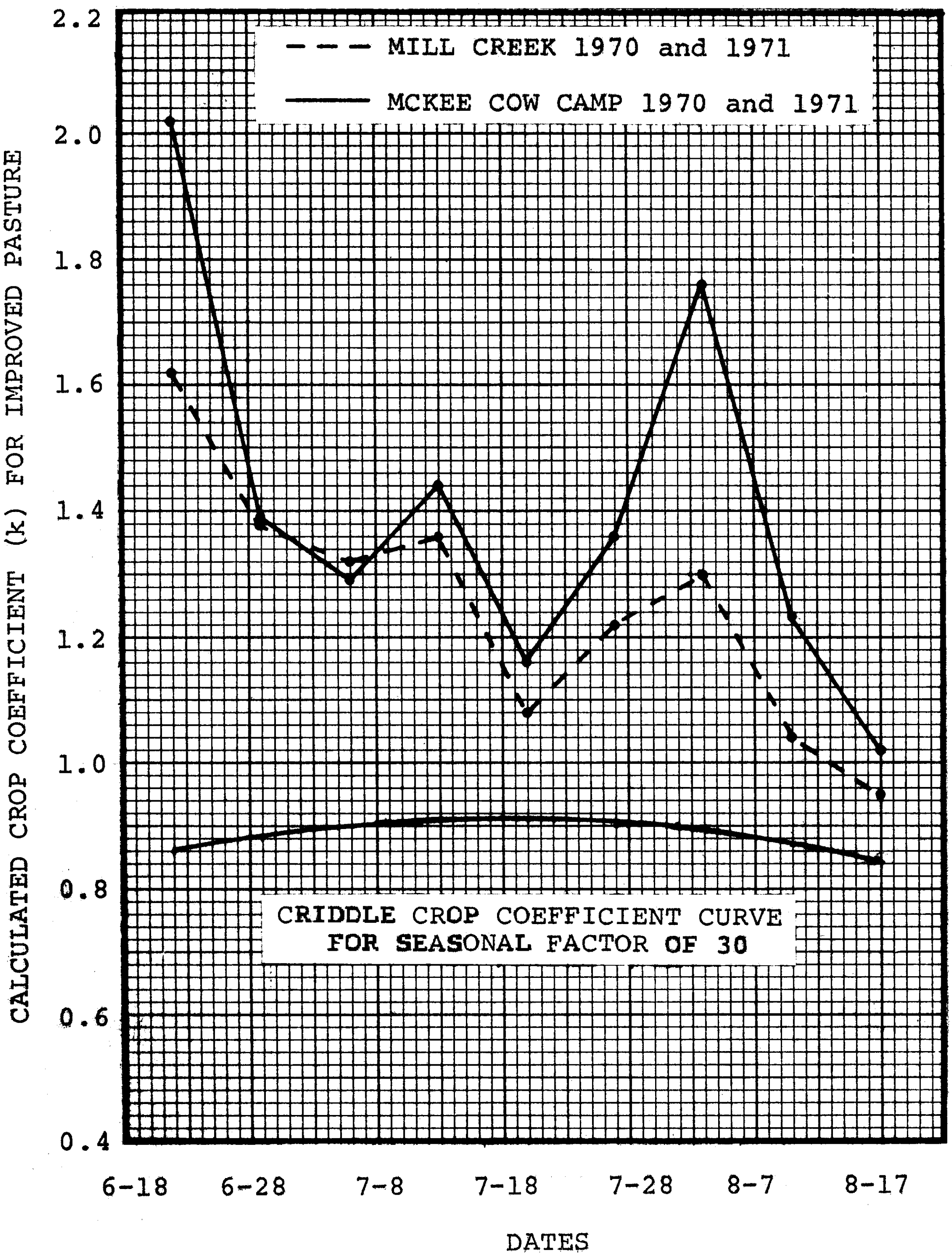
MEDICINE BOW RIVER FLATS - NO. 0201

LATITUDE 42-00 LONGITUDE 106-22 ELEVATION 7720

1969		1970		1971	
FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM	FIRST DAY OF SEVEN DAY PERIOD	SEVEN DAY SUM
04-20-69	.89	04-20-70	.58	04-20-71	.50
04-27-69	1.02	04-27-70	.60	04-27-71	1.24
05-04-69	.88	05-04-70	1.03	05-04-71	.69
05-11-69	1.30	05-11-70	1.04	05-11-71	1.14
05-18-69	1.59	05-18-70	1.38	05-18-71	.81
05-25-69	1.68	05-25-70	1.24	05-25-71	1.32
06-01-69	1.55	06-01-70	1.47	06-01-71	1.34
06-08-69	.94	06-08-70	1.11	06-08-71	1.39
06-15-69	1.20	06-15-70	1.62	06-15-71	1.99
06-22-69	1.14	06-22-70	2.18	06-22-71	2.10
06-29-69	2.08	06-29-70	2.01	06-29-71	1.75
07-06-69	2.31	07-06-70	1.81	07-06-71	2.02
07-13-69	1.83	07-13-70	1.96	07-13-71	2.05
07-20-69	2.05	07-20-70	1.84	07-20-71	1.69
07-27-69	1.90	07-27-70	1.86	07-27-71	1.43
08-03-69	1.90	08-03-70	1.91	08-03-71	1.54
08-10-69	1.77	08-10-70	1.86	08-10-71	1.49
08-17-69	1.34	08-17-70	1.42	08-17-71	1.45
08-24-69	1.31	08-24-70	1.61	08-24-71	1.38
08-31-69	1.46	08-31-70	1.25	08-31-71	1.24
09-07-69	1.39	09-07-70	1.12	09-07-71	1.40
09-14-69	1.18	09-14-70	1.04	09-14-71	.54
09-21-69	1.17	09-21-70	.79	09-21-71	.75

It appears by this discussion that the Blaney-Criddle method of estimating evapotranspiration on a weekly basis for irrigated high mountain meadows produces values that are consistently low. With the information collected from the tank lysimeters and weekly consumptive use factors calculated by the computer, an attempt was made to develop more appropriate crop coefficient curves for this area. To accomplish this, the average weekly consumptive use measured from the lysimeters at each site independently was divided by the weekly consumptive use factor for the same week for 1970 and 1971 respectively. This resulted in weekly crop coefficients for each week during the period of operation each year of the tank lysimeters. These weekly coefficients were averaged for each station for 1970 and 1971 and are presented in Figure 10. These curves though developed from a small quantity of data, and over a small portion of the growing season, imply that crop coefficients for the irrigated high mountain meadows in a semi-arid area may approach 1.5 to 2.0 times the coefficients presented by Criddle (Figure 5). Also included in Figure 10 for the same time period is a portion of the crop coefficient curve for a seasonal factor of 30 as presented by Criddle (Figure 5).

It was observed above that the crop coefficient (k) curves for improved pasture presented by Criddle (4) are too low for semi-arid, irrigated high mountain meadows. Therefore, a similar but more appropriate crop coefficient curve for



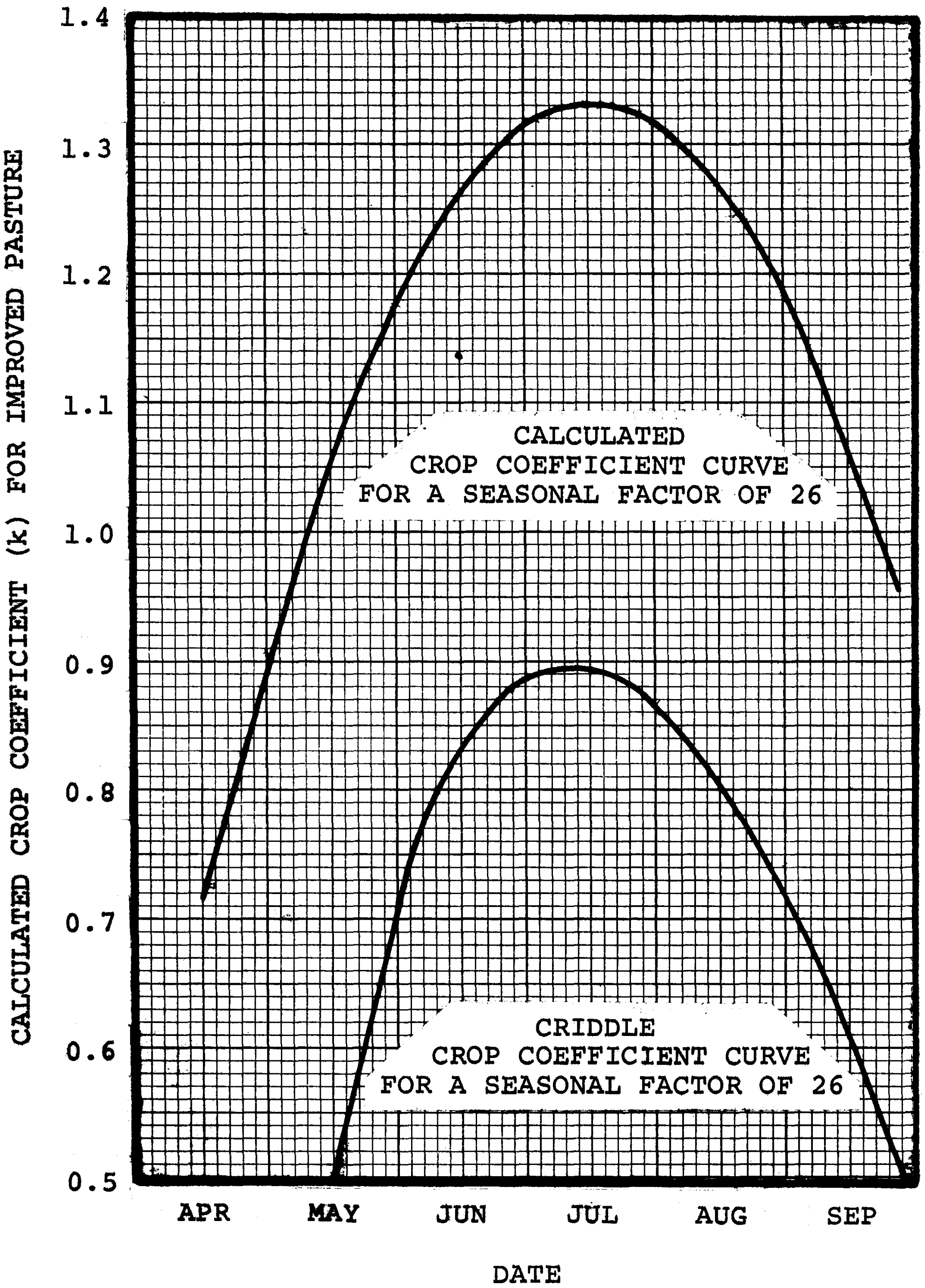
CALCULATED BLANEY-CRIDDLE CROP COEFFICIENTS
FOR MEDICINE BOW RIVER AREA

Figure 10

improved pasture was developed for this study area (Figure 11).

It would be desirable to develop the crop coefficient curve using measured evapotranspiration from the tank lysimeters. Unfortunately it was not possible to operate the tanks for the entire season. Considering the wild flood irrigation practices conducted, the high water table within the area which maintains considerable free water on the wetland surface, and the near agreement of the potential evapotranspiration estimates determined by the Modified Jensen-Haise procedure with the measured evapotranspiration from the tank lysimeters, presented later in this report, it appeared to be warranted to assume that the evapotranspiration computed by the Jensen-Haise method could be used to develop the revised Criddle crop coefficient curve.

Daily evapotranspiration estimates determined by the Modified Jensen-Haise procedure were divided by the daily consumptive use factor determined by the Blaney-Criddle procedure. The ratio, (ET/f) is Criddle's crop coefficient (k), and was correlated to the day of occurance for each day of the growing season. Data from the Medicine Bow Guard Station and from the Mill Creek location for the seasons of 1970 and 1971 indicate that the seasonal consumptive use factor for the area averages 26. This value was used in the correlation procedure. From this correlation, it appears that a more suitable crop coefficient curve for improved pasture in the



CROP COEFFICIENT CURVES FOR IMPROVED PASTURE FOR THE MEDICINE BOW RIVER AREA

Figure 11

type of study area discussed herein would be about .45 higher than the equivalent curve presented by Criddle. Criddle's curve for a seasonal factor (F) of 26 is shown on Figure 11 with the suggested curve for this area.

Table 13 contains tank lysimeter data gathered for a similar site located near the Laramie River, approximately eleven miles north of Laramie, Wyoming. This system was operated under the direction of the Wyoming Water Resource Research Institute during the same 1970 and 1971 seasons for the purpose of comparison with the Medicine Bow River Area. This Laramie River site was maintained after the completion of a study by Mr. Gideon Abraham (1) during 1969 and 1970. The results for this site indicate an average consumptive use for 1970 of 1.51 inches per week and 1.53 inches per week in 1971.

An attempt was made to develop the parameters, T_X and C_T as recommended by Jensen (7). Linear regression analyses were conducted utilizing lysimeter tank evapotranspiration data, solar radiation data, and temperature data for the Mill Creek, Medicine Bow Guard Station, and Laramie River locations for the years 1970 and 1971 combined. These yielded values of T_X and C_T which were erratic and unreliable due to the extreme scatter of data points over a narrow temperature range. Figures 12, 13, and 14 present these data for the various locations. Included on these figures are the regression lines of best fit and the regression lines as

TABLE 13. 1970 AND 1971 WEEKLY LYSIMETER DATA
(ALL VALUES IN INCHES)

DATE 1970	LARAMIE RIVER CONSUMPTIVE USE NO.1	NO.2	AVE	PREC	ET
6/03-6/09	NR*	NR			--
6/10-6/16	NR	NR		.75	--
6/17-6/23	1.47	1.65	1.56	.31	1.87
6/24-6/30	2.12	NR			2.12
7/01-7/07	1.38	NR		.54	1.92
7/08-7/14	1.19	1.32	1.25	.15	1.40
7/15-7/21	1.19	1.33	1.26	.45	1.71
7/22-7/28	.98	.84	.91	.63	1.54
7/29-8/04	NR	NR		.05	--
8/05-8/11	1.10	1.08	1.09	.17	1.26
8/12-8/18	1.26	1.21	1.24		1.24
8/19-8/25	1.04	NR			1.04
8/26-9/01	.81	1.06	.94	.10	1.04
TOTAL					15.14
AVE/WK					1.51
1971					
6/07-6/13	1.07	1.44	1.25	.12	1.37
6/14-6/20	1.64	1.64	1.64		1.64
6/21-6/27	1.92	2.08	2.00		2.00
6/28-7/04	1.51	1.74	1.62	.04	1.66
7/05-7/11	1.26	1.46	1.36	.25	1.61
7/12-7/18	1.45	1.70	1.58	.18	1.76
7/19-7/25	1.21	1.43	1.32	.16	1.48
7/26-8/01	1.24	1.12	1.18	.23	1.41
8/02-8/08	1.51	1.56	1.54	.04	1.58
8/09-8/15	1.48	.93	1.20	.27	1.47
8/16-8/22	1.50	1.30	1.40	.03	1.43
8/23-8/29	1.01	.81	.91	.07	.98
TOTAL					18.39
AVE/WK					1.53

*No Record

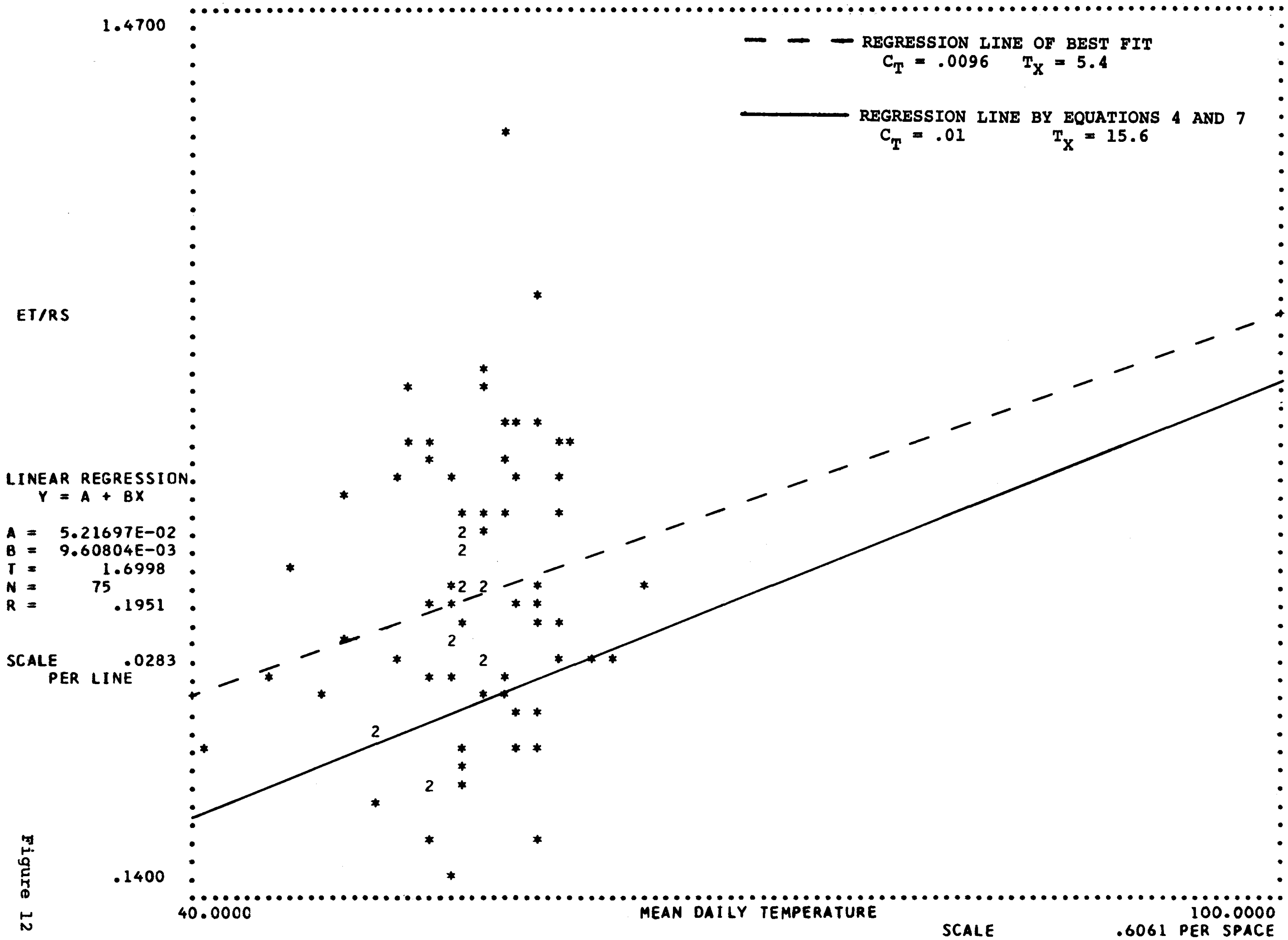
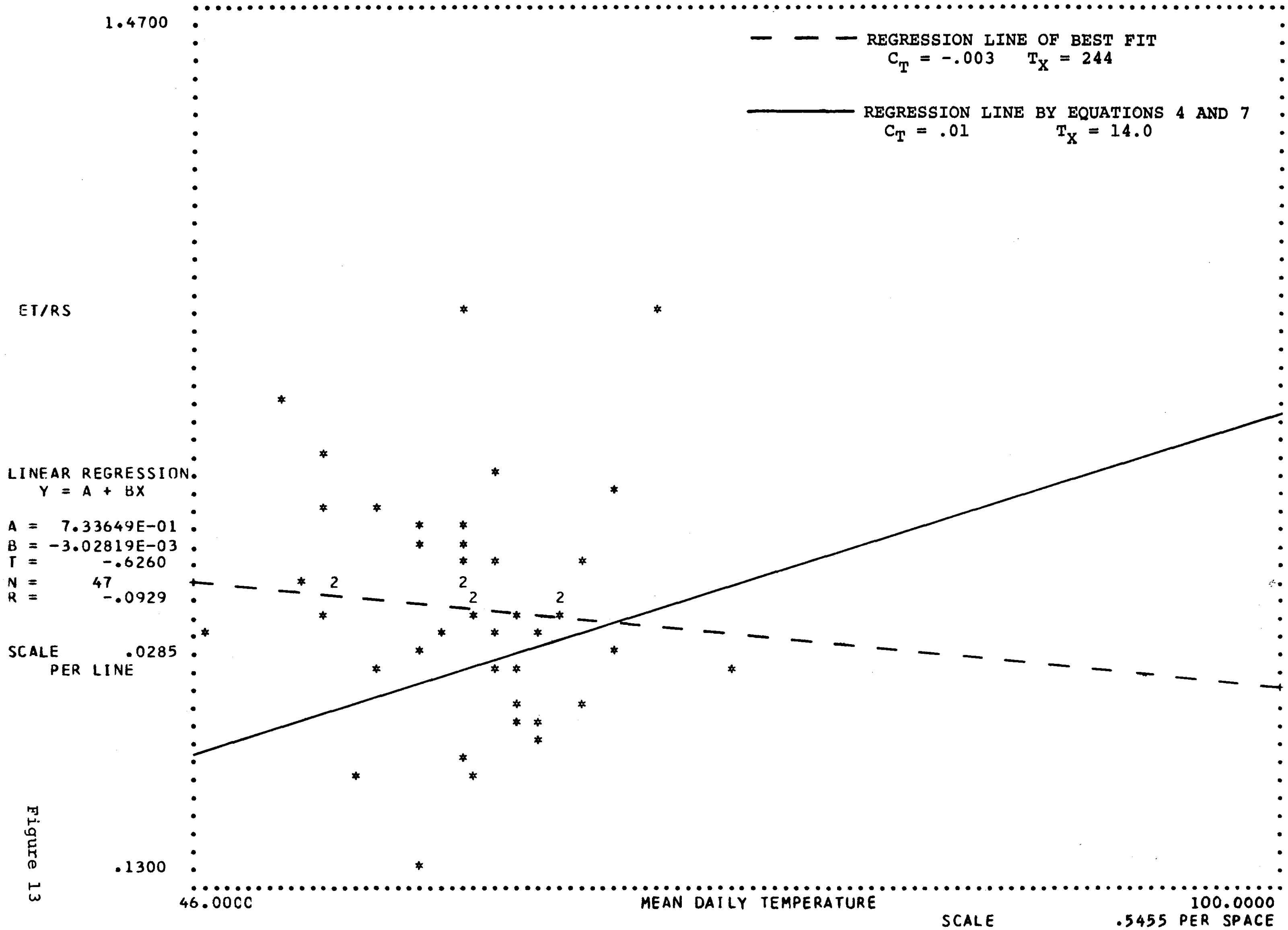


Figure 12

LINEAR REGRESSION ANALYSIS TO DETERMINE JENSEN'S C_T AND T_X
FOR MEDICINE BOW GUARD STATION AREA
FOR 1970 AND 1971



LINEAR REGRESSION ANALYSIS TO DETERMINE JENSEN'S C_T AND T_X
FOR THE MILL CREEK AREA
FOR 1970 AND 1971

Figure 13

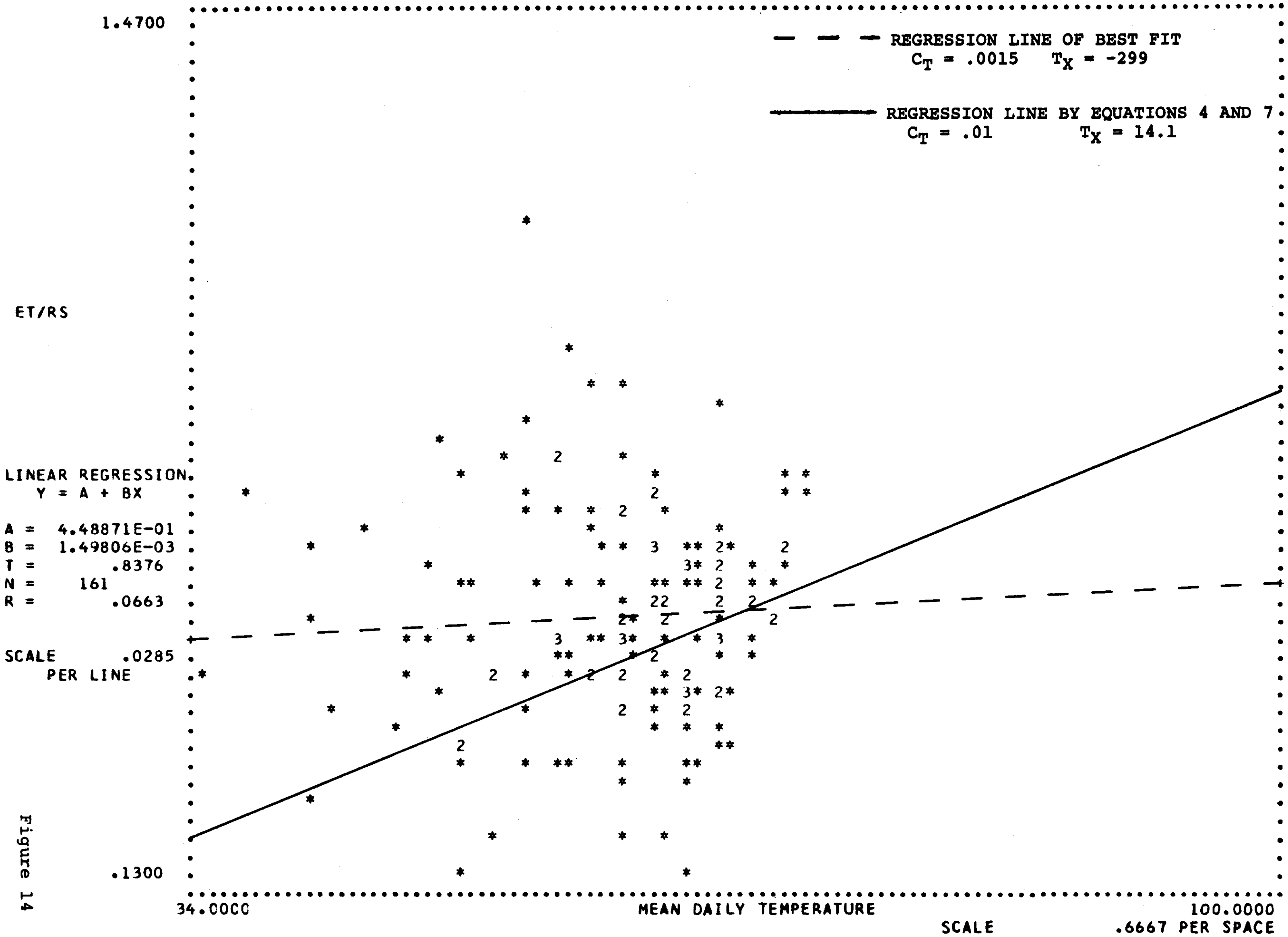


Figure 14

LINEAR REGRESSION ANALYSIS TO DETERMINE JENSEN'S C_T AND T_X
FOR LARAMIE RIVER AREA
FOR 1970 AND 1971

determined by equations 4 and 7.

The calculated value of T_X for the combined seasons of 1970 and 1971 at the Medicine Bow Guard Station was 5.4 degrees Fahrenheit and C_T was .01. These values were reasonably compatible with the values obtained from equations 4 and 7 but inconsistent with the values obtained for the other locations.

Regression analysis produced values of T_X equal to 244 degrees Fahrenheit and C_T equal to -.003 for the combined 1970 and 1971 seasons at Mill Creek. Analysis for the Laramie River location revealed T_X equal to -299 degrees Fahrenheit and C_T equal to .0015 for the 1970 and 1971 seasons.

Further analyses were then conducted combining the data from Mill Creek with the data from the Medicine Bow Guard Station. Figure 15 presents the scatter of data points and includes the regression line of best fit and the regression line determined from equations 4 and 7 for the combination of data. T_X and C_T determined from this analysis were -261 degrees Fahrenheit and .0018 respectively.

The data from all three locations (Figure 16) were combined. The values of T_X and C_T determined from this analysis were -588 degrees Fahrenheit and .0009 respectively.

In view of the extreme variations in T_X and C_T presented by the regression analysis of the observed data. The values obtained by employment of equations 4 and 7 were used for comparisons of the methods of determining or estimating

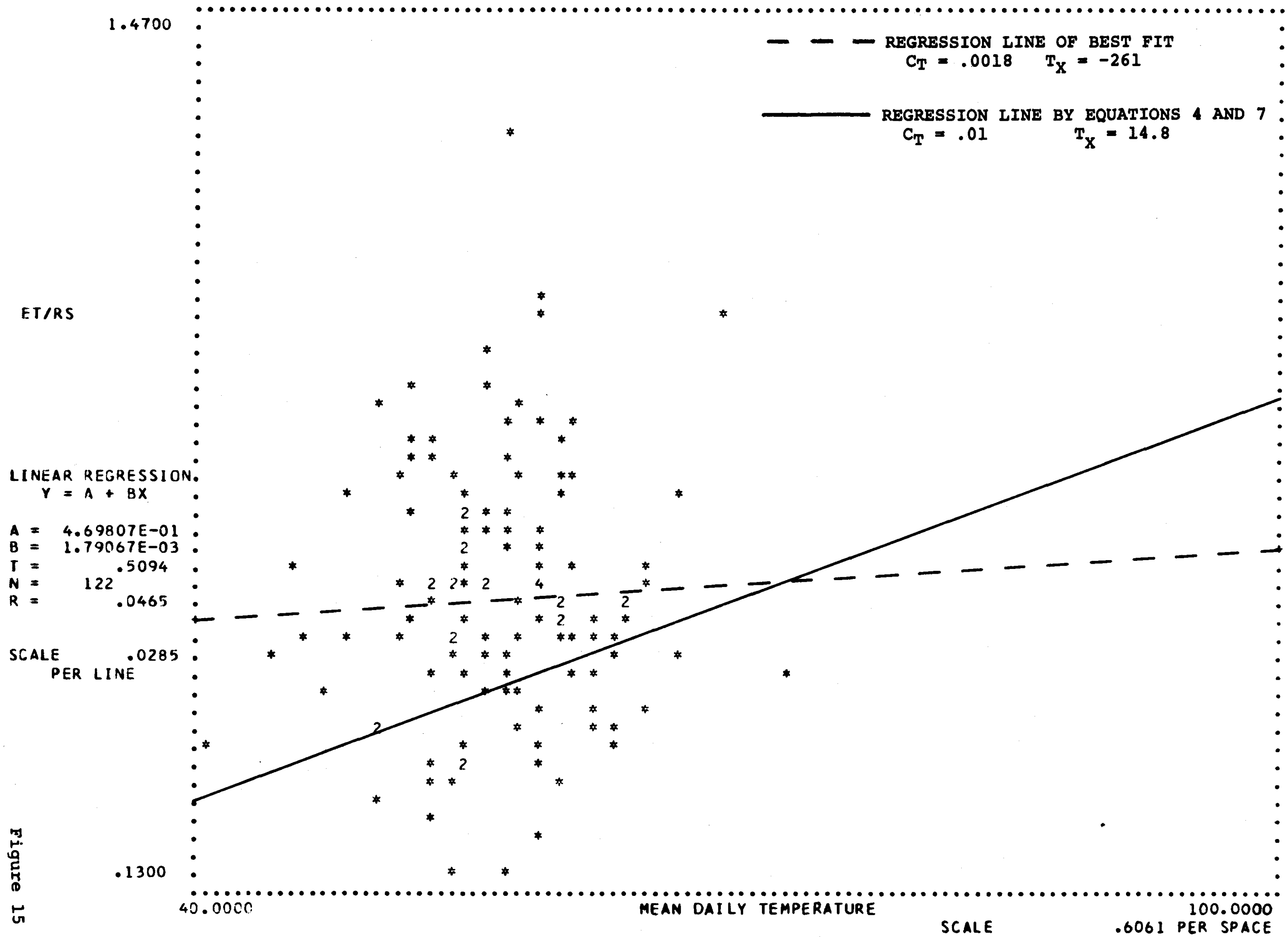


Figure 15

LINEAR REGRESSION ANALYSIS TO DETERMINE JENSEN'S C_T AND T_X VALUES FOR MILL CREEK AND MEDICINE BOW GUARD STATION FOR 1970 AND 1971 SEASONS

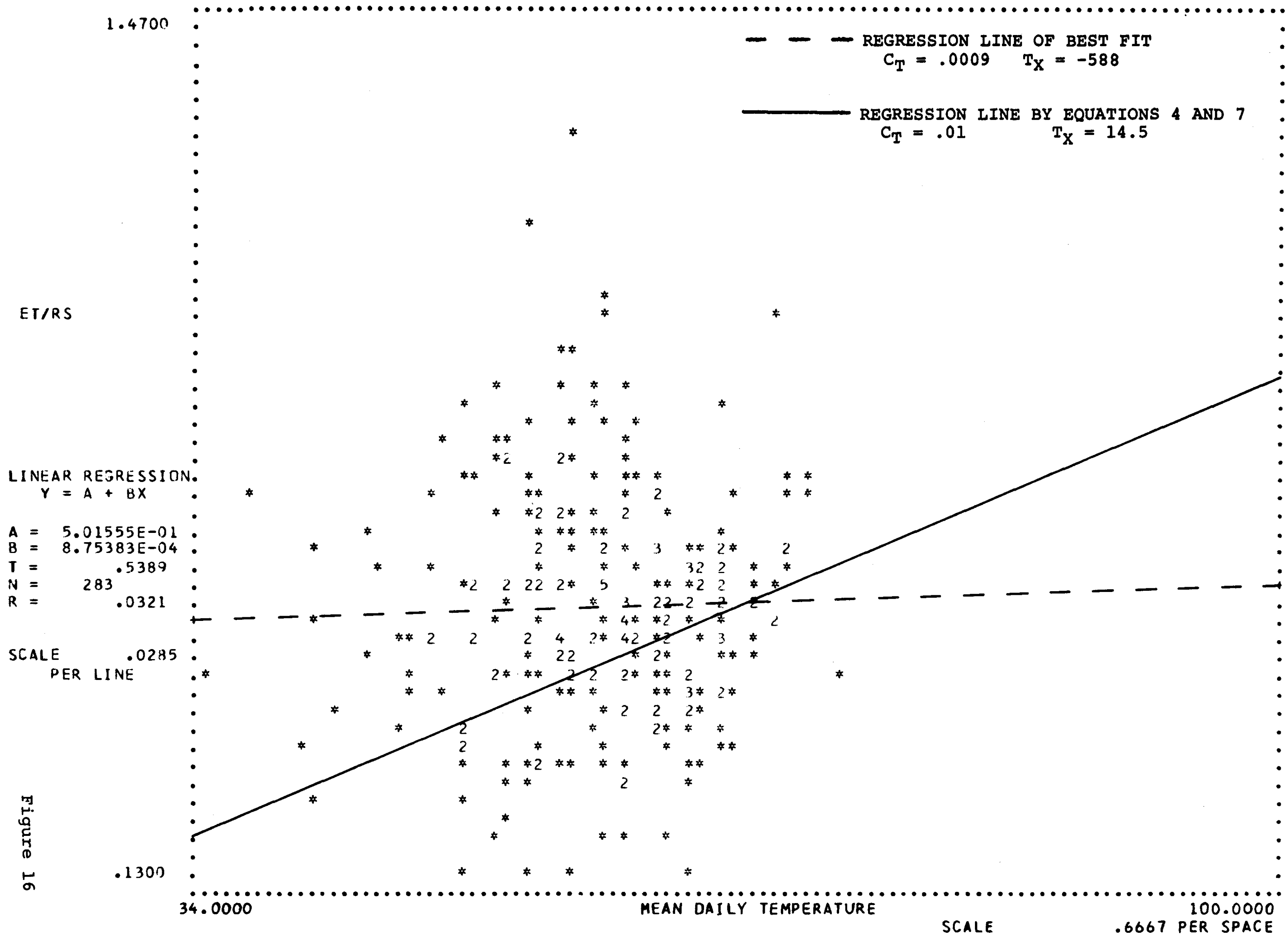


Figure 16

LINEAR REGRESSION ANAYLSIS TO DETERMINE JENSEN'S C_T AND T_X
FOR ALL THREE LOCATIONS FOR 1970 AND 1971 SEASONS

evapotranspiration as presented later in this report. It is noted, however, that the regression lines determined from these equations and shown in figures 12 through 16 do not fit the observed data since the line does not go through the center of the data points. Therefore, it can be concluded that for the area studied herein either T_X as computed from equation 7 is too high or C_T as computed by equation 4 is too small, or a combination of both conditions exist.

Results of the hydrologic budget investigations for the wetland area, considering the division of the area by the Thiessen method, and the separation of the yearly period into summer and winter portions, indicate that in the water year 1969, 25357 second-feet-days (41.4 inches per acre for the 14550 acres of wetland area) were consumptively used. During water years 1970 and 1971, 26836 second-feet-days (43.8 inches) and 20453 second-feet-days (33.4 inches) were consumptively used respectively. Table 14 presents the summary of the components entered into the hydrologic budget for water years 1969, 1970, and 1971, along with the consumptive use for the entire wetland area. Due to the assumptions and procedures used for the development of Equation 17, the consumptive use determined by this method is an approximation of seasonal consumptive use. The average seasonal consumptive use from the total wetland area for the three year period, 1969 through 1971, determined by the hydrologic budget was 39.5 inches.

TABLE 14. SUMMARY OF COMPONENTS ENTERING INTO THE HYDROLOGIC BUDGET FOR THE WETLAND AREA, IN SECOND-FEET-DAYS.

COMPONENTS	WATER YEAR 1969	1970	1971
INFLOW SOURCE			
Turpin Creek	2930	7946	7273
Mill Creek	6073	8478	8660
Medicine Bow River at Guard Station	22153	36851	47148
East Fork of Medicine Bow River	5444	10204	11076
Summer recorded precipitation on wetland area (P_{ai} Summer)	5025	7861	4807
Summer runoff from non-irrigated area (P_{rn} Winter)	724	1195	550
Winter runoff (P_r Winter)	1556	2386	3534
TOTAL	43905	74921	83048
OUTFLOW			
Medicine Bow River at the Orton Ranch	18548	47953	62219
Orton Flumes	NR	132	376
TOTAL	18548	48085	62595
CONSUMPTIVE USE FROM WETLAND AREA			
Consumptive Use	25357	26836	20453

CHAPTER VI. COMPARISON OF RESULTS

Tables 15 and 16 present a comparison of the weekly consumptive use data from the lysimeters, the Modified Jensen-Haise method, and the Blaney-Criddle method. This comparison is for the time period when data were available from both of the tank lysimeter sites during 1970 and 1971 respectively. The comparison includes a total consumptive use, an average consumptive use per week, and an average daily consumptive use for the period. This comparison indicates that the estimates yielded by the Jensen-Haise method for 1970 are for the most part quite favorable to the measured consumptive use from the tank lysimeters. The Blaney-Criddle method produced estimates consistently and substantially lower than the tank lysimeter measurements. During 1971, the Jensen-Haise method estimates were also quite favorable to the measured consumptive use from the tank lysimeters. Again the Blaney-Criddle method estimates were consistently and substantially lower than the measured consumptive use from the tank lysimeters. A daily arithmetic average of the measured consumptive use from the tank lysimeters for 1970 was .23 inches per day while a similar average for the Modified Jensen-Haise and the Blaney-Criddle methods were .27 inches per day and .17 inches per day re-

TABLE 15. 1970 COMPARISONS OF WEEKLY CONSUMPTIVE USE BY TANK LYSIMETERS, BLANEY-CRIDDLE METHOD, AND MODIFIED JENSEN-HAISE METHOD, DURING THE PERIOD OF OPERATION OF THE TANK LYSIMETERS. (ALL VALUES IN INCHES)

DATE*	LYSIMETERS		MEDICINE BOW GUARD STATION		MEDICINE BOW RIVER FLATS		MILL CREEK AT LARSON RANCH	
	MILL CREEK	COW CAMP	BLANEY-CRIDDLE	JENSEN-HAISE	BLANEY-CRIDDLE	JENSEN-HAISE	BLANEY-CRIDDLE	JENSEN-HAISE
6-22-70	2.12	2.32	.88	1.84	1.02	2.18	1.09	2.56
6-29-70	2.02	1.68	1.15	1.64	1.28	2.01	1.32	2.41
7-06-70	1.32	1.98	1.08	1.62	1.23	1.81	1.29	2.17
7-13-70	1.76	1.95	1.16	1.68	1.28	1.96	1.35	2.38
7-20-70	1.41	1.83	1.19	1.60	1.31	1.84	1.37	2.19
7-27-70	1.63	1.68	1.14	1.62	1.25	1.86	1.29	2.21
8-03-70	1.72	2.00	1.15	1.60	1.26	1.91	1.30	2.27
8-10-70	1.18	1.26	1.14	1.59	1.25	1.86	1.28	2.21
8-17-70	.87	.69	1.05	1.21	1.15	1.42	1.18	1.66
TOTAL	14.03	15.39	9.94	14.40	11.03	16.85	11.47	20.06
AVE/WK	1.56	1.71	1.10	1.60	1.22	1.87	1.27	2.23
AVE/DAY	.22	.24	.15	.23	.18	.27	.18	.32

*First day of seven day period.

TABLE 16. 1971 COMPARISONS OF WEEKLY CONSUMPTIVE USE BY TANK LYSIMETERS, BLANEY-CRIDDLE METHOD, AND MODIFIED JENSEN-HAISE METHOD DURING THE PERIOD OF OPERATION OF THE TANK LYSIMETERS.

DATE*	LYSIMETERS		MEDICINE BOW GUARD STATION		MEDICINE BOW RIVER FLATS		MILL CREEK AT LARSON RANCH	
	MILL CREEK	COW CAMP	BLANEY-CRIDDLE	JENSEN-HAISE	BLANEY-CRIDDLE	JENSEN-HAISE	BLANEY-CRIDDLE	JENSEN-HAISE
6-22-71	2.32	2.49	1.01	1.82	1.19	2.10	1.16	2.23
6-29-71	2.01	2.11	1.12	1.39	1.30	1.75	1.18	1.73
7-06-71	2.17	1.82	1.05	1.58	1.21	2.02	1.10	1.97
7-13-71	2.12	1.85	1.16	1.72	1.34	2.05	1.21	2.04
7-20-71	1.70	1.41	1.23	1.35	1.36	1.69	1.23	1.68
7-27-71	1.67	1.75	1.10	1.21	1.22	1.43	1.14	1.50
8-03-71	1.65	2.25	1.02	1.35	1.12	1.54	1.05	1.63
8-10-71	1.56	1.83	1.05	1.40	1.14	1.49	1.08	1.70
8-17-71	1.58	1.84	1.05	1.28	1.14	1.45	1.07	1.43
8-24-71	1.29	2.07	1.01	1.08	1.09	1.38	.98	1.38
TOTAL	18.08	19.42	10.80	14.18	12.11	16.90	11.20	17.29
AVE/WK	1.81	1.94	1.08	1.42	1.21	1.69	1.12	1.73
AVE/DAY	.26	.28	.15	.20	.18	.24	.16	.25

*First day of seven day period.

spectively. An arithmetic average for 1971 yields daily consumptive use of .27 inches per day from the tank lysimeters and .23 inches per day and .16 inches per day as determined by the Modified Jensen-Haise and Blaney-Criddle methods respectively.

To compare the calculated estimates on a seasonal basis, a growing season from April 20 through September 27 was estimated utilizing personal experience in the area and the growing season tabulation presented by Trelease, et al. (18). This growing season consists of 22 weeks. With this growing season established, Figures 11 through 14 were developed for Mill Creek and for the Medicine Bow Guard Station for 1970 and 1971, to show the variation in estimated consumptive use on a weekly basis during the growing season between the Modified Jensen-Haise method and the Blaney-Criddle method. These figures also incorporate the tank lysimeter data during the period of operation of the lysimeters for the respective locations and years. Data for these figures were taken from previously presented Tables 5 through 10. Again these figures show a consistently lower estimate of consumptive use by the Blaney-Criddle method than that yielded by either the Modified Jensen-Haise method or the tank lysimeters. These figures also indicate that on an average the Modified Jensen-Haise method compares favorably with the measured consumptive use from the tank lysimeters.

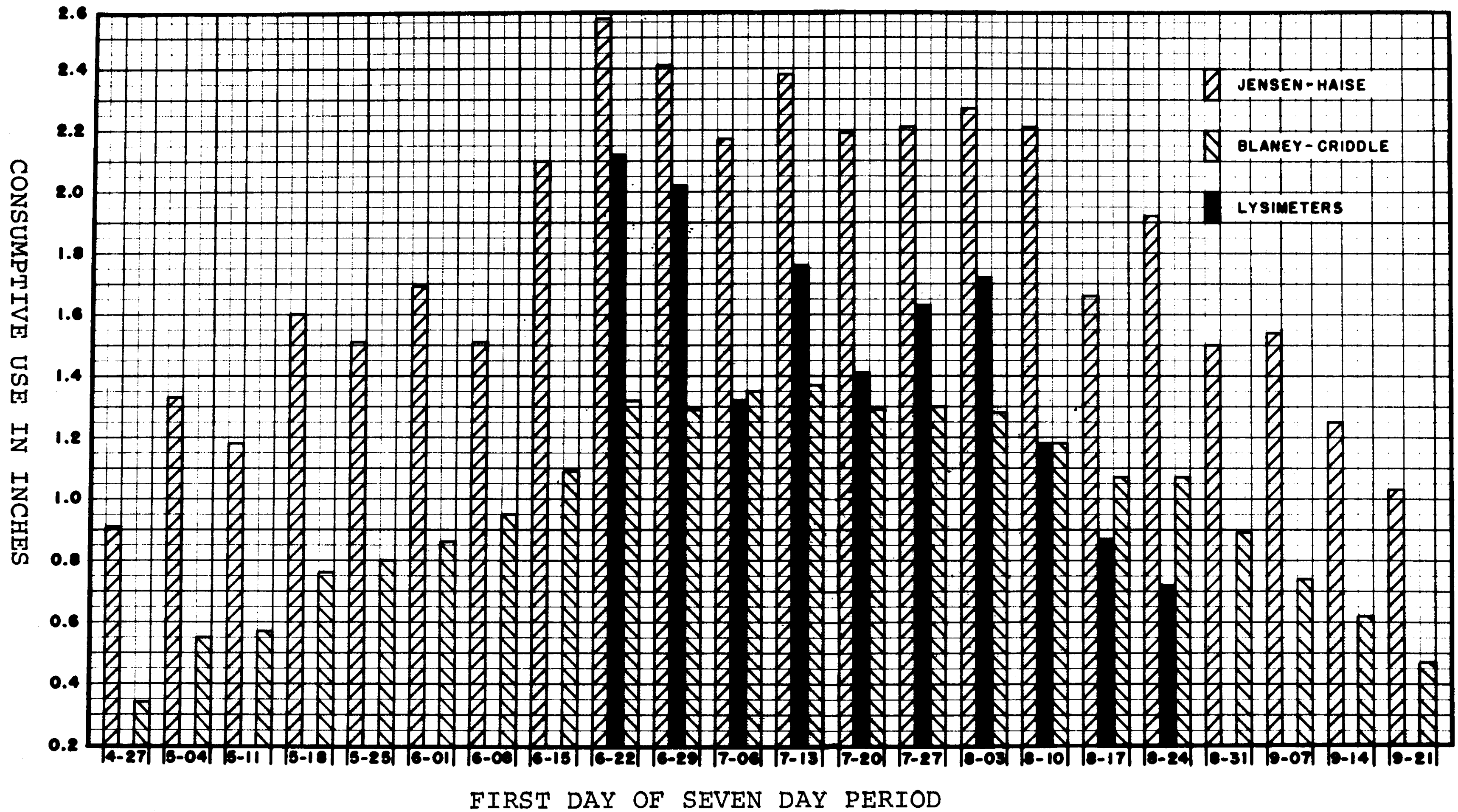


Figure 17

VARIATION OF WEEKLY CONSUMPTIVE USE
DURING THE GROWING SEASON FOR
MILL CREEK DURING 1970

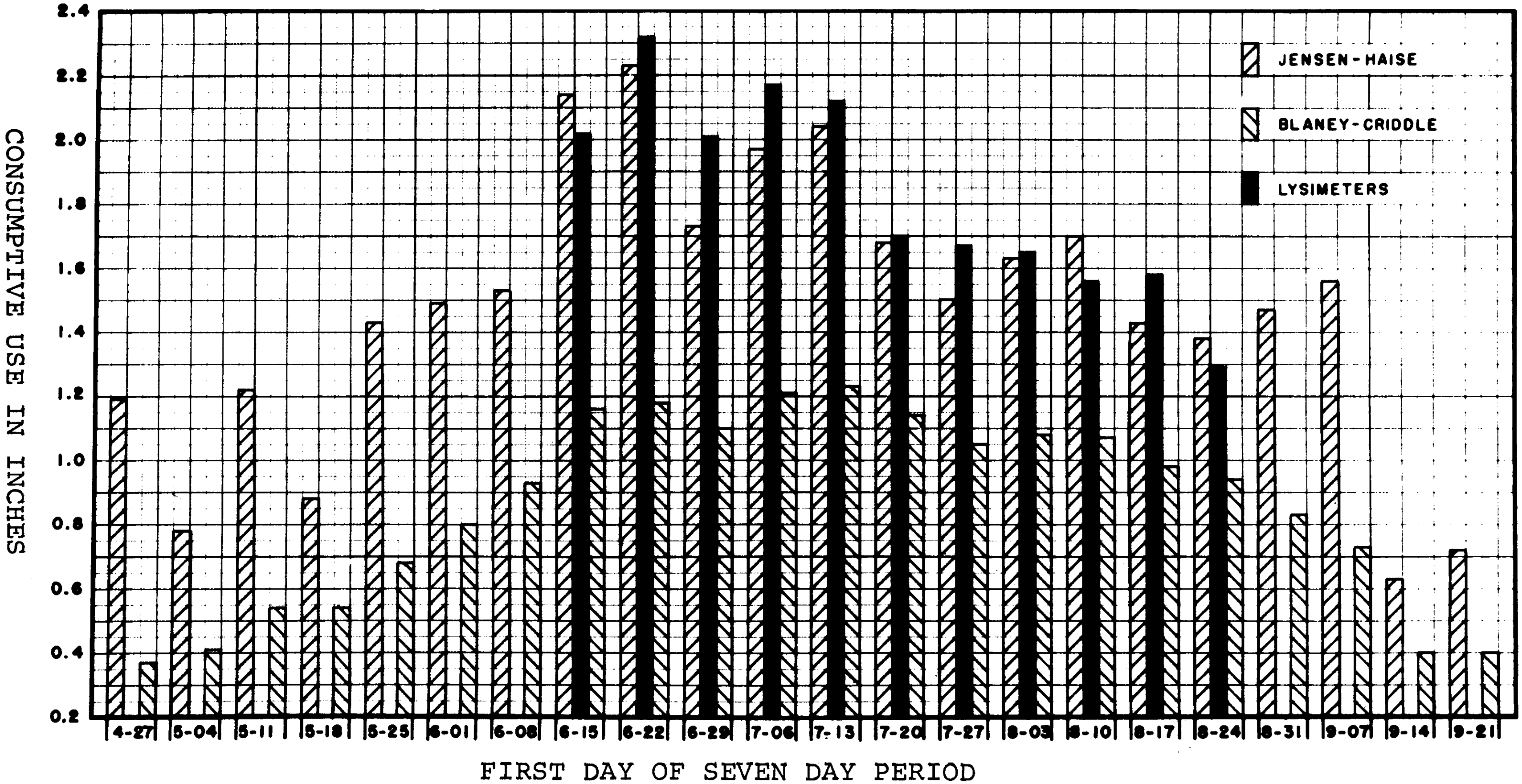
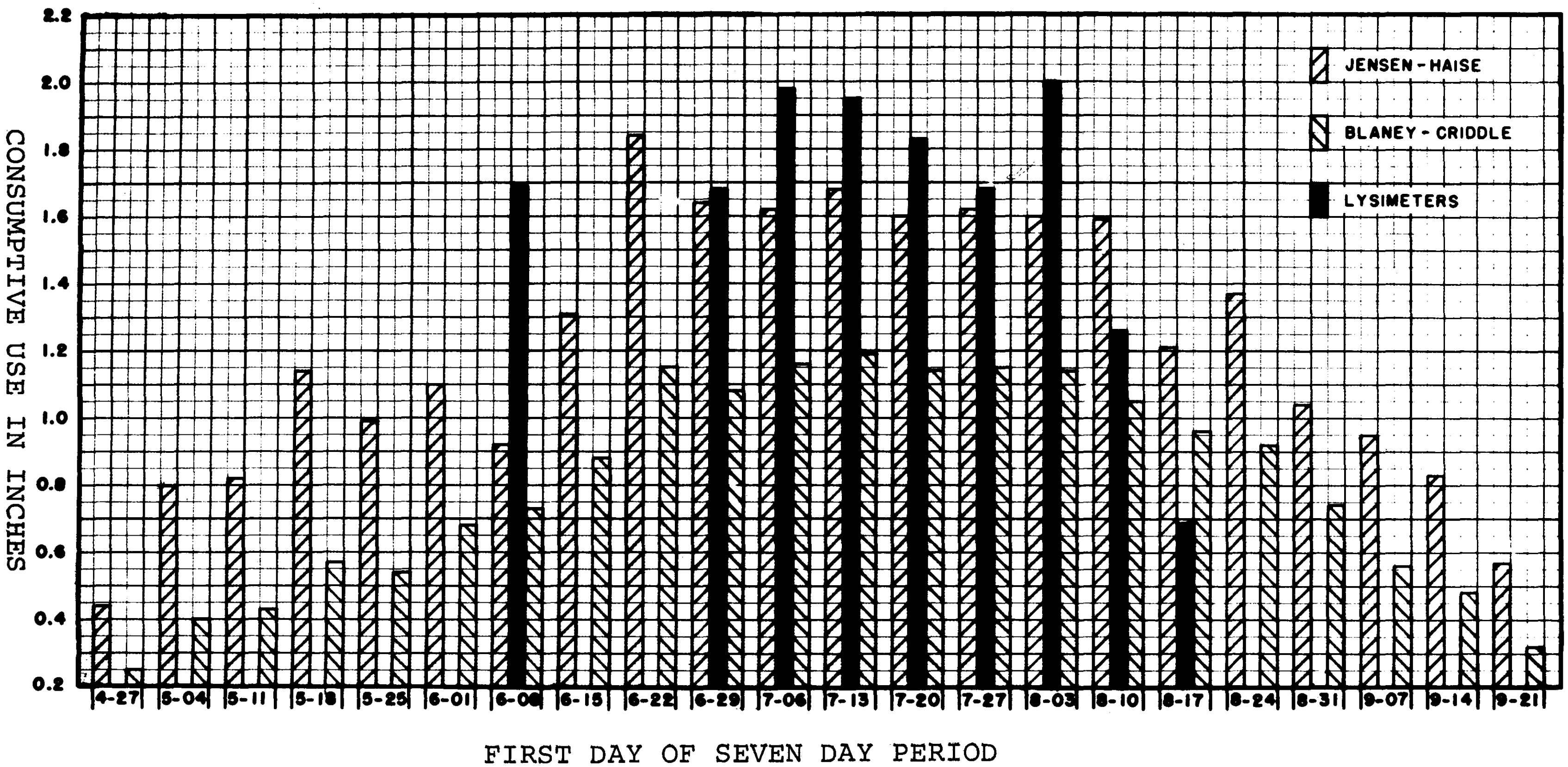


Figure 18

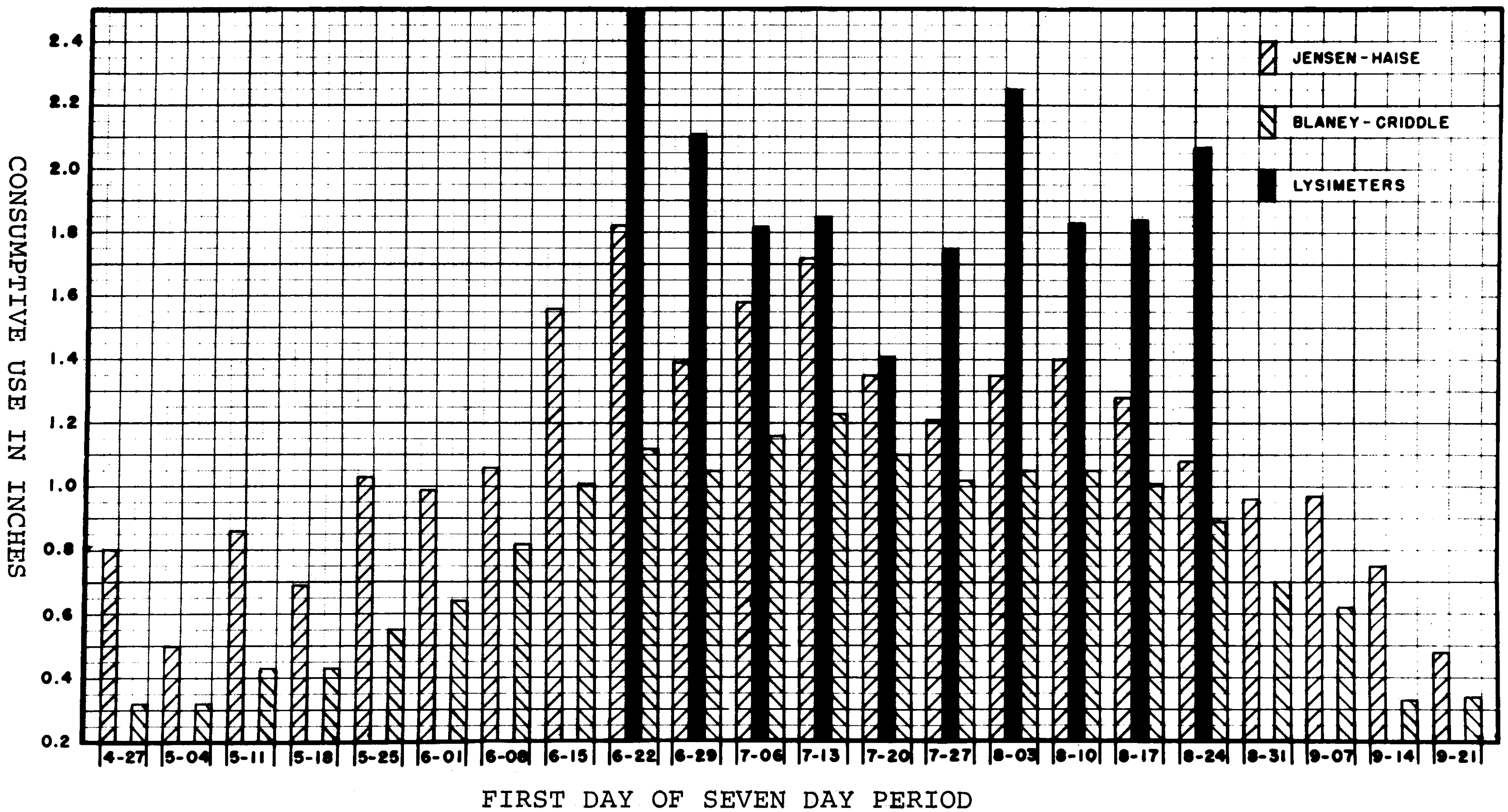
VARIATION OF WEEKLY CONSUMPTIVE USE
DURING THE GROWING SEASON FOR
MILL CREEK DURING 1971



VARIATION OF WEEKLY CONSUMPTIVE USE
DURING THE GROWING SEASON FOR
MEDICINE BOW GUARD STATION
DURING 1970

Figure 19

Figure 20



VARIATION OF WEEKLY CONSUMPTIVE USE
DURING THE GROWING SEASON FOR
MEDICINE BOW GUARD STATION
DURING 1971

Monthly comparison of estimated consumptive use by the Modified Jensen-Haise method and the Blaney-Criddle method, during the growing season for the entire wetland area, are included in Figures 14, 15, and 16 for 1969, 1970, and 1971. These figures are composed of the monthly consumptive use estimates for each station by both estimating methods. A weighted average obtained by employing the Thiessen distribution principle (16) was developed for the entire area for each month for both the Modified Jensen-Haise method and the Blaney-Criddle method. The sum of these weighted average consumptive use estimates then yielded a seasonal consumptive use. The seasonal consumptive use estimate is then compared to the seasonal consumptive use determined by the hydrologic budget (Inflow-Outflow) on the same figures. The data from which these figures were developed are presented in Tables 17 and 18.

The monthly consumptive use estimates were obtained by summing the daily estimates as calculated by the computer for the months of the growing season discussed earlier. Several calculations using the Blaney-Criddle method were made employing the mean monthly temperature, the monthly percent of daytime hours, and a monthly consumptive use coefficient. These monthly values compared closely to the estimates obtained by summing the daily values.

On a monthly basis the Jensen-Haise method consistently yielded considerably higher estimates than did the

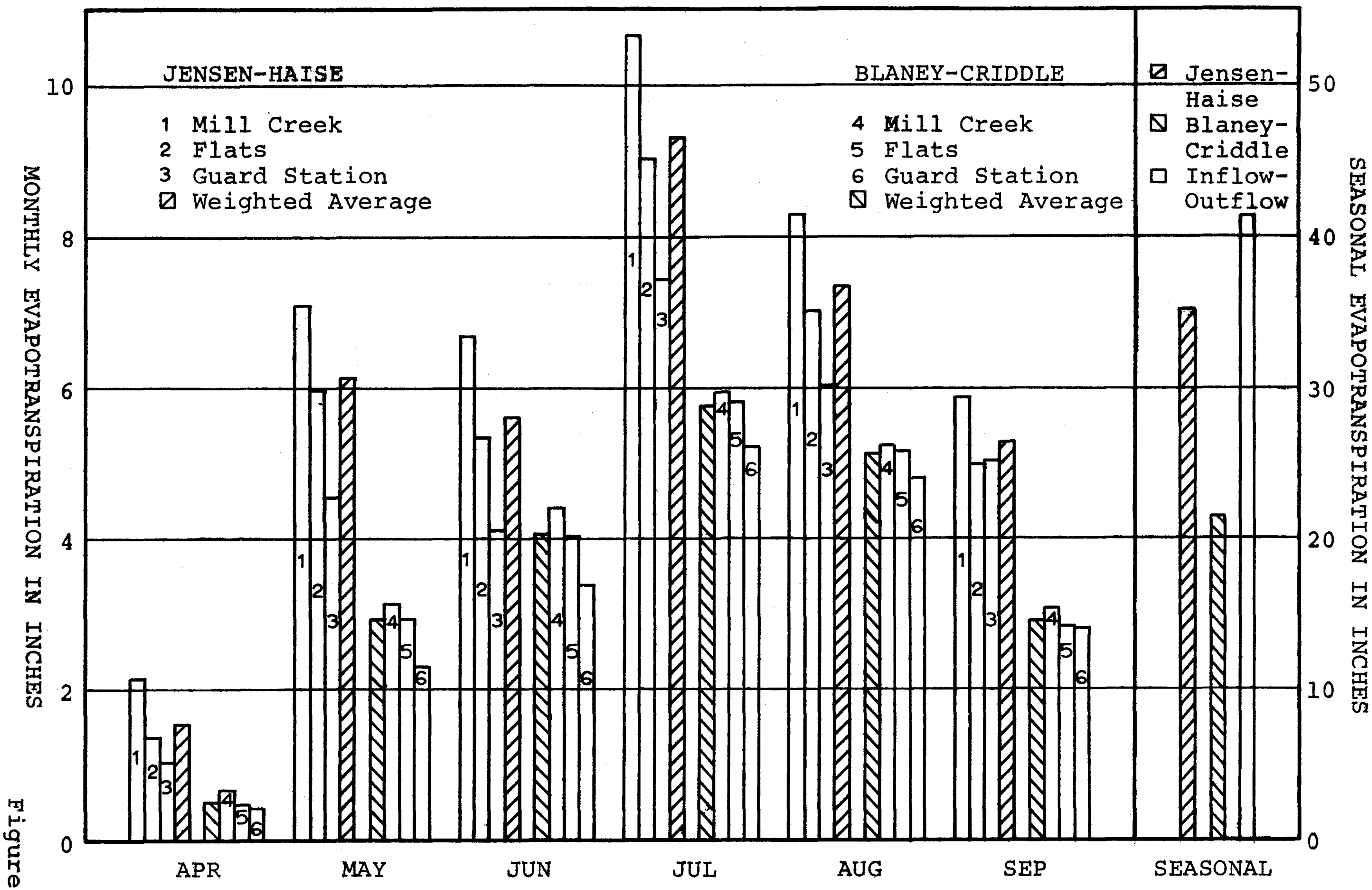


Figure 21 COMPARISON OF MONTHLY AND SEASONAL ESTIMATED EVAPOTRANSPIRATION FOR 1969

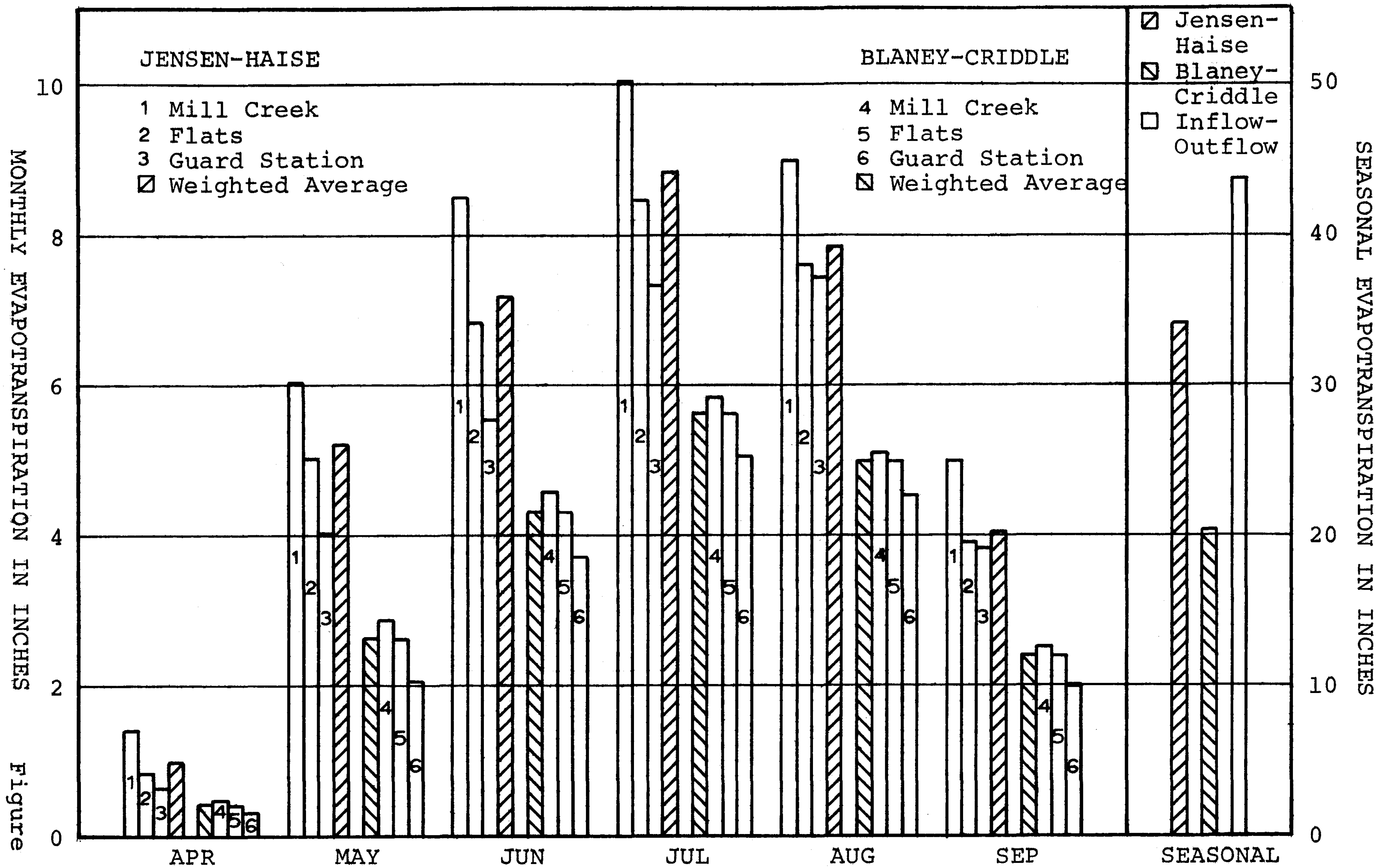


Figure 22

COMPARISON OF MONTHLY AND SEASONAL ESTIMATED EVAPOTRANSPIRATION FOR 1970

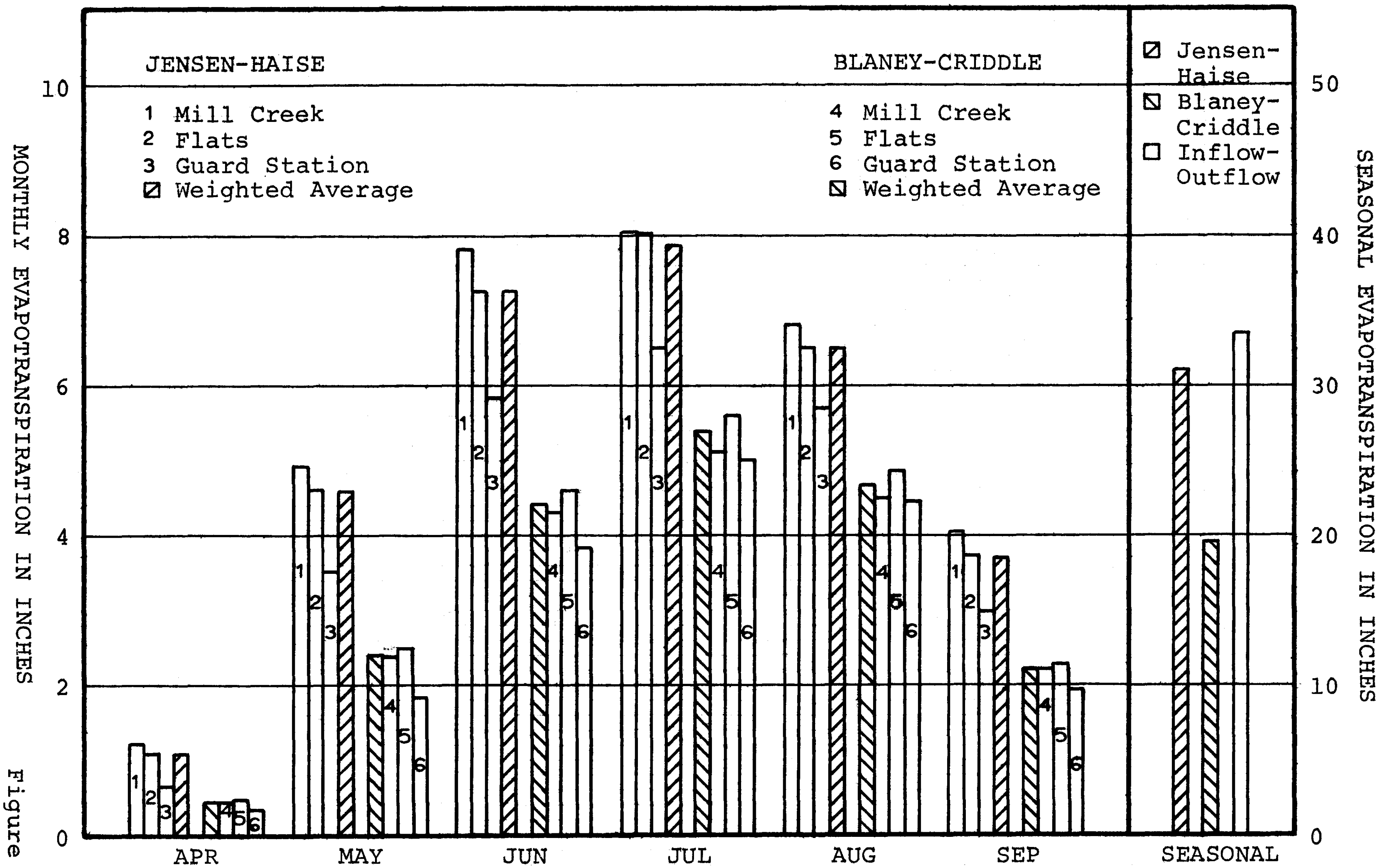


Figure 23

COMPARISON OF MONTHLY AND SEASONAL ESTIMATED EVAPOTRANSPIRATION FOR 1971

TABLE 17

BLANEY-CRIDDLE MONTHLY AND SEASONAL EVAPOTRANSPIRATION FOR THE WETLAND AREA NEAR THE THREE CLIMATOLOGICAL DATA STATIONS AND THE TOTAL WETLAND AREA FOR A GROWING SEASON INCLUDING APRIL 20 THROUGH SEPTEMBER 27 FOR 1969, 1970, AND 1971.

DATE	MILL CREEK	MEDICINE BOW RIVER FLATS	MEDICINE BOW GUARD STATION	WEIGHTED AVERAGE FOR TOTAL WETLAND
1969				
Apr	.62	.51	.43	.53
May	3.15	2.94	2.31	2.93
Jun	4.41	4.03	3.39	4.07
Jul	5.95	5.81	5.21	5.78
Aug	5.26	5.19	4.80	5.17
Sep	3.09	2.85	2.82	2.92
SEASONAL	22.48	21.33	18.96	21.40
1970				
Apr	.48	.41	.37	.42
May	2.85	2.64	2.07	2.64
Jun	4.59	4.35	3.73	4.35
Jul	5.86	5.61	5.08	5.62
Aug	5.13	4.98	4.56	4.98
Sep	2.57	2.38	1.99	2.39
SEASONAL	21.48	20.37	17.80	20.40
1971				
Apr	.47	.49	.39	.47
May	2.38	2.51	1.83	2.40
Jun	4.33	4.59	3.85	4.43
Jul	5.14	5.59	4.96	5.39
Aug	4.52	4.84	4.46	4.70
Sep	2.22	2.28	1.87	2.22
SEASONAL	19.06	20.30	17.36	19.61

TABLE 18

JENSEN-HAISE MONTHLY AND SEASONAL EVAPOTRANSPIRATION FROM THE WETLAND AREA NEAR THE THREE CLIMATOLOGICAL DATA STATIONS AND THE TOTAL WETLAND AREA FOR A GROWING SEASON INCLUDING APRIL 20 THROUGH SEPTEMBER 27 FOR 1969, 1970, AND 1971.

DATE	MILL CREEK	MEDICINE BOW RIVER FLATS	MEDICINE BOW GUARD STATION	WEIGHTED AVERAGE FOR TOTAL WETLAND
1969				
Apr	2.13	1.38	1.02	1.56
May	7.14	5.97	4.57	6.15
Jun	6.71	5.36	4.12	5.61
Jul	10.66	9.06	7.45	9.34
Aug	8.32	7.12	6.11	7.36
Sep	5.91	4.98	5.11	5.27
SEASONAL	40.90	33.87	28.38	35.29
1970				
Apr	1.40	.84	.66	.98
May	6.04	5.03	3.99	5.21
Jun	8.48	6.86	5.55	7.18
Jul	10.13	8.48	7.34	8.83
Aug	8.99	7.59	6.44	7.87
Sep	5.00	3.93	3.16	4.15
SEASONAL	40.04	32.73	27.14	34.22
1971				
Apr	1.21	1.09	.66	1.08
May	4.95	4.61	3.53	4.59
Jun	7.81	7.27	5.85	7.27
Jul	8.08	8.05	6.50	7.88
Aug	6.82	6.52	5.68	6.51
Sep	4.12	3.71	2.97	3.74
SEASONAL	32.99	31.25	25.19	31.07

Blaney-Criddle method for all three years. The peak consumptive use estimated by the Modified Jensen-Haise method for the area occurred in July with values of 9.34 inches for 1969, 8.83 inches for 1970, and 7.88 inches for 1971. Estimates of consumptive use by the Blaney-Criddle method yielded peak values of 5.78 inches in 1969, 5.62 inches in 1970, and 5.39 inches in 1971, also occurring in July.

On a seasonal basis the measurements from the hydrologic budget were greater than either the Modified Jensen-Haise or the Blaney-Criddle estimates. The estimates from the Modified Jensen-Haise method approached the inflow-outflow measurements with a maximum discrepancy of 21 percent occurring in 1970. Seasonal estimates from the Blaney-Criddle method produced a maximum discrepancy of 53 percent, also occurring in 1970.

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of this study, the following conclusions can be made concerning the applications of the methods used to determine or estimate evapotranspiration from irrigated high mountain meadows in southern Wyoming.

The conclusions are that:

(1) The Modified Jensen-Haise method during the periods when the tank lysimeters were in operation presents compatible estimates of evapotranspiration on a potential basis for the total wetland area, although the applications at independent sites did present some variations.

(2) The Modified Jensen-Haise method presents greater estimates of potential evapotranspiration for a season than does the Blaney-Criddle method considering weekly, monthly and seasonal analysis.

(3) The Blaney-Criddle crop coefficients appear to be low for irrigated high mountain meadows. From this study it appears that the k values as presented by Criddle should be increased about

.45 throughout the season.

(4) The hydrologic budget yielded larger evapotranspiration values for the growing season than did either of the estimating procedures. It should be noted that Reichenbaugh's study (11) revealed an average consumptive use of 39.6 inches for the years of 1966 through 1968 in this wetland area as determined by the hydrologic budget. Similarly, this study presents an average consumptive use of 39.5 inches for the wetland area for the years of 1969 through 1971. The near agreement of these two figures implies that more confidence may be applied to the hydrologic budget procedure.

(5) It was not possible with the data obtained to compute reasonable values of T_X and C_T for the study area as recommended by Jensen. The regression analysis using the lysimeter tank data did indicate however, that based on present literature, estimates of T_X are too high, or C_T are too low, or a combination thereof.

(6) The estimated growing season may be slightly shorter than the actual growing season due to the magnitude of evapotranspiration rates still occurring in September. An extension of the growing season to mid- or - late - October may

produce estimates by the Jensen-Haise method for the season that are more comparable to the seasonal consumptive use determined by the hydrologic budget. Blaney-Criddle estimates utilizing the present procedure would still be considerably less than either of the other methods.

Recommendations

Based on the conduct of this study, certain recommendations are noted to assist further research in similar areas. These recommendations are:

(1) Further investigations should be conducted to obtain more appropriate crop coefficients for the Blaney-Criddle method and T_X and C_T values for the Modified Jensen-Haise procedure for irrigated high elevation meadows.

(2) More detailed investigations should be conducted during the winter months to determine the distribution, quantity and density of the snow in the area to assist with the determination of the volume of water contributing to the hydrologic budget. In addition, mini-watersheds should be established to determine the portion of recorded precipitation that is consumptively used by the area being investigated.

(3) Groundwater and soil moisture monitoring should be conducted during the extent of the research to obtain reliable determination of consumptive use by the hydrologic budget on a seasonal basis. This may lead to drilling of small observation wells and the establishment of access tubes for neutron measuring of soil moisture at several locations within the study area.

(4) Since one possible use of the findings from a study such as this is the prediction of water salvage by modifying the water use patterns in the watershed, further studies should be made of phreatophyte use. These studies should involve several disciplines such as engineering, hydrology, plant sciences, soil sciences, etc.

(5) Data systems should be of the type to obtain accurate information for application of various estimating approaches.

(6) Lysimeter units similar to the units employed in this study should have more positive flow control mechanisms. In addition, the water transmission lines supplying the lysimeters from the storage tanks should be of metallic composition to minimize loss of data due to weathering and rodent damage.

REFERENCES

1. Abraham, Gideon, "A Study of Evapotranspiration from a High Altitude Meadow," thesis presented to the University of Wyoming, at Laramie, Wyoming, in 1971, in partial fulfillment of the requirements for the degree of Master of Science in Agricultural Engineering.

2. Blaney, Harry F., and Criddle, Wayne D., "Determining Consumptive Use and Irrigation Water Requirements," Technical Bulletin No. 1275, Agricultural Research Service, U. S. Department of Agriculture, Washington, D.C., 1962.

3. Blaney, Harry F., and Criddle, Wayne D., "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," Technical Publication No. 96, Soil Conservation Service, U. S. Department of Agriculture, Washington, D. C., 1960.

4. Criddle, Wayne D., Harris, Karl, and Wellandson, Lyman S., "Consumptive Use and Water Requirements for Utah," Technical Publication No. 8, (Rev.), Office of the State Engineer, State of Utah, 1962.

5. Grable, A.R., Hanks,R. J., Willhite, F. M., and Haise, H. R., "Influence of Fertilizer and Altitude on Energy Budgets for Native Meadows," Agronomy Journal, Vol. 58, 1966, pp. 234-237.

6. Israelson, Orson W., and Hansen, Vaughn E., Irrigation Principles and Practices, 3rd ed., John Wiley and Sons, New York, 1962.

7. Jensen, Marvin E., "Empirical Methods of Estimating or Predicting Evapotranspiration Using Radiation", Proceedings Evapotranspiration and Its Role in Water Resources Management, American Society of Civil Engineers, St. Joseph, Michigan 49085, 1966, pp. 49-53, 64.

8. Lowry, Robert L. Jr., and Johnson, Arthur F., "Consumptive Use of Water for Agriculture," Transactions, American Society of Civil Engineers, Vol. 107, 1942, pp. 1243-1302.

9. Penman, H.L., "Natural Evapotranspiration from Open Water, Bare Soil, and Grass," Proceedings, Royal Society of London, Ser. A., Vol. 193, 1948, pp.120-145.

10. Rechard, Paul A., personal communication, April 15, 1972.

11. Reichenbaugh, Ronald C., "Selected Methods of Estimating Consumptive Use from Mountain Meadows in Wyoming," thesis presented to the University of Wyoming, at Laramie, Wyoming, in 1969, in partial fulfillment of the requirements for the degree of Master of Science in Water Resources.

12. Saulnier, George J. Jr., "Ground Water Resource and Geomorphology of the Pass Creek Basin Area, Albany and Carbon Counties, Wyoming," thesis presented to the University of Wyoming, at Laramie, Wyoming, in 1968, in partial fulfillment of the requirements for the degree of Master of Science.

13. Seltzer, Leon E., ed., Columbia Lippincott Gazeteer of the World, Columbia University Press, New York, 1952, p.1176.

14. Sprinkler Irrigation Association, Sprinkler Irrigation, Compiled and edited by the Textbook Re-editing Committee, Claude H. Pair, editor-in-chief, 3rd ed., Sprinkler Irrigation Association, Washington, D.C., 1969.

15. Sturges, David L., "Evapotranspiration at a Wyoming Mountain Bog," Journal of Soil and Water Conservation, Vol. 23, No.1, January-February, 1968.

16. Thiessen, Alfred H., "Precipitation for Large Areas," Monthly Weather Review, July 1911, pp.1082-1089.

17. Thornthwaite, C.W., "An Approach Toward a Rationale Classification of Climate," Geographical Review, Vol. 38, 1948, pp.55-94.

18. Trelease, F.J., Swartz, T.J., Rechard, P.A., and Burman, R.D., "Consumptive Use of Irrigation Water in Wyoming," Wyoming Water Planning Report No.5, Water Resources Series No.19, July 1970.

19. U.S. Geological Survey, Water Resources Data for Wyoming, Part I - Surface Water Records for 1969, U.S. Department of the Interior, Washington, D.C., 1969.

20. van Bavel, C.H.M., "Potential Evapotranspiration: The Combination Concept and Its Experimental Verification," Water Resource Research, Vol.2, No.3, 1966, pp.455-467.

21. Veihmeyer, Frank J., "Evapotranspiration," Handbook of Applied Hydrology, V.T. Chow, ed., Section 11, McGraw-Hill Book Co., New York, pp. 33-38.

22. Walton, William C., Groundwater Resource Evaluation, McGraw-Hill Book Co., New York, 1970.