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A WATER BALANCE ON A SMALL AGRICULTURAL WATERSHED,
LATAH COUNTY, IDAHO

A Thesis
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DEGREE OF MASTER OF SCIENCE
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by

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BIOGRAPHICAL SKETCH OF THE AUTHOR

Darryl Jerome Davis was born in Los Angeles, California on May 14, 1938. During the period 1958-1960 he was enrolled in Fresno City College and Fresno State College where he completed most of his general education courses. From 1961 to 1963 he was a participant in an international service project in a rural area of southern Mexico with the American Friends Service Committee.

After leaving Mexico he returned to California to work with the U.S. Forest Service. In 1967 he enrolled in the College of Agriculture at the California State Polytechnic College, San Luis Obispo, California. He received his Bachelor of Science degree in Agricultural Engineering in August 1969. During the academic year 1969-70 he was employed as a Lecturer in the same department.

He entered the University of Idaho and was enrolled in the Graduate School in September 1970. This thesis is a part of his work toward a Master of Science degree in Agricultural Engineering.

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ABSTRACT

During the 1969-70 water year instrumentation was installed to begin a water balance study on the Thompson watershed near Moscow, Idaho. A water balance was made for this initial year using many rough estimates for some of the water balance factors. During the 1970-71 water year a better water balance was made that included actual measurements for all factors except deep percolation which was the unknown factor in the water balance equation.

The overall water balance for 1970-71 indicated that of the total precipitation 27% went to runoff, 57% to evapotranspiration and 16% to deep percolation. These percentages are close to those obtained from previous studies.

Several methods were used to determine evapotranspiration. Measurement of changes in soil moisture storage was considered the most accurate method used. Correlation analysis showed both the Jensen-Haise and Penman methods will give good values for evapotranspiration when the crop coefficients used take into consideration crop stress. Pan evaporation in its present form was found to be a poor method for determining evapotranspiration at the Thompson watershed.

Analysis of the results of the water balance for the 1970-71 water year was made to determine what further study was needed on the water balance. It was found that the factors of precipitation and deep percolation will require additional study.

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INTRODUCTION

The first law of thermodynamics states that the energy entering a system equals the sum of the change in energy of the system plus the energy leaving the system. This is an energy balance. A mass balance is identical in form except mass is used in place of energy as a unit of measure. The water balance is one application of the mass balance. Since the density of water remains nearly constant over the normal range of temperatures and pressures encountered in nature the water balance can be measured either in units of mass or volume. Customarily the units of volume have been used as the primary expression in the water balance, although many of the actual field measurements are made in terms of mass.

The hydrologic cycle can be described using the water balance. One good place to study such a cycle is on a watershed. The surface of a watershed acts to divide the incoming precipitation among the components of surface runoff, subsurface water movement and evapotranspiration. Once the magnitude of these component parts has been determined (measured or calculated) an indication of the distribution of water in the hydrologic cycle is obtained. Studies of this type have been made on large and small watersheds. The results of these studies have been valuable in planning future development of water resources.

The water balance has been used in recent years to predict regional water requirements and to schedule irrigations.

Computer programs are now available to assist the farmer in planning irrigations. Increased yields from improved water use efficiency and the resulting increase in profits have been strong incentives to apply the water balance to irrigated agriculture.

Dry farming depends on precipitation for soil moisture used for crop growth. Precipitation is, however, difficult to predict and nearly impossible to control. When the water balance is applied to irrigated agriculture, it is usually assumed that adequate soil moisture is available at all times and that the rate of water use is limited only by the crop and the climate. This assumption is not valid for dry farming since the soil moisture is usually not replaced immediately or completely and soil moisture tensions often reach high values. Under conditions such as these the available soil moisture becomes a limiting factor in water use by the crop.

In arid regions, the magnitude of the consumptive use term in the water balance equation is usually greater than any other term, often exceeding the other outflow terms combined, and therefore must be accurately known. There is a need to improve the accuracy of predicted values of consumptive use by crops in dry farming regions.

The purpose of the Thompson watershed project is to study the water balance of a small dry-farmed watershed. Topographically and climatically it is similar to much of the surrounding region. The cropping pattern of small grains is typical of the Palouse region.

The purpose of this thesis is to provide an indication of the relative magnitude of the various components of the hydrologic cycle at the Thompson watershed, and to indicate the probable error of determination of these components. Most of the components of the hydrologic cycle can be measured directly with instruments at the watershed. However two components, evapotranspiration and deep percolation, can only be measured indirectly by observing changes in soil moisture. An additional purpose of this thesis is to indicate the magnitude of the evapotranspiration component as calculated by several of the more common formulas relating evapotranspiration to various climatic parameters.

LITERATURE REVIEW

The water balance for a watershed can be written in three general terms: Inflow = Change in Storage + Outflow.

Precipitation is often the only significant source of inflow to a watershed. Other possible sources of inflow are surface water that flows onto the watershed from a higher elevation and water that is transported onto the watershed for a particular reason such as to irrigate a crop.
The second term of the water balance describes the changes of moisture storage in the soil mantle and water content of snow cover. Evapotranspiration by the crop and subsurface flow out of the soil mantle usually account for most of the outflow from a watershed. Water that is pumped from wells and transported away from the watershed is another form of outflow.

The water balance is a very broad topic to consider. Two of the factors in the water balance equation, soil moisture storage and evapotranspiration, have been the subjects for many investigations. Rijtema (1965) and Ward (1971) review much of the work dealing with evapotranspiration, and Gardner (1968) presents an extensive list of references dealing with soil moisture. To the knowledge of the author there has been no single review that completely covers the subject of the water balance. Many good summaries, however, have been written which discuss the use of the water balance as it relates to each of its components.

It is not within the scope of this paper to unify all these summaries. An attempt has been made to point to a few examples of typical work that has been done using the water balance principal. Also, a few references are cited which describe methods for the determination of evapotranspiration and a concept of soil moisture movement. These have been included in this literature review because they are of particular importance to the study at the Thompson watershed.

Some Uses of the Water Balance

Early water balance studies began with measurement of water use by single plants. MacDougal and Spalding (1910) related changes in size of sahuaro (cactus) trunks to available moisture in the desert of Sonora, Mexico. They also tried to relate water use to climatic conditions by weighing small cacti in pots. Briggs and Shantz (1916) used potted plants to show that climate and water use by plants could be related. Their measurements were sufficiently precise to indicate hourly moisture loss.

The use of the water balance was later expanded to large watersheds. Lowry and Johnson (1942) used the water balance in large basins to develop a cumulative heat equation for predicting evapotranspiration. Soloman (1967) used the water balance to determine the actual evapotranspiration in a large basin in a tropical climate. As part of the International Hydrological Decade the water balance is being applied to watersheds in all nations of the world in an attempt to measure the total water resources of the earth (Ward, 1967).

Blaney and Criddle (1950) used the water balance in irrigated areas to develop their water use coefficients for various crops. Their work has been continued throughout the world. Thornthwaite and Mather (1955) showed that evapotranspiration can be calculated from climatic data and can be used in a moisture budget to schedule irrigations. Jensen and others (1970) developed a computer program, based on the water balance, to be used for irrigation scheduling.

The water balance has been used in recent years to study specific aspects of soil-water-plant relationships. Shaw (1962) used it to determine the soil moisture requirements for corn in Ohio. Baier and Robertson (1966) used it to develop their "Versatile Budget" which allows for different extraction coefficients in different layers of soil. Black, Gardner and Tanner (1970) used the water balance to determine water storage and drainage for a row of snap beans and found good agreement with results from a lysimeter. Stark (1970) used it to identify the sources of water used by desert shrubs in Death Valley, California.

Recent studies (Stevens 1959, Ross 1965, Lin 1967) used the water balance to study ground water supplies in the basin of Moscow, Idaho and Pullman, Washington. These studies have shown that recharge into the aquifier is less than the present pumpage. Bloomsburg (1959) used the water balance on two forested watersheds near Moscow. He suggested that for a normal year the annual precipitation would be distributed approximately 60% to evapotranspiration, 25% to runoff and 15% to deep percolation.

Methods Used to Determine Evapotranspiration

In most arid regions the largest single component of the water balance equation is evapotranspiration. Direct measurement of evapotranspiration is not possible at present, but indirect measurement is very common using changes in soil moisture storage. Many investigators have developed formulas that relate evapotranspiration to one or more climatic parameters. These formulas are easy to use, however, best results are obtained for monthly or annual water balances. There are a few formulas that give good results for shorter time periods.

The equation developed by Penman (1948) and later modified by Walker (Torrance 1962) is generally accepted as the most accurate equation available for predicting evapotranspiration. It takes into consideration the energy factors that change water from a liquid to a gas and the mass transfer factors that move the gas away from the evaporating surface.

Jensen and Haise (1963) decided that solar radiation was the single most important factor of the energy balance. The equation they developed was found to give fairly good predictions, even for relatively short periods of time.

Considerable work has been done to relate pan evaporation to evapotranspiration (Christiansen 1968). Several complete climatological stations have been set up in California to study pan evaporation as a function of climate for the more important agricultural regions.

An Important Concept Dealing with Soil Moisture

A controversy over the relationship between crop stress and evapotranspiration has occurred for many years. Some investigators felt that the rate of water use by a crop was not effected by the tension at which water is held by the soil. Others felt that there was an effect at very high tension, but that this was not important since moisture rarely, if ever, was allowed to reach these tensions. Another group thought that there was a continuous decrease in the rate of water use as progressively higher tensions were reached.

The basis for the confusion among these opinions seems to be centered around the concepts related to static moisture conditions. The terms field capacity and wilting point were used to imply a static state of moisture in the field, a state that seldom exists. Researchers are therefore becoming more hesitant to use these terms today.

Veihmeyer and Hendrickson (1955) attempted to show that soil moisture tension has no effect on evapotranspiration. Denmead and Shaw (1962) review much of the evidence that shows there is a definite decrease in evapotranspiration with increasing moisture tension. Gardner (1960) introduced the dynamics of soil moisture and developed a model to predict the release of soil moisture to the plant roots.

THOMPSON WATERSHED PROJECT

Currently the Thompson watershed is being operated under a dual lease. The Agricultural Engineering department is using it to conduct water resource related studies, and Mr. David Bull, a local grain grower, is using it for production of barley.

The watershed is located on the eastern edge of the Palouse agricultural region about 6 miles northeast of Moscow, Idaho. The watershed is roughly oval in shape and covers approximately 8 acres. Slopes range up to 20%. No permanent stream channel exists because of continuous cropping during the last three years. However, when left in fallow previously it did develop a pronounced gulley that made tillage difficult.

There are four water bearing Latah horizons in the Moscow basin which are separated by three layers of Columbia River Basalt. The upper horizon is covered by the Palouse formation which is a loess (Lin 1967). Seismic work done by Gordon Stephensen (personal communication) at the watershed indicates the Palouse formation ranges from 20 to 70 feet in depth and the upper Latah horizon extends down 150 ft. The drilling logs for four observation wells show that there are many layers that alternate between sands and clays.

The soil is basically a silt which ranges from a sandy silt to a clayey silt. Soil density was measured at 6-inch intervals down to a depth of 8 feet at six different locations

FIGURE 1: Views of the Thompson Watershed near Moscow Idaho 1971.

Watershed with bare soil during winter.

Watershed with a stand of barley during summer.

(sites) within the watershed. Figure 2 illustrates the locations of these six sites. The averages of the densities for each interval were used to develop the curve presented in Figure 3. The upper portion of this curve appears to agree fairly well with the curve developed from data obtained by Neff (1966) for the same watershed. The dense region indicated for the soil depths from 3 to 6 feet results from a compacted clay layer. This layer is believed to restrict deep percolation and confine the root zone.

There is one perched water table known to exist which is probably caused by a dense clay layer in the subsoil. At two locations on the watershed clay layers are exposed at the surface and the crop growth here is noticeably less than on the remainder of the field. The elevation of free water was measured using three observation wells. All three wells had high water levels during January through June which corresponds to the period of recharge. Data collected from these wells is presented in Appendix B.

Neff (1966) found that the soil on the watershed could hold an average of 5.7 inches of moisture per foot of soil at a moisture tension of 1/3 atmosphere, and 2.3 inches at 15 atmospheres. This would indicate that 3.4 inches of moisture per foot of soil are available for plant use. This value is extremely high for any type of soil. Therefore another test was made which indicated a total moisture capacity of 5.2 inches per foot at 1/3 atmosphere. This value is reasonably close to Neff's results and indicates

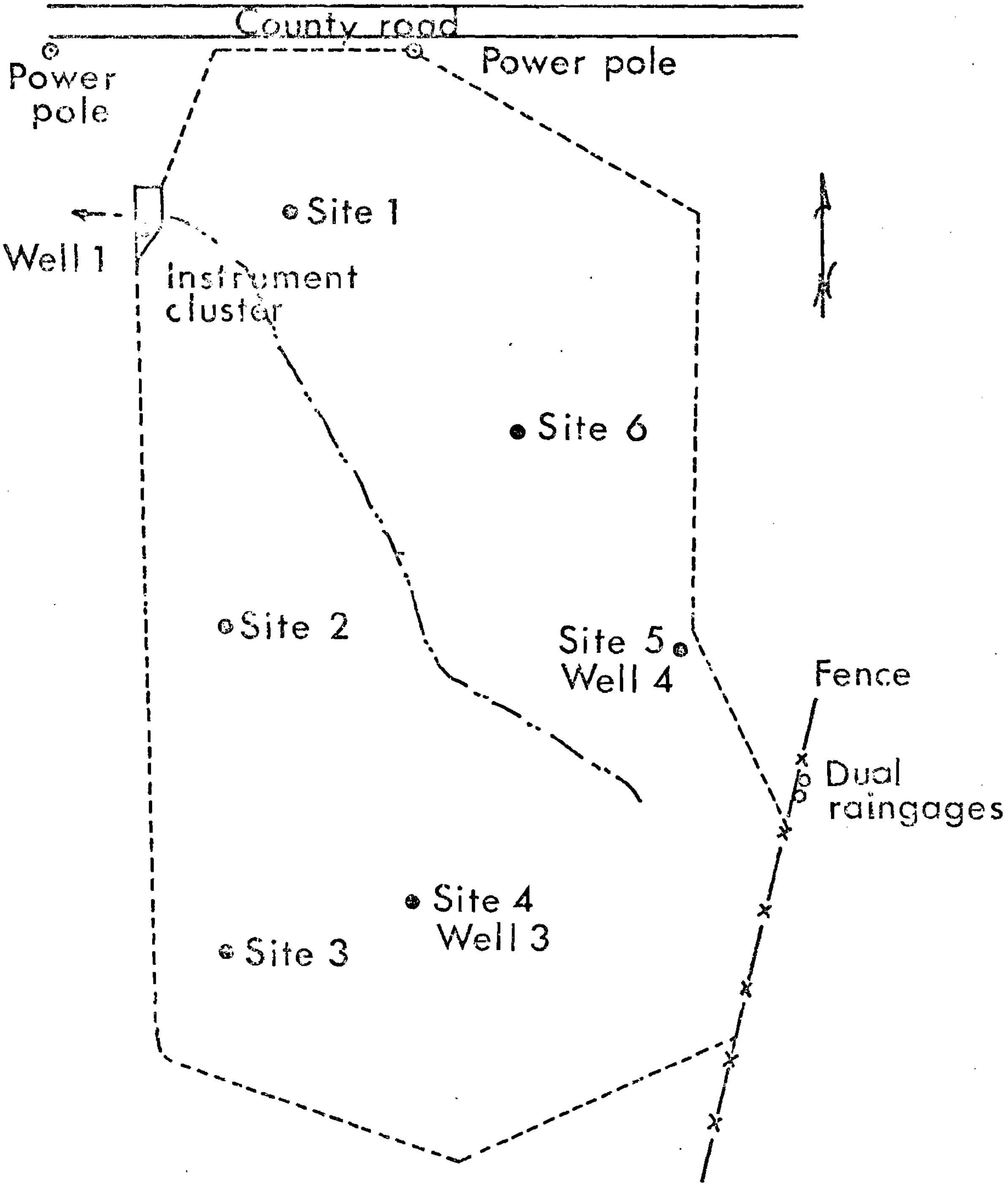


FIGURE 2 : Instrumentation and measurement locations on the Thompson watershed near Moscow, Idaho.

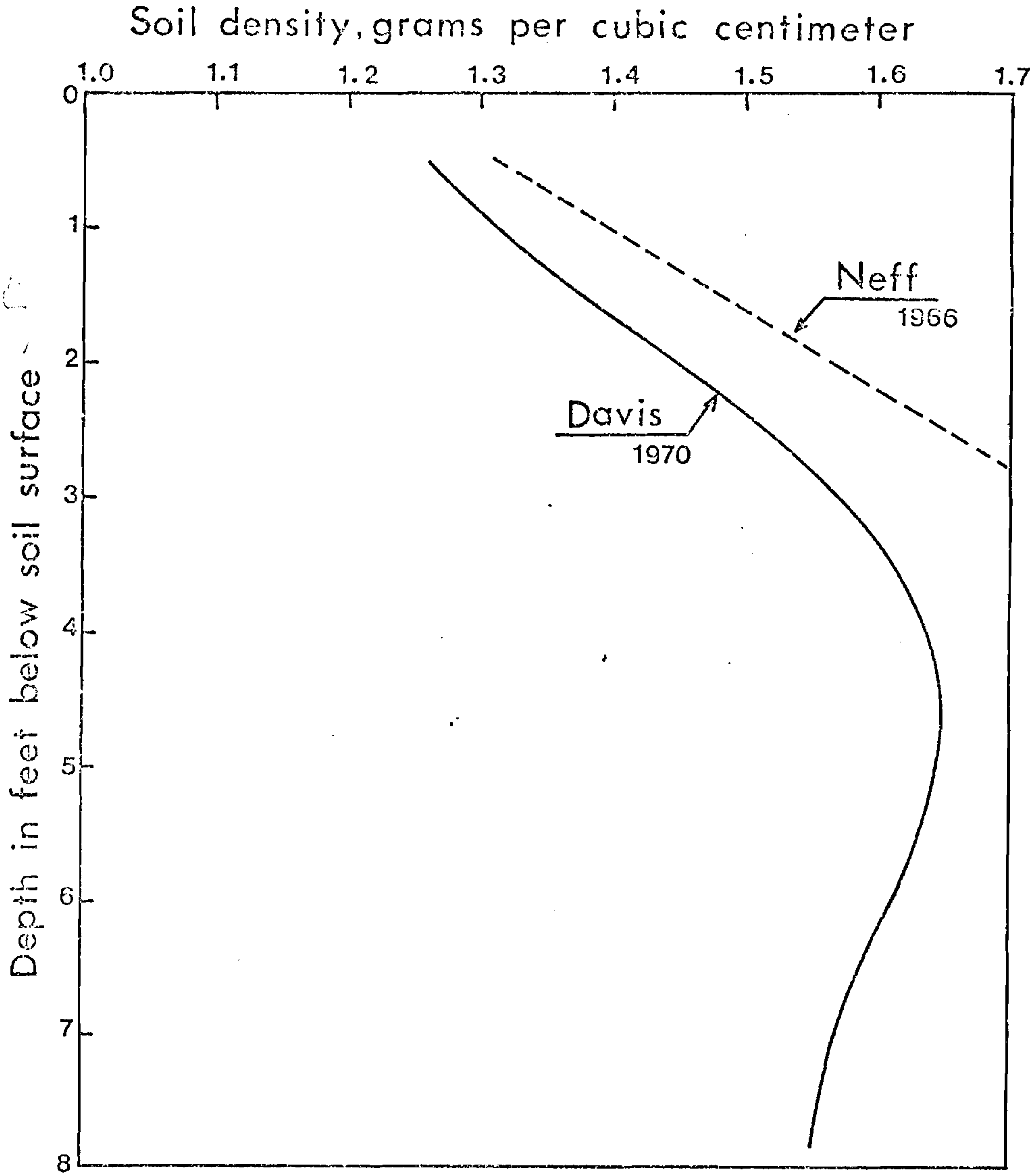


FIGURE 3: Average soil density profile for Thompson watershed near Moscow, Idaho.

that this soil probably does have a high moisture holding capacity. For the purposes of this study it will be assumed that 3.0 inches of moisture per foot of soil are available for crop use at the start of the growing season.

INSTRUMENTATION AND EXPERIMENTAL DATA

All of the data obtained during the 1969-70 and 1970-71 water years are included in Appendix B. Much of the data were punched on cards to facilitate routine calculations with the IBM 360 computer.

Water Budget Instrumentation

Precipitation was measured using a standard 8-inch precipitation gauge located at the instrument cluster. There is also a dual raingauge system located at the crest of the watershed. In theory the dual gauge should give a reasonably accurate value of moisture caught at the soil surface after the measured precipitation has been adjusted using the method developed by Smith and Hamon (1969). Since the crest of the watershed represents very little of the total area involved, it is believed that this measurement would give a poor indication of the average areal distribution of precipitation on the watershed. The standard gauge at the instrument cluster is located on a long gradual slope. For this reason it was decided that precipitation values obtained from this gauge would be more representative of the average areal distribution than those obtained from the dual gauge. Neff (1967) suggested that a correction of rain gauge data should only be made as dictated by accuracy of the other parameters of the project. He found that a gauge located on a 30% slope would catch 10% less than the soil and a gauge on the crest of a ridge would receive 16% less than the soil. Since the gauge at the Thompson watershed is located along a gentle slope, somewhat less than 30%, no correction was applied to the measured values. An average accuracy of 10% is reasonable for annual precipitation. During the winter when most of the precipitation is snow accompanied by wind the accuracy of measurement is probably 20% to 30% at best.

Surface runoff was measured with a Stevens water level recorder on a drop-box weir. The stage-discharge relationship was checked using a bucket of known volume and a stop watch. An adjusted rating curve was drawn using these measured flows. Accuracy of this parameter is limited by a leak in the cutoff wall. This wall extends nine feet below the channel bottom to intercept and bring to the surface any subsurface flow. The leak is only a trickle. The flow passing over the weir on February 24, 1971 was measured at 0.003 inches per day and appeared to have approximately the same discharge as the leak. During a month this leak could amount to 0.1 inches of unmeasured interflow or runoff. Since 2 to 3 inches of surface runoff were measured for the two months that had flow nearly all month, an error of about 5% can be attributed due to the leak.

Soil moisture was measured to a depth of 3 feet by the gravimetric method during the summer of 1970. In October 1970 six access tubes were installed to allow measurement of soil moisture to a depth of 7 feet using a neutron probe. A Nuclear-Chicago probe and scaler was used from October

1970 to January 1971, and a Troxler unit after January 1971. The calibration of both probes was checked during the year by gravimetric methods. Measurements were taken at 6-inch intervals down to 3 1/2 feet and at 12-inch intervals on down to a depth of 7 feet. Measurements were made monthly during the winter and weekly during the summer. Accuracy should be close to 5%.

Energy Budget Instrumentation

Air temperature and humidity were measured with a hygrothermograph. Recorded temperatures were checked using maximum and minimum thermometers. The average daily temperature is the average of the daily maximum and minimum temperatures. Recorded humidity was checked using an aspirated psychrometer each time the chart was changed, except when the temperature was below freezing. The mean daily humidity was obtained by averaging the area under the recorded curve for each day. All values for humidity were read to the nearest 2%. Air temperature is probably accurate to within 2F° and humidity to within 2%.

Pan evaporation, water temperature and wind movement are all used for determination of evapotranspiration using methods of energy balance and mass transfer. Evaporation was measured in a standard 4-foot diameter pan connected to a Stevens water level recorder for a continuous recording of the water level. The recorder float was located in a vertical 16-inch culvert pipe which was connected to the pan by a 1-inch pipe. Two pints of mineral oil were put in the culvert to prevent evaporation from this water surface. There is a consistant error in this system of measurement that must be corrected. The volume of water removed from the pan when E inches of evaporation occurs is:

$$V = (\pi/4)(48)^2E \quad \text{cubic inches.}$$

But while evaporation is occurring from the water surface of the pan additional water moves to the pan from storage in the 16 inch culvert pipe to maintain equal water elevations at both surfaces. After E inches of evaporation have occurred the water level in both the pan and the culvert pipe will be shown by the water level recorder to have dropped d inches. The volume of water removed may now be calculated as:

$$V = (\pi/4)(48)^2d + (\pi/4)(16)^2d.$$

Since both volumes are the same we can equate these two expressions and solve for the actual evaporation E,

$$E = 1.11d.$$

Therefore if the measured value is increased by 10% the actual evaporation is determined to within 1%.

A 24-point Honeywell recorder with Type-J thermocouples was used for hourly measurements of water temperature in the evaporation pan. Recorded values were periodically checked with a maximum-minimum thermometer in the pan. It was found that an average correction of 3F° must be added to the recorded values to make them correspond to the thermometer readings. The maximum-minimum thermometer in the pan was found to read to within a few tenths of a degree of another mercury thermometer used for checking. Shielding direct solar radiation from the temperature sensors did not have an affect on the values recorded. Therefore it was decided to apply the correction to the recorded temperatures. Water temperatures are probably accurate to within 2F°.

Daily wind movement is simply the wind speed integrated over a 24 hour period. The standard 3-cup anemometer converts wind movement into rotational motion. The rotation of the spindle drives the counter or readout device through a gear train. In the case of a recording anemometer the readout device is a pair of electrical contacts that can be used to send a pulse of current to a recorder. By using the proper gears in the gear train it is possible to calibrate the counter to read miles or other units as desired. Electrical pulses were fed into an Esterline-Angus event recorder which made a mark on the chart corresponding to each mile of wind movement. These marks were counted for each 24 hour period to obtain values of daily wind movement. Accuracy of measurement should be within 1 mile.

Solar radiation and soil heat flux are needed for computation of evapotranspiration by the Jensen-Haise and Penman equations. During the summer of 1970 an Eppley pyranometer coupled to a Bristol recorder was used at the watershed to measure solar radiation. During the winter of 1971 the pyranometer was sent to the factory to be checked and calibrated. For the growing season of 1971 this pyranometer was coupled to a Lintronic Mark V digital volt-time integrator and located on the roof of the Buchanan Engineering Laboratory on the University campus. It is believed that even though the pyranometer is located 6 miles from the watershed, the readings are representative of both locations. Accuracy of radiation values should be within 5%.

Soil heat flux was measured using two Thornthwaite heat flux discs wired in series to a Bristol recorder. The discs were placed 1-inch below the soil surface in the barley field. Accuracy of soil heat flux values is probably 20% at best. However, an error of this magnitude for net heat flux presents no problem since the magnitude of the net heat flux during a week will be less than 1% of the total radiation involved.

Correlation Analysis of Climatic Parameters

Occasionally it is desirable to extend climatological records at a particular location using data from stations in the surrounding area. As a test of the feasibility of doing this for the Thompson watershed, several climatic parameters were chosen for regression analysis. The three parameters chosen for this analysis were air temperature, precipitation and pan evaporation. The results of this analysis are presented as Table 1.

TABLE 1

Regression Analysis of climatic parameters for the Thompson Watershed and University farm.

Parameter	Regression Equation	R^2
Weekly Temperature	$T_1 = -1.89 + 1.02\ T_2$	0.990
Weekly Precipitation	$P_1 = +0.01 + 0.88\ P_2$	0.903
	$P_1 = +0.07 + 1.06\ P_3$	0.935
Weekly Evaporation	$E_1 - -0.52 + 1.12\ E_2$	0.697
Daily Evaporation	$E_1 = +0.10 + 0.34\ E_2$	0.172

Subscripts are used as follows:

1 for gauge located at Thompson watershed

2 for gauge located at University farm

3 for the shielded precipitation gauge at Thompson Watershed

The R^2 term in a regression analysis is an indicator of the fraction of the variance accounted for by the regression equation. If the value drops below 0.50 then less than half of the variance can be explained and a value of the dependent variable calculated using the regression equation will probably be significantly different from the measured value. Whether or not this difference is acceptable depends greatly on the accuracy of the measured data used in the equation and the desired results.

The weekly temperature at the Thompson watershed and the University farm showed a good correlation. This should be the case for two reasons. First, the time base of one week is long enough to smooth out any errors in daily measurements. Second, the weekly mean values at both locations come from representative populations which should have the same statistical trends.

The regression analysis of weekly precipitation for the standard gauge at the Thompson watershed was done twice, once using data from the standard gauge at the University farm as the independent variable and then using data from the shielded recording gauge at the Thompson watershed as the independent variable. Both regressions resulted in high correlations. Probably the samples taken in these tests were representative of similar statistical populations.

Both weekly and daily evaporation had a low degree of correlation. There are two major factors that would cause a poor correlation for pan evaporation between the two locations. First, different techniques were used to account for rainfall catchment in the evaporation pan. At the University farm the precipitation measured in the standard precipitation gauge was used for the amount of water added to the pan by rain. This is the standard meteorological practice used at most stations. At the Thompson watershed the water level was continuously recorded on a chart which allowed direct measurements of rainfall catchment by the pan. An examination of the data from both stations indicates nearly equal evaporation on days of no rainfall but consistently large differences in evaporation on days with measurable rain. This is probably the major cause for low values of R^2 for weekly evaporation. A regression analysis of weekly evaporation for weeks with and without rainfall would be desireable to illustrate this point. Such an analysis, using the small amount of data available, would be very difficult due to the fact that most weeks consisted of both days with and days without rainfall. However a regression analysis of daily evaporation should illustrate the fact that the method of accounting for rainfall added to the evaporation pan had an influence on the values of measured evaporation. Such analysis was made and the values of R^2 were <u>0.035</u> and <u>0.237</u> for days with and days without rainfall respectively. The large difference between these values of R^2 illustrates the importance of rainfall measurement technique on pan evaporation.

The second cause of a poor correlation for evaporation between the two locations was the difference in the hour of measurement. At the University farm most parameters are measured at 5:00 p.m. local time each day, but at the Thompson watershed all recorded data were measured from midnight to midnight standard time each day. This difference in time of measurement should introduce a consistant error of considerable size since warm temperatures and strong wind usually continue during the late afternoon and evening. The magnitude of this error will vary from one day to the next. The regression analysis for daily evaporation indicates a very low R^2 value even when compared with weekly evaporation. This indicates that the data for daily evaporation are independent and therefore represent different populations.

EQUATIONS OF THE WATER BALANCE

Water Balance Equation

The basic water balance equation can be written as

$$P = SS + Q + ET + SM + DP$$

where P is precipitation, SS is the change in surface storage, Q is surface discharge, ET is evapotranspiration, SM is the change in soil moisture storage and DP is loss to deep percolation.

Precipitation comes in the form of rain during the fall, snow during the winter and resumes as rain during the spring and early summer. Fairly high intensities of 1-inch per hour lasting 5 to 10 minutes sometimes occur from thermal convection storms in the summer. Accuracy of measurement is probably within 10% during most of the year. During the winter the probable error will increase to as much as 20% due to the sensitivity of snow catch to wind.

Surface storage of snow is an important factor during the winter and can amount to more than 1-inch of water. Snow is often not uniformly distributed over the field. Often there will be only a few inches of snow on the crest of the hill at the watershed boundary when there is more than a foot at the instrument cluster. By measuring the depth and density of the snow at several locations a representative value for surface storage can be obtained for the watershed. This measurement can be made at each site where soil moisture is being measured. Accuracy of measured surface storage is within 10% if the density determination of the snow is made carefully.

Surface discharge usually begins in January during the first break in cold weather. During the first day or two the melt is absorbed by the snow or infiltrates into the soil. Runoff begins when saturation of the soil is reached and continues until the surface storage and interflow are depleted, usually in March. Flows during this period are steady and moderate to low, usually less than 0.1 cfs. If, however, a rain of moderate to high intensity comes during the period of snow melt runoff, then considerably greater flow will occur. The storm of March 23, 1971 came at such a time and resulted in a peak discharge of 0.7 cfs. Runoff will occasionally occur from a heavy rain in June, but the rainfall must be of high intensity with a relatively high antecedent moisture condition in the soil. Usually the duration of these storms is too short for runoff to result. Accuracy of measured surface discharge is within 10%. Much of this error is caused by seepage through the cutoff wall.

Evapotranspiration is assumed to be negligable during much of the winter due to low temperature and high humidity. During the four months of December through March the mean monthly temperature was at or below 32°F and the mean monthly humidity was over 75%. Evapotranspiration during the summer, however, becomes the largest component in the water balance equation. In June it is moderated by heavy clouds, in July it reaches a peak and in August it drops due to crop maturity. Four different methods were used to determine evapotranspiration. These methods include (1) measurement of the change in soil moisture, (2) estimation from pan evaporation, and calculation from climatic data using the (3) Penman and (4) Jensen-Haise equations.

Soil moisture measurements, starting at a depth of 6-inches and continuing downward at 12-inch intervals, were averaged for all six sites on the watershed. These data were punched on IBM cards and analyzed on the computer. The printout consisted of a summary of soil moisture in inches per foot. A copy of the computer program is included as Appendix C . These results were used to prepare Figure 4 which illustrates the average distribution of soil moisture for the watershed on several dates. Soil moisture stored in the root zone was at a minimum during late summer and early fall. Recharge began in late fall and continued through spring. Maximum total storage occurred early in June. During the growing season the soil moisture was rapidly depleted by the crop as illustrated by Figure 5. The computed changes in soil moisture should be within 5% of the actual values. The accuracy of measurements using the Nuclear-Chicago and Troxler probes is 6% and 3% respectively, based on variations in the standard count.

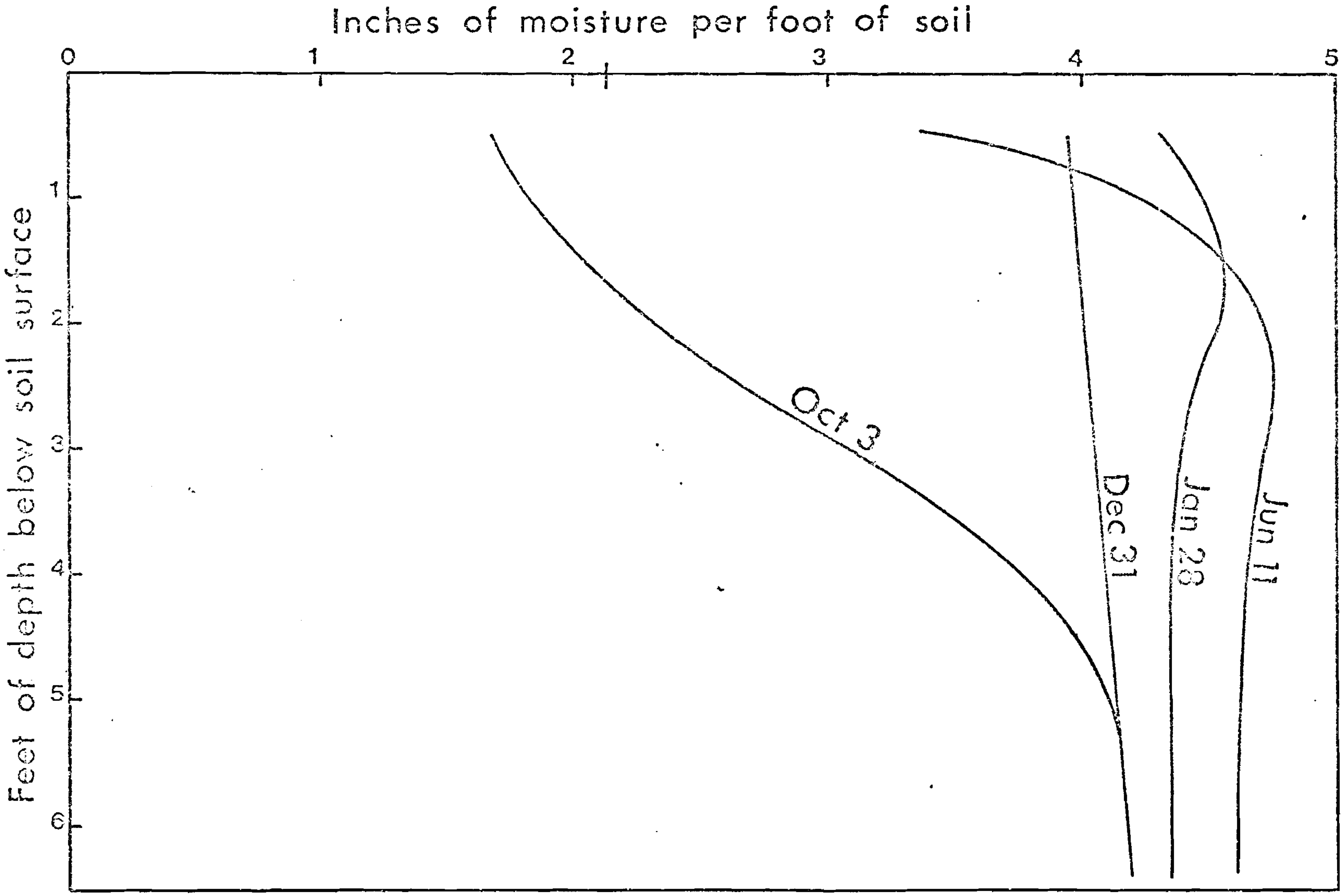


FIGURE 4: Soil moisture profiles during recharge. Thompson watershed, 1970-1971 wateryear.

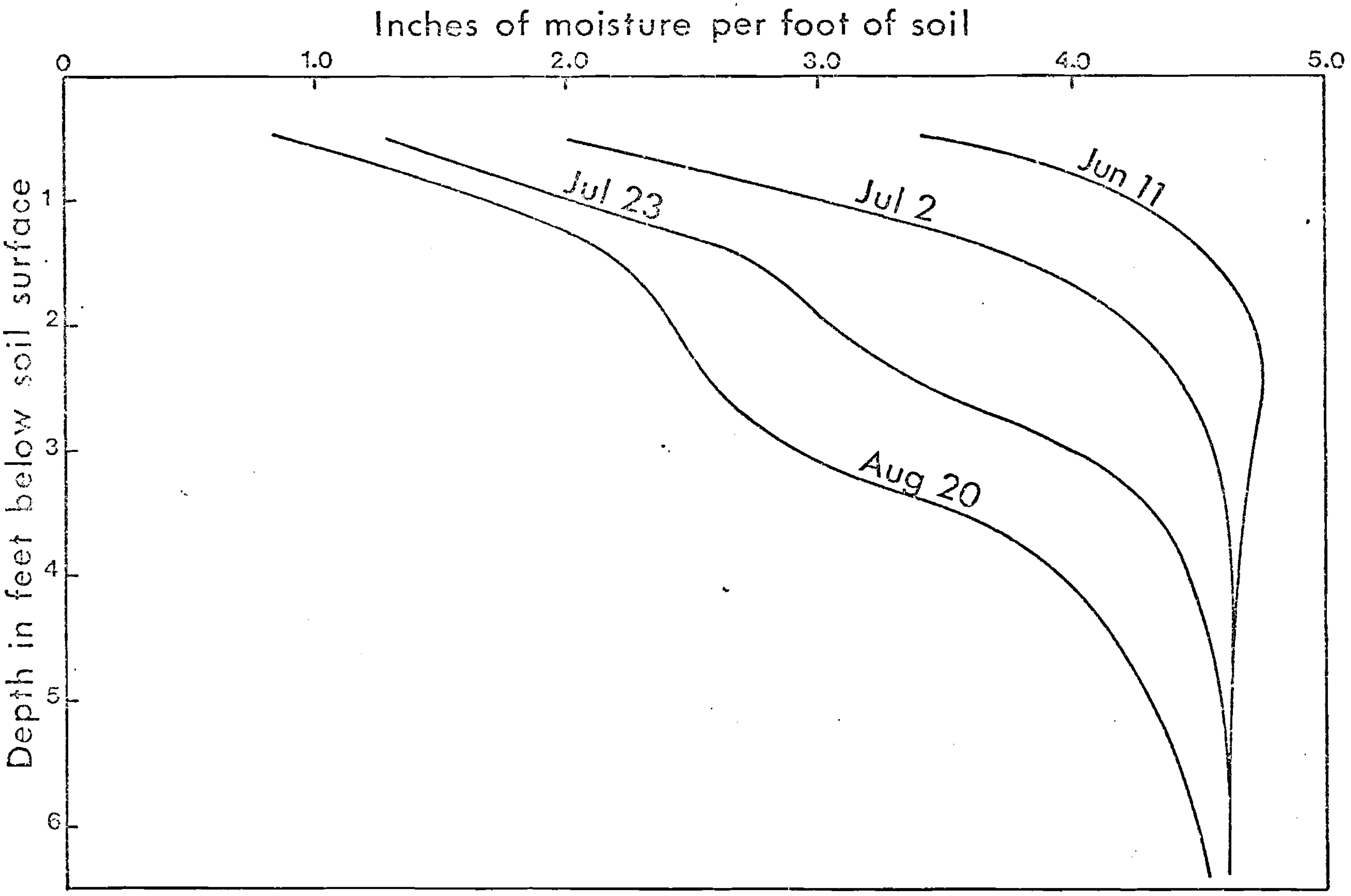


FIGURE 5: Soil moisture profiles during consumptive use. Thompson watershed, 1970-1971 wateryear.

Deep percolation is the downward movement of moisture out of the upper soil. The magnitude of this downward movement of water was not measured, and it is therefore the unknown value in the water balance determination. Because no measured value is available its accuracy depends on the net total effect of the errors for the other components of the water balance. Before a definite value can be assigned to deep percolation sufficient data is needed to evaluate the hydraulic properties of this soil. These data can be obtained from samples taken at different depths and sites. From this information a flow model could be developed that is typical for the watershed. This model could then be checked using the water balance.

Determination of Evapotranspiration

One of the most accurate methods for determining evapotranspiration is by measuring changes in soil moisture storage. During the summer months of June, July, August and September it is usually true that $SS = Q = DP = 0$. If this assumption can be accepted then the water balance equation may be shortened to $P = ET + SM$. This equation can be solved for evapotranspiration to give

$$ET = P - SM.$$

Both the precipitation and soil moisture can be measured, the evapotranspiration can be calculated. During much of the summer there is no precipitation, thus the equation can be further simplified to

$$ET = - SM.$$

In this last case the accuracy of the calculated evapotranspiration will be as good as the accuracy of the measurement of changes in soil moisture, about 5%.

Another method used to determine evapotranspiration employs the standard evaporation pan. An estimate of the evapotranspiration can be obtained by multiplying the measured evaporation by a coefficient of crop growth. This equation can be written.

$$ET = Kc\ (Ep)$$

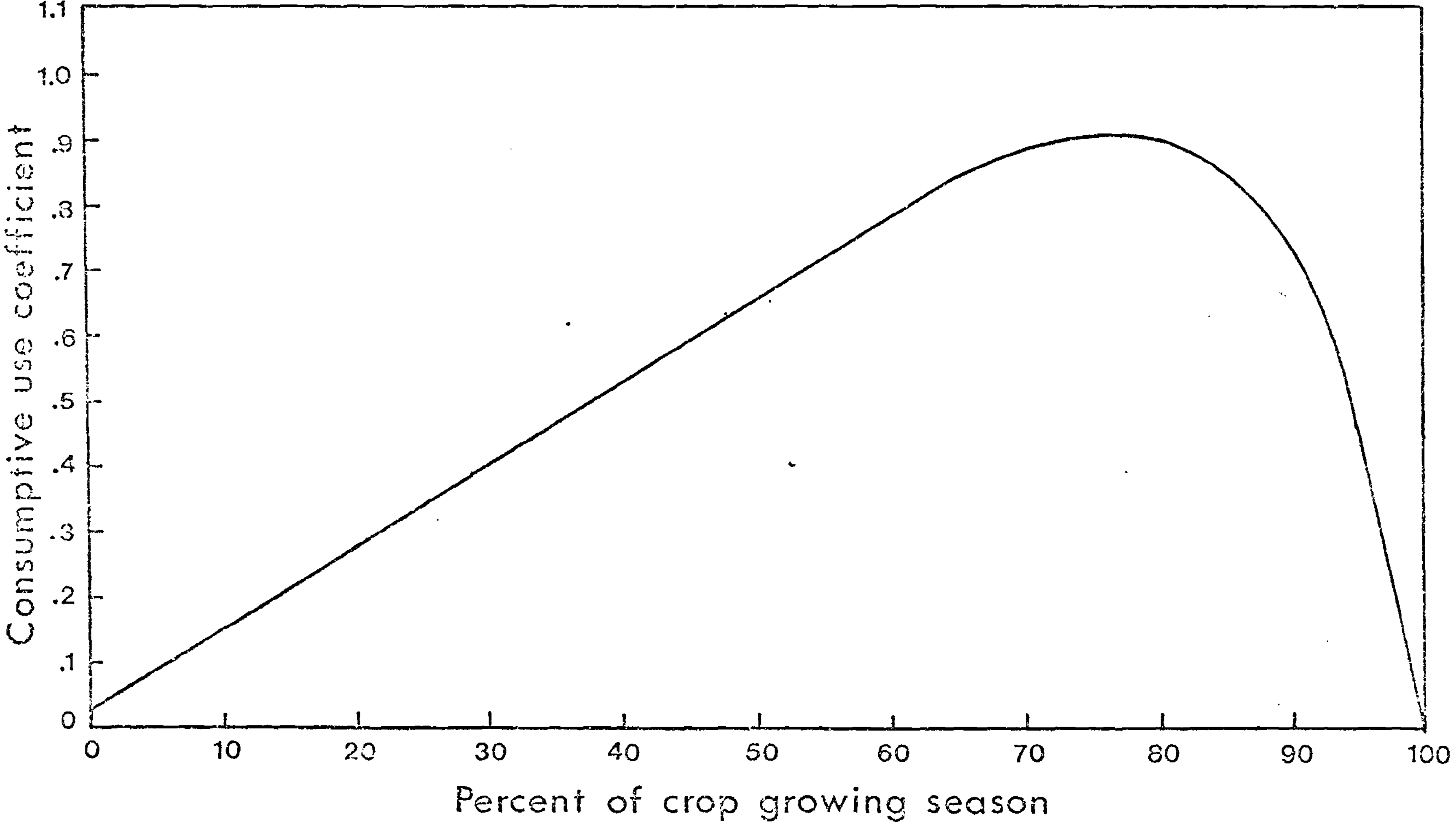
where ET is the estimated evapotranspiration, Kc is a crop growth coefficient and Ep is the measured pan evaporation. A curve of crop coefficients for use with pan evaporation is illustrated in Figure 6. This method is not as accurate as the other methods since only one measured parameter, pan evaporation, is used. The use of this method is questionable for dry land farming because advected energy is not properly accounted for particularly when soil moisture tensions are high.

The Jensen-Haise method uses two parameters, solar radiation and air temperature, to compute evapotranspiration. The equation is

$$PET = Ct\ (T-Tx)\ Rs$$

where PET is the potential evapotranspiration, Ct is a temperature coefficient, T is air temperature, Tx is a base temperature at which evaporation will cease and Rs

FIGURE 6: Consumptive use coefficients to be used with measured or calculated pan evaporation. (Paper presented by Hargraves, Irrigation-Drainage Conference, Las Vegas, 1966)



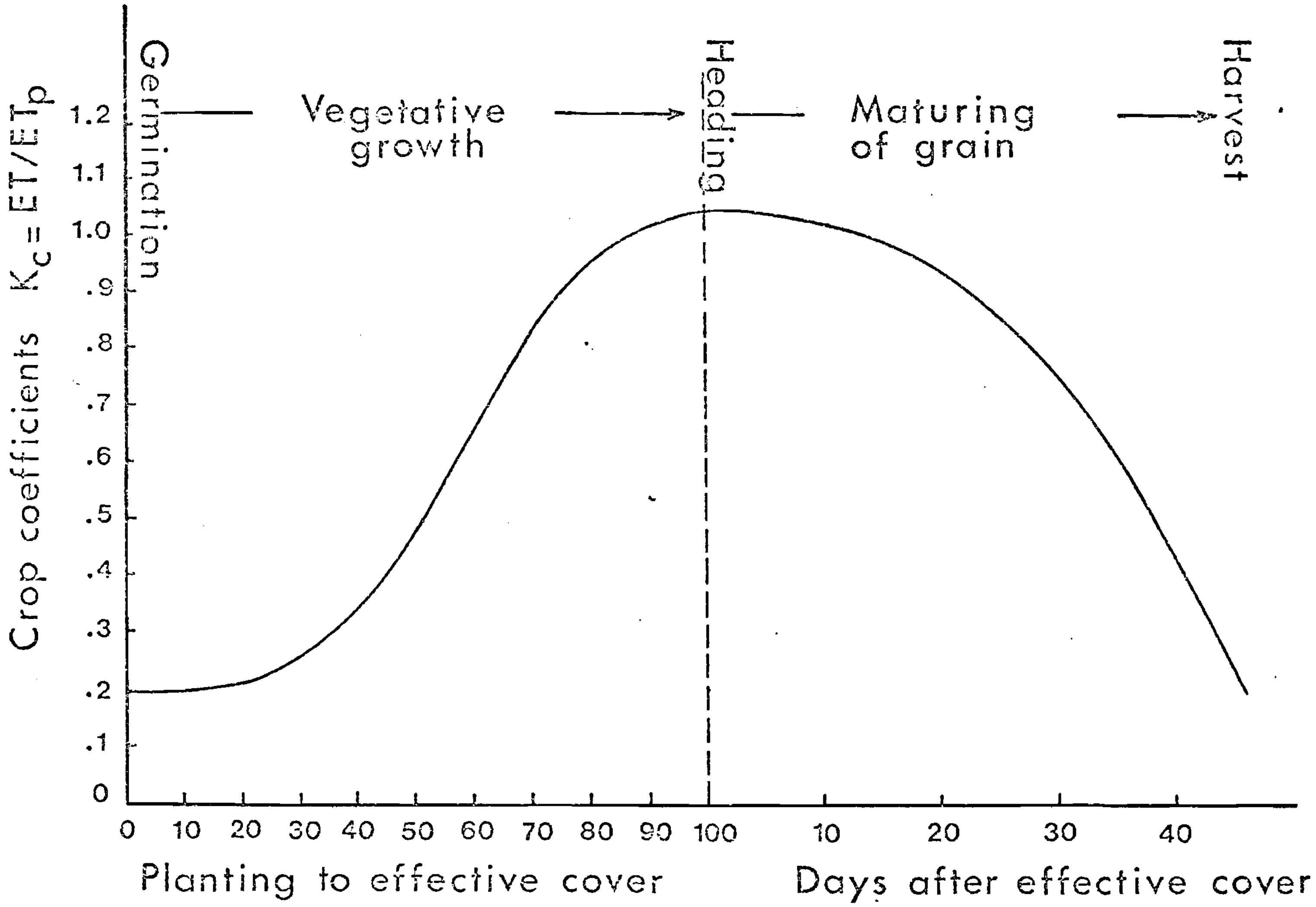
is solar radiation. A crop coefficient is needed to adjust the potential to the actual evapotranspiration. The curve of crop coefficients used in this thesis for both the Jensen-Haise and the Penman equations is illustrated in Figure 7.

The Penman method (Jensen and others, 1970) is considered the most accurate method for determining potential evapotranspiration using climatic data. The form of the Penman equation most often used involves a combination of the concepts of the energy balance and mass transfer. The equation can be expressed as

$$PET = Ke\ (Rn-G) + Kt\ f(u)\ (es-ed)$$

where Ke is a coefficient for the energy terms, Rn is net radiation, G is soil heat flux, Kt is a coefficient for the transfer terms, f(u) is a function of wind speed, and es-ed is the vapor pressure deficit in the atmosphere. Both of the coefficients, Ke and Kt, involve several other terms. The exact terms for this equation in all its forms can be found in many research papers dealing with this subject (Ward 1971, Rijtema 1965). The Penman equation attempts to give a complete explanation for the evaporation process using the significant physical parameters. The complexity of the relationship is evidenced by the number of parameters required. The same crop coefficient used for the Jensen-Haise equation must be applied to the Penman equation in order to obtain the actual evapotranspiration.

FIGURE 7: Crop coefficients for small grains at all stages of development. (From chapter five, Sprinkler Irrigation, third edition.)



All of the equations for calculating evapotranspiration can be reduced to a form involving only two factors.

$$ET = K(PE)$$

where PE is a measure of the potential evaporative climatic demand. This term can be as simple as measured evaporation from a free water surface or as complex as Penman's equation for potential evapotranspiration. In all cases this evaporative potential must be modified by a crop coefficient (K) to account for the changing transpiration capability of the crop during its growth. Many investigations during the last two decades have used, modified and perfected both the crop coefficient and the evaporative potential terms.

There is a third coefficient that must be included when considering evapotranspiration in dry land agriculture. This is a soil moisture coefficient. Army and Ostle (1957) found that during years of low rainfall there was a negative correlation between pan evaporation and evapotranspiration. In the Palouse, where dry farming prevails the soil moisture during July is at a low level. The high soil moisture tensions that are implicit from such low levels of soil moisture, could be a limiting factor for evapotranspiration. With high temperature and low humidity the climatic demand causes rapid evaporation from the free water surface of the evaporation pan. The soil, however, may not be able to supply moisture at this rate and a pressure deficit in the plant could result in closure of the stomata of the leaf (Denmead and Shaw, 1962).

Many of the equations used to calculate evapotranspiration were originally developed to determine potential evapotranspiration, which by definition implies a continuously adequate supply of soil moisture. Where dry land farming occurs the soil moisture supply is only adequate during the period of early growth when incomplete crop cover invalidates effective use of many equations. Pierce (1958) developed a method for "adjusting" the Thornthwaite equation to account for soil dryness. Jensen and others (1970) have included an adjustment for available soil moisture in a formula for computing the crop coefficient. This formula is written

$$Kc = (Ka)(Kco) + Ks$$

where Kc is the crop coefficient used to adjust the potential evapotranspiration, Ka is a logarithmic function of soil moisture storage which is used to adjust the nonlimiting soil moisture crop coefficient (Kco) to account for the limiting effects of soil moisture tension. Ks is a coefficient to account for unusually high evaporation from the soil surface following a rain or irrigation. This last term can be ignored if little or no rain occurs during the growing season in dry land agriculture.

Results of Evapotranspiration Calculations

Values of evapotranspiration determined by four methods are presented in Table 2. The data from Table 2 was used to develop the curves of Figure 8. The ideal curve depicting water consumption by a crop will have a shape similar to the crop coefficient curves in Figures 6 and 7. The curves in Figure 8 follow this shape approximately and there appears to be good agreement between several of the curves. There are two important differences among the curves that are readily apparent. First, the peak for the pan evaporation method occurred about one week later than the peak for the other methods. This clearly indicates the importance of considering the effect of soil moisture as a limiting factor for evapotranspiration. This factor was not included in the crop coefficient applied to the evaporation. Second, there is a noticeable decrease in the evapotranspiration during the first part of July. During this period there were heavy clouds, near freezing minimum temperatures, high humidity and strong winds which caused some lodging of the grain. The combined effect of all these could have caused a reduced rate of evapotranspiration.

The results of the correlation analysis for the methods of determining evapotranspiration are presented at the bottom of Table 2. It is reasonable to assume that the change in soil moisture should give the most accurate picture since it is a direct measurement of moisture removal from the soil by the crop during most of the summer.

TABLE 2

Evapotranspiration in inches per day
for the Thompson watershed, 1971

Dates	Soil Moisture	Evaporation Pan	Jensen Haise	Penman
5/14				
	.004	.018	.033	.040
5/28				
	.125	.023	.075	.073
6/11				
	.193	.078	.183	.192
7/2				
	.179	.144	.196	.185
7/9				
	.150	.165	.219	.172
7/16				
	.230	.240	.243	.209
7/23				
	.204	.264	.185	.217
7/30				
	.171	.208	.127	.115
8/6				
	.103	.228	.088	.072
8/13				
	.083	.078	.025	.026
8/20				

Methods Correlated	R^2
Soil moisture and Pan Evaporation	0.384
Soil moisture and Jensen-Haise	0.686
Soil moisture and Penman	0.748
Jensen-Haise and Penman	0.920

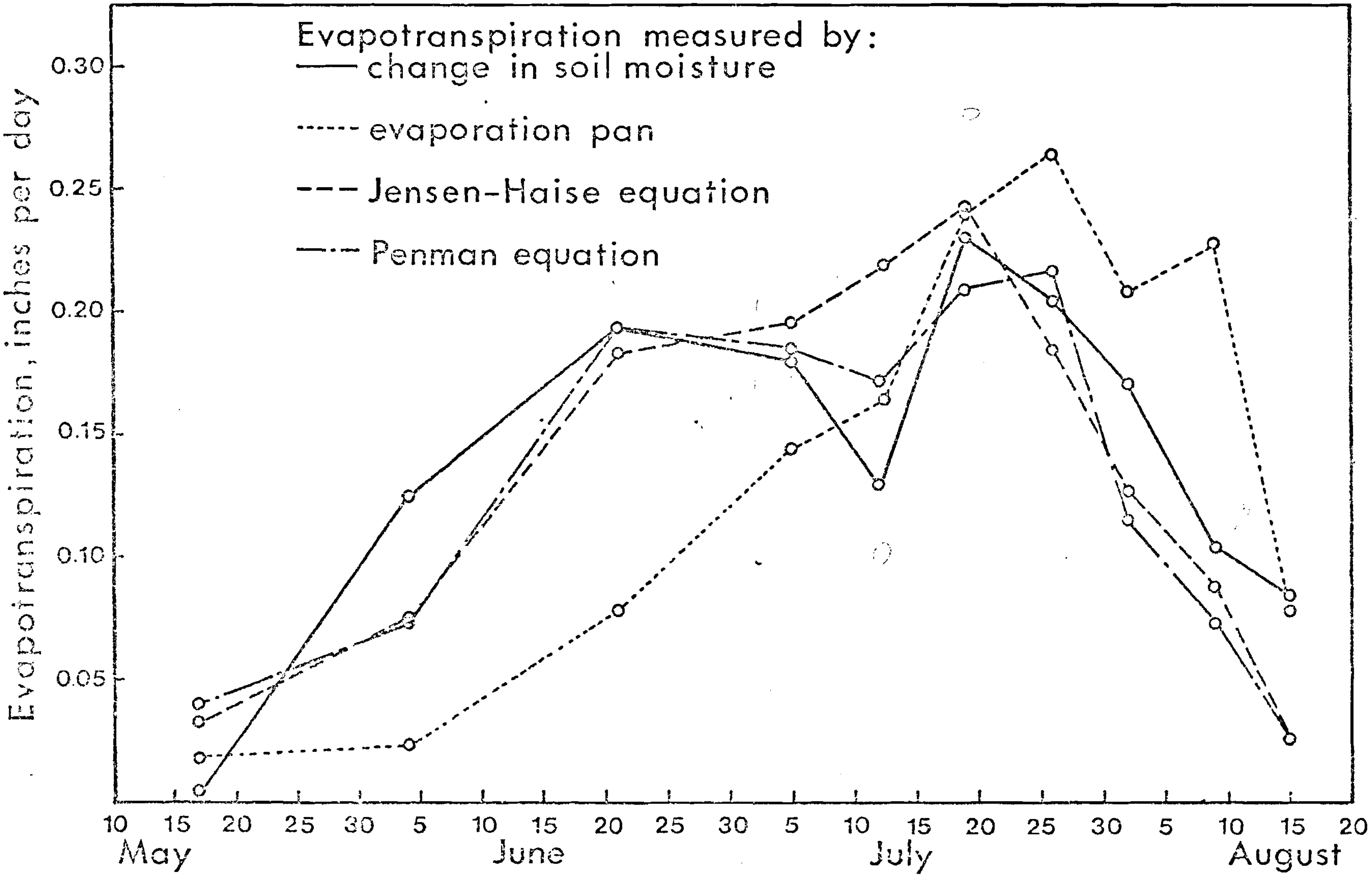


FIGURE 8: Evapotranspiration developed by four methods for barley at the Thompson watershed near Moscow, Idaho, 1971.

By correlating the change in soil moisture with each of the other methods a good idea of their correlation with actual evapotranspiration is obtained. Many good books on statistics list the minimum acceptable values of the correlation coefficient (R) for a given level of significance. For the correlations of evapotranspiration there were 8 degrees of freedom and the minimum allowable values of R are 0.765 and 0.632 for the 1% and 5% levels of significance respectively. The corresponding values of R^2 will be 0.585 and 0.399 respectively. The pan evaporation method had an R^2 value that is too low (less than that allowed at the 5% level). Therefore, this method is not acceptable in its present form as a method for determining evapotranspiration on the watershed. If the crop curve was adjusted with less skew to the left, it probably would give much better results. The Jensen-Haise and the Penman methods had values of R^2 significantly higher than the minimum required at the 1% level, and therefore these methods are acceptable for the present water balance. The good agreement between these two methods is illustrated by the high value of R^2. Both these methods could probably be improved by including Jensen's coefficient Ks to account for excessive surface evaporation during the rainy part of June. The evapotranspiration values used in the water balance portion of this study will be those obtained by measurement of changes in soil moisture.

WATER BALANCE RESULTS

Water Balance for 1969-70

During the water year 1969-70 a rough water balance was made on the Thompson watershed. The primary purpose of this water balance was to test the equipment that had been set up during that year. The report of this initial study (Molnau and Davis 1971) showed that the annual precipitation was divided so that 53% went to evapotranspiration, 17% to runoff and about 30% to deep percolation. These values indicate that normal cropping practices result in less runoff and more deep percolation than Bloomsburg (1959) found on adjacent land that was mostly forested and at a higher elevation.,

Water Balance for 1970-71

The water balance for the 1970-71 water year was ended on August 20, 1971 because the soil mantle had reached its minimum moisture content at that time. Each period between dates when soil moisture measurements were made constitutes a short period water balance. A summary of the short period water balance, is shown as Table 3.

All of the short period water balances presented in Table 3, with one exception, are from actual unadjusted field data. The values for each parameter are clearly of reasonable magnitude and can be assumed to fall within an accuracy range of 20%. The one exception occurred between December 31, 1970 and January 28, 1971. Some precipitation data during this period was missing, there-

TABLE 3

Water balances at the Thompson watershed near Moscow Idaho for periods indicated during the 1970-71 water year.

Date	P		SS	Q	ET	SM	DP
10/3							
	7.76	=	+0.69	0.0	0.0	+6.03	+1.04
12/31							
	3.54*	=	-0.69	+3.04	0.0	+1.99	-0.80
1/28							
	1.83	=	+0.42	+0.82	0.0	-0.21	+0.80
3/4							
	2.31	=	-0.42	+2.05	0.0	+0.18	+0.50
4/2							
	1.43	=	0.0	0.0	0.0	+0.28	+1.15
5/3							
	0.53	=	0.0	0.0	0.0	-1.48	+2.01
5/14							
	0.91	=	0.0	0.0	+0.06	+0.85	0.0
5/28							
	3.31	=	0.0	+0.38✓	+1.75✓	+1.18✓	0.0
6/11							
	1.67	=	0.0	0.0	+4.05	-2.38	0.0
7/2							
	0.08	=	0.0	0.0	+1.25	-1.17	0.0
7/9							
	0.65	=	0.0	0.0	+0.91	-0.26	0.0
7/16							
	0.00	=	0.0	0.0	+1.61	-1.61	0.0
7/23							
	0.0	=	0.0	0.0	+1.43	-1.43	0.0
7/30							
	0.53	=	0.0	0.0	+1.20	-0.67	0.0
8/6							
	0.0	=	0.0	0.0	+0.72	-0.72	0.0
8/13							
	0.0	=	0.0	0.0	+0.58	-0.58	0.0
8/20							
TOTALS	23.72	=	0.0	+6.29	+13.56	0.0	3.87

*There was data missing for this parameter during this period. The value shown was obtained using the regression equation for the shielded precipitation gauge at the watershed. The shielded gauge was chosen for this computation because of the high degree of correlation between the standard and shielded gauges at the Thompson watershed.

fore, the regression equation was used to obtain a reasonable value for the precipitation.

A more serious problem exists for the short period mentioned above. A negative value is indicated for deep percolation. This implies upward flow which is an unlikely situation during this period when greatest recharge is occurring. Therefore, one or several of the other parameters contains a large error. To determine the probable magnitude of this error a reasonable value for deep percolation during this period was adopted from a comparison with other similar periods. The two following periods were chosen since they also were characterized by long intervals of total surface saturation and nearly continuous runoff. The average daily rates of deep percolation for the later two periods both fall within 15% of their average value of 0.02 inches per day. If this rate of recharge is applied to the 28 day period in question a value of 0.56 inches is obtained for deep percolation. For this value to exist there must be an error of 1.36 inches in the other terms of the water balance equation.

There are five terms, not including deep percolation, in the water balance equation. Each of these five terms has a maximum probable error, and the magnitude of these errors in inches for this period are:

Precipitation	0.2
Change in surface storage	0.1
Evapotranspiration	0.1
Change in soil moisture	0.1
Surface discharge	0.3

Assume that all of these errors accumulated in such a manner that the maximum probable total error of 0.8 inches occurred. This would have accounted for only part of the 1.36 inches needed to accept the deep percolation value of 0.56 inches obtained by using the average rate of deep percolation for the following months. If the maximum probable error of 0.8 inches is included in the water balance the result would be no deep percolation during this period. Deep percolation must have occurred, however, since soil moisture measurements and observation well records indicate that this was a period of recharge. If further assumptions are made that allow distribution of additional error to the five terms, there is a good chance that by doing this the water balances for the other short periods would be disturbed. Since the other short periods have reasonable values for each component, addition of more error to the five terms can not be justified. The terms for the short period in January do not balance. Further study must be made during succeeding years to determine how much deep percolation can occur at this time of year.

The results of the total water balance indicate that the precipitation was distributed as 27% runoff, 57% evapotranspiration and 16% deep percolation. These figures are very close to those obtained by Bloomsburg (1959).

Analysis of Probable Errors

The annual totals for the various factors of the water balance for 1970-71 are reasonably close to those obtained at Thompson watershed for 1969-70 and by Bloomsburg (1959) for Crumerine Creek. This implies that the measured values of the factors are probably not too far from their actual values. By how much they differ is an important question.

An estimate of the probable accuracy of the measured value for each factor of the water balance equation was stated earlier. Since these measurement accuracies are not the same, it can be expected that the probable error of the values assigned to the factors will not be the same. Also, the significance of these errors will vary according to the relative magnitude of the value of each factor. Therefore, the measurement accuracy of each factor must be weighted before the relative accuracy becomes clear. There is no measurement accuracy for deep percolation because it was not measured. Since its relative accuracy is dependent on the combination of the other factors, its probable error can be at least as large as the largest error of any other factor. Table 4 is a summary of the weighted relative accuracies and magnitudes of error for the four factors that remained significant throughout the water year.

TABLE 4

Relative accuracy and magnitude of error for the water balance factors at the Thompson watershed, 1970-71.

Factor	Relative Magnitude	Measurement Accuracy	Relative Accuracy	Magnitude of error
Precipitation	100%	10%	10%	3.0 inches
Surface discharge	27	10	2.7	.8
Evapotranspiration	57	5	2.8	.9
Deep percolation	16	*	10	3.0

The relative accuracy is simply the product of the relative magnitude and the measurement accuracy. A value of 30 inches for annual precipitation can be assumed for a typical wetter than normal year. The magnitude of maximum probable error for each factor for such a year is equal to the product of 30 inches and the relative accuracy. Let us assume that an accuracy within 1-inch for each factor of a water balance study of the type at the Thompson watershed is a reasonable goal. Then, as shown in Table 4, the allowable error is exceeded for precipitation and deep percolation measurements. These two factors, therefore, should be studied in more detail.

The two factors, surface and soil moisture storage, appeared only in the short period water balances. Probable errors for both of these are low and further study to improve their accuracy is not practical at this time.

RECOMMENDATIONS

There are several recommendations that should be made for future studies at the Thompson watershed. The following list enumerates these recommendations.

1. A more accurate measurement of actual catch of precipitation on the watershed is needed. This should take into account the differences between gauge catch and soil catch, and the areal distribution of moisture. A study of data collected by the duel gauge system should be made to determine the catch at the soil surface along the crest of the watershed. To determine moisture catch on the larger sloping portion of the watershed the standard (or other) gauge should be placed about 100 feet south of the instrument cluster in order to avoid unusual wind currents. At this location it should be possible to apply a simple correction to the gauge catch to obtain a good value for surface catch.
2. Deep percolation must be considered in more detail to determine a reasonable rate of recharge. Soil samples should be taken from several sites to analyze the hydraulic properties of the soil mantle. A recharge model can then be developed. This model can be compared with deep percolation measured by the water balance equation.

3. The assumption that gauge precipitation can be used as a measure of rainfall added to the evaporation pan appears to be invalid. A study is needed to check the validity of this assumption.
4. Comparison of the water balance at the Thompson watershed with other water balances in the Palouse region is needed. Only after such a comparison is made will it be possible to draw conclusions about water use in this region.

CONCLUSIONS

During the 1969-70 water year instrumentation was installed to begin a water balance study on the Thompson watershed near Moscow, Idaho. A water balance was made for this initial year using many rough estimates for some of the water balance factors.

There are several conclusions that can be drawn from the water balance study at the Thompson watershed during the water years of 1969-70 and 1970-71. These conclusions can be summarized as follows.

1. The relative magnitudes for the various components of the hydrologic cycle were determined for the 1970-71 water year. The precipitation was distributed 57% to evapotranspiration, 27% to surface runoff and 16% to deep percolation.
2. The relative accuracies for the components of the water balance equation, expressed as a percentage of the total precipitation, were determined. It was found that components of precipitation and deep percolation could each have an error as great as 10% and that the components of surface discharge and evapotranspiration would each have a probable error of less than 5%.
3. Several methods for calculating evapotranspiration using climatic parameters were compared with evapotranspiration determined from measurements of changes in soil

moisture storage. The Jensen-Haise and Penman equations were found to give a good estimate of evapotranspiration and can be used to predict evapotranspiration if consideration is given to soil moisture as a limiting factor in the crop coefficient.

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APPENDIX A

Glossary of Terms

GLOSSARY OF TERMS

Anemometer - an instrument used to measure the movement of air, usually the horizontal component, over a field or a water surface.

Aquifer - a water bearing strata in the soil.

Available soil moisture - the portion of the total moisture content of the soil that can be extracted by the plant.

Consumptive use - same as evapotranspiration.

Crop coefficient - the fractional relationship between the actual and potential evapotranspiration which is affected by the stage of growth of the crop.

Drop box weir - a weir that was designed so that all sediments would pass through and thereby maintain a constant stage-discharge relationship.

Dry farming - or dry land agriculture uses precipitation as the only source of moisture for crop growth.

Evapotranspiration - is the sum of the evaporation of water from plant and soil surfaces, and the transpiration of water extracted from the soil by the plant. Consumptive use is another term used to express the same meaning.

Field capacity - a term that was used to give a measure of the upper storage limit of the soil after all gravitational water had drained away. Another term, wilting point, was used to express the lower limit of soil moisture storage extractable by plants. Between these two moisture levels was the total available moisture for plant growth.

Hydrologic cycle - a concept used to describe all the possible paths that water might take when changing from state to state and moving from place to place or in the earth. Some of the more important terms used to describe the movement of water in the hydrologic cycle are precipitation, surface runoff, evapotranspiration, deep percolation, groundwater flow.

Loess - is a fine textured soil that was transported and deposited by wind.

Lysimeter - an instrument used to measure the actual moisture removal from the soil by plants.

Potential evapotranspiration - the maximum possible rate of evapotranspiration that could occur if soil moisture was not limiting and the crop canopy completely covered the soil.

Pyranometer - an instrument used to measure the total radiation from the sky.

Root zone - the layer of soil in which most of the plant roots are located and from which the major part of the extracted soil moisture comes.

Soil moisture storage - is the amount of moisture filling the void spaces in the soil.

Soil moisture tension - a measure of the effort required extract moisture from soil moisture storage. As the amount of moisture stored in the soil decreases it becomes increasingly more difficult to remove additional amounts of moisture.

Thermocouple - an instrument that measures the change in current produced by a change in temperature at the juncture of two dissimilar metals.

Water year - begins on October 1 and goes to September 30 in the arid regions of the United States. This allows delayed stream flow during the late summer to be included in the same year that the major precipitation source occurred.

Watershed - the drainage basin or catchment area.

Water use coefficient - same as crop coefficient.

APPENDIX B

Project Data for 1969-70 and 1970-71

TABLE B-1

WATER LEVELS IN OBSERVATION WELLS

Thompson Watershed, Moscow, Idaho (1970)

Well Number	1	3	4
Elevation of Soil Surface, feet	2790	2835	2840
Depth of Well, feet	74	29	26
Date of Measurement	Depth to Free Water Surface, Feet		
Jan. 2	36.0	--	15.0
Jan. 20	0.5	0.2	8.5
Mar. 5	6.5	2.0	11.5
Apr. 2	2.0	1.5	10.5
Apr. 9	7.0	2.0	11.0
Apr. 16	8.2	2.2	11.7
Apr. 22	12.6	3.2	13.6
May 3	9.2	2.8	13.8
May 14	19.7	8.5	13.6
May 28	34.5	14.2	15.7
Jun. 11	3.0	1.0	8.0
Jun. 18	6.6	2.2	11.0
Jun. 25	9.7	--	--
Jul. 2	25.5	17.2	12.3
Jul. 9	34.5	28.4	13.2
Jul. 16	36.0	*	13.5
Jul. 23	--		14.0
Jul. 30	--		14.5
Aug. 20	--		15.8
Aug. 27	37.8		16.4
Oct. 1	38.8		18.0

*There was no free water in this well on this day and during succeeding weeks.

TABLE B-2

MEAN DAILY RELATIVE HUMIDITY, PERCENT

Thompson Watershed, Moscow Idaho (1970-71)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	51	68	62	84	80	82	58	42	99	--	44	84
2	--	--	88	87	86	74	61	44	92	66	38	82
3	--	--	87	86	70	92	62	53	96	58	54	80
4	--	--	76	80	70	72	50	74	81	62	44	58
5	--	78	73	79	69	87	36	78	70	78	50	40
6	--	87	69	80	72	66	48	66	60	68	63	82
7	--	100	78	95	58	76	72	45	72	56	46	60
8	--	92	78	93	58	78	36	60	70	54	46	40
9	--	95	93	87	74	92	67	46	64	77	42	56
10	78	79	80	78	88	92	66	44	94	78	34	41
11	67	90	82	82	78	76	82	30	76	68	32	52
12	67	98	70	84	59	80	62	44	68	62	32	40
13	60	87	60	73	84	96	38	56	92	52	31	46
14	39	66	76	82	72	90	58	54	76	52	34	50
15	41	54	80	90	74	84	66	56	68	60	36	44
16	35	85	72	88	62	68	56	66	72	60	34	38
17	30	88	86	82	77	80	95	70	68	54	38	29
18	52	98	99	90	88	70	87	65	92	52	32	34
19	66	94	76	92	98	59	73	70	74	48	28	30
20	64	80	67	78	88	64	70	60	78	64	42	38
21	68	70	88	68	78	64	77	42	68	54	46	40
22	70	60	67	88	94	84	95	52	72	54	22	34
23	79	90	86	84	86	95	100	62	74	56	68	27
24	77	94	94	68	84	75	100	60	68	48	44	50
25	87	94	75	88	80	74	54	76	86	54	34	74
26	77	90	65	82	74	72	42	74	66	52	36	64
27	62	94	74	82	92	84	56	64	70	52	35	62
28	54	100	86	78	86	82	70	38	78	46	40	58
29	52	85	82	63	--	74	70	64	--	50	40	62
30	52	93	87	82	--	82	58	34	--	44	38	60
31	65	--	79	82	--	72	--	94	--	46	70	--
SUMS	1393	2309	2435	2555	2174	2437	1965	1833	2144	1725	1323	1555
MEANS	60.6	85.5	78.5	82.4	77.6	78.6	65.5	59.1	76.6	57.5	42.7	51.8

TABLE B-2 (Continued)

1969-70

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90	90	92	91	86	92	69	59	--	56	68	39
81	81	91	90	77	90	67	52	--	62	84	--
75	85	90	85	77	88	57	37	36	58	65	--
70	80	99	92	74	86	58	31	52	60	53	78
60	98	92	74	67	79	66	55	--	55	56	81
47	93	87	66	98	81	70	78	--	46	48	63
43	90	96	57	80	89	66	83	--	49	50	78
70	72	89	56	80	82	62	84	--	54	51	56
72	82	98	91	76	72	75	75	72	57	42	52
79	92	87	--	88	56	72	73	64	66	35	45
60	92	82	--	90	70	68	57	59	56	36	--
28	--	90	87	77	83	--	87	57	57	34	--
32	--	76	90	100	76	--	80	57	88	48	--
43	--	83	88	89	90	--	63	88	65	45	--
42	--	81	87	85	82	--	45	82	59	38	--
50	86	68	95	79	88	--	40	70	45	36	--
70	86	78	92	82	76	--	55	55	57	38	--
86	63	90	100	83	75	58	30	60	59	42	--
78	--	90	97	75	62	92	52	62	51	36	--
76	--	90	90	60	60	87	--	57	51	32	--
69	88	95	92	64	76	79	--	67	59	24	--
59	78	82	93	76	72	77	70	52	60	23	--
84	72	89	97	80	69	71	70	60	63	18	--
93	77	89	95	70	58	78	--	58	54	18	--
86	75	80	88	71	63	83	--	52	87	--	--
47	80	98	89	73	57	74	--	53	75	26	59
76	70	92	88	75	62	80	--	80	79	25	54
100	88	88	89	58	82	70	--	55	92	26	47
88	70	90	69	--	82	72	80	62	62	36	48
85	63	95	66	--	45	66	74	57	70	24	55
97	--	94	84	--	48	--	50	--	68	31	--
68.9	81.3	88.4	85.4	78.2	73.9	71.5	61.7	61.1	61.9	39.6	58.1

TABLE B-3

AVERAGE DAILY AIR TEMPERATURE, °F

Thompson Watershed, Moscow Idaho (1970-71)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	--	42	28	17	44	18	38	60	42	--	80	45
2	--	43	28	15	32	24	40	65	49	60	78	50
3	68	48	27	17	27	29	38	62	50	55	72	55
4	61	49	25	13	28	24	44	53	52	58	74	59
5	44	44	35	9	21	27	53	45	54	54	73	69
6	37	42	42	17	19	28	54	53	59	49	71	47
7	36	36	39	26	25	34	32	62	55	52	78	52
8	41	39	36	36	28	33	43	58	51	63	79	62
9	43	40	29	37	31	35	47	55	55	64	77	59
10	44	37	28	32	39	35	37	58	52	55	77	57
11	50	38	27	30	41	35	35	69	57	57	78	55
12	42	38	24	22	48	36	37	67	64	60	77	58
13	42	38	27	24	44	29	49	48	55	61	76	52
14	46	39	29	22	43	27	47	46	51	65	65	47
15	51	44	31	33	37	29	37	52	53	68	67	49
16	54	43	31	37	37	30	39	39	52	75	65	47
17	58	38	27	41	39	26	37	40	55	74	64	51
18	52	33	20	40	38	30	41	49	57	75	68	52
19	47	36	22	41	29	37	45	42	60	77	72	55
20	42	34	24	33	29	37	45	42	63	75	68	51
21	42	18	15	28	32	35	42	52	68	75	66	53
22	41	15	8	29	33	33	38	53	71	73	53	55
23	42	30	21	36	35	41	36	57	56	72	54	65
24	38	39	22	37	37	39	33	60	57	72	64	52
25	34	30	26	38	30	37	44	60	52	71	67	48
26	33	28	25	41	27	43	46	59	52	72	71	50
27	34	32	26	40	23	35	50	63	50	75	75	50
28	40	32	31	41	22	35	46	64	47	76	70	47
29	43	34	29	44	--	45	44	54	--	72	74	46
30	46	32	33	50	--	37	51	41	--	75	74	44
31	42	--	28	48	--	35	--	45	--	77	53	--
SUMS	1293	1091	843	974	918	1018	1273	1673	1539	2007	2180	1582
MEANS	44.6	36.4	27.2	31.4	32.8	32.8	42.3	54.0	55.0	66.9	70.3	52.7

TABLE B-3 (Continued)

1969-70

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	47	46	28	14	33	25	39	50	62	60	72	63
2	45	46	27	22	33	23	41	55	--	67	62	60
3	46	45	25	21	32	27	37	52	72	74	64	57
4	49	47	28	10	29	30	43	63	68	77	76	45
5	45	44	28	15	33	28	48	--	71	73	75	51
6	52	43	30	17	34	36	44	--	--	68	74	58
7	55	43	29	20	41	38	33	--	--	71	66	56
8	49	44	28	29	41	36	40	45	--	73	60	48
9	46	38	29	33	42	33	43	44	51	76	61	49
10	45	42	29	26	39	39	37	40	47	73	67	57
11	42	43	35	26	38	37	--	41	50	69	--	49
12	36	--	36	31	43	38	--	42	51	70	--	44
13	36	--	40	37	33	43	--	41	57	60	--	42
14	38	--	38	38	37	40	--	48	52	67	62	41
15	39	--	35	34	38	42	--	59	50	71	69	46
16	44	31	34	28	40	36	--	68	53	82	70	49
17	47	31	37	24	35	35	--	56	63	69	63	61
18	43	33	38	32	35	38	--	56	65	72	60	51
19	42	39	37	37	38	38	--	58	69	77	67	50
20	51	42	--	38	40	40	34	66	69	74	70	44
21	55	39	--	38	43	40	38	58	74	66	69	48
22	61	36	35	39	41	40	39	59	74	62	74	48
23	51	35	36	38	40	38	40	58	74	64	76	43
24	45	35	32	36	39	39	38	59	71	66	80	42
25	42	36	32	32	42	37	36	64	70	58	69	44
26	46	34	29	33	41	40	37	--	78	70	65	52
27	42	--	21	33	34	42	41	--	59	72	67	61
28	41	30	20	29	30	42	43	--	55	58	64	66
29	42	31	26	27	--	39	40	48	47	60	61	66
30	45	34	27	33	--	39	45	51	51	57	70	59
31	48	--	19	31	--	41	--	57	--	63	72	--
AVG	45.6	38.7	30.6	29.1	37.4	36.7	39.8	53.5	61.7	68.4	68.0	52.7

TABLE B-4

AVERAGE DAILY EVAPORATION PAN WATER TEMPERATURE, °F

Thompson Watershed, Moscow Idaho (1970-1971)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1								--	47	67	80	46
2								--	53	--	81	48
3								--	53	63	75	52
4								--	57	65	74	59
5								--	61	64	75	66
6								--	65	58	--	52
7								--	64	61	--	56
8								--	62	70	--	63
9								--	64	71	--	63
10								--	56	57	--	64
11								--	64	62	--	62
12								--	68	66	72	59
13								49	59	68	74	57
14								49	60	70	72	54
15								54	62	74	69	--
16								40	61	75	70	--
17								41	62	75	69	54
18								55	58	76	70	55
19								49	66	79	72	54
20								51	68	79	72	59
21								58	71	79	72	55
22								60	75	76	58	56
23								65	65	75	58	60
24								70	63	74	65	56
25								67	61	75	68	50
26								66	61	77	69	50
27								71	57	76	69	48
28								68	49	77	70	45
29								63	63	77	72	49
30								44	65	77	74	48
31								48	--	78	58	--
SUMS								1068	1840	2141	1758	1540
MEANS								56.2	61.3	71.4	70.3	55.0

TABLE B-4 (Continued)

1969-70

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1										--	--	66
2										--	71	62
3										--	70	54
4										--	71	49
5										--	74	51
6										--	74	53
7										--	73	51
8										--	--	49
9										--	--	52
10										--	65	55
11										--	--	52
12										--	70	47
13										--	66	43
14										--	65	47
15										--	69	50
16										78	67	48
17										74	62	54
18										--	62	52
19										--	67	52
20										73	68	47
21										--	68	50
22										--	71	43
23										67	72	--
24										69	74	--
25										--	69	--
26										--	65	--
27										68	64	--
28										72	62	--
29										57	64	--
30										63	65	--
31										66	69	--
AVG										68.7	68.0	51.2

TABLE B-5

DAILY SURFACE RUNOFF, INCHES

Thompson Watershed, Moscow Idaho (1970-71)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				--	.01	--	--	--	--			
2				--	.01	--	--	--	--			
3				--	.01	--	--	--	.16			
4				--	--	--	--	--	.11			
5				--	--	--	--	--	.05			
6				--	--	--	--	--	.03			
7				--	--	--	--	--	.02			
8				--	--	--	--	--	.01			
9				--	--	--	--	--	--			
10				.21	.32	--	--	--	--			
11				.15	.21	.01	--	--	--			
12				.07	.08	.27	--	--	--			
13				.04	.04	.20	--	--	--			
14				.02	.05	.10	--	--	--			
15				.07	.02	.06	--	--	--			
16				.35	.01	.04	--	--	--			
17				.64	.01	.02	--	--	--			
18				.23	.01	.02	--	--	--			
19				.40	.01	.03	--	--	--			
20				.18	--	.11	--	--	--			
21				.05	--	.10	--	--	--			
22				.02	--	.07	--	--	--			
23				.04	--	.41	--	--	--			
24				.09	--	. 3	--	--	--			
25				.19	--	.09	--	--	--			
26				.16	--	.18	--	--	--			
27				.08	--	.04	--	--	--			
28				.05	--	.03	--	--	--			
29				.03	--	.02	--	--	--			
30				.02	--	.01	--	--	--			
31				.02	--	.01	--	--	--			
SUMS				3.11	0.75	2.05	--	--	0.38			

TABLE B-5 (Continued)

1969-70

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1				---	.01							
2				---	.01							
3				---	.01							
4				---	.01							
5				---	.01							
6				---	.01							
7				---	.01							
8				---	.05							
9				---	.03							
10				---	.02							
11				---	.01							
12				---	.01							
13				---	.06							
14				---	.15							
15				---	.15							
16				---	.28							
17				---	.27							
18				---	.07							
19				.01	.05							
20				.17	---							
21				.90	---							
22				.17	---							
23				.45	---							
24				.45	---							
25				.30	---							
26				.14	---							
27				.24	---							
28				.09	---							
29				.06	---							
30				.04	---							
31				.02	---							
TOTAL				3.04	*							

* Some runoff occurred during the last two weeks in February but the records are missing. Therefore a value of two inches is estimated for the month.

TABLE B-6

DAILY SOLAR RADIATION, LANGLEYS

Thompson Watershed, Moscow Idaho (1970-71)

* Daily measurements were not made during this period and therefore average values for the period are shown.

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1								537	421*	783	711	119*
2								487	421*	783	730	119*
3								537	421*	837	721	257
4								302	421*	786	736	478
5								401	728*	665	625	475
6								434	728*	768	435	96
7								637	728*	827	715	484
8								328	828	765	691	470
9								654	618	627	726	440
10								661	442	618	721	428
11								645	744	599	710	421
12								513	655	865	712	473
13								642	615	805	680	463
14								483	833	810	692	466
15								307	827	780	695	440
16								258	790	773	695	452
17								314	772	865	571	417*
18								612	447	681	435	417*
19								291	750	740	654	417*
20								490	688	688	515	417*
21								757	755	750	508	417*
22								692	740	790	103	417*
23								621	569	745	562	417*
24								628	656	641	553	246*
25								452	665	875	539	246*
26								513	725	771	483	246*
27								668	512	735	431	246*
28								705	405	735	497*	246*
29								421*	827	752	497*	246*
30								421*	783	727	417	246*
31								421*	---	715	232	---
SUMS								15832	19514	23301	17992	10723
MEANS								511	650	752	580	357

TABLE B-6 (Continued)

1969-70

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1									---	596	680	555
2									---	758	574	532
3									755	734	693	233
4									747	654	722	106
5									748	754	558	453
6									617	754	680	233
7									502	779	730	164
8									441	676	680	402
9									367	705	688	538
10									397	590	688	535
11									606	635	680	522
12									285	---	693	522
13									488	---	680	348
14									107	---	713	462
15									164	---	660	519
16									328	541	---	238
17									758	712	697	279
18									725	719	641	85
19									717	676	580	326
20									717	701	584	193
21									717	644	598	221
22									705	475	580	75
23									655	697	551	295
24									722	504	541	450
25									725	185	574	453
26									578	443	578	447
27									176	508	549	432
28									441	258	562	408
29									254	701	537	398
30									631	684	445	318
31									---	721	483	---
SUMS									15073	16804	18619	10742
MEANS									538	622	621	358

TABLE B-7

DAILY NET SOIL HEAT FLUX, LANGLEYS*

Thompson Watershed, Moscow Idaho (1970-71)

*Positive values indicate a net gain of heat in the soil.

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1								--	-18	+13	+21	-30
2								--	+11	-5	+12	-32
3								--	-1	+12	-18	-21
4								--	-9	+12	-10	0
5								--	+17	-1	0	0
6								--	+35	-26	-8	-50
7								--	0	+13	+21	-16
8								--	+10	+27	+25	-8
9								--	+21	-2	--	-12
10								--	-21	-19	--	-7
11								--	+7	-15	+22	-28
12								--	+34	-5	+17	-7
13								--	-35	-4	+17	-25
14								--	-16	+3	-8	-12
15								--	-5	+12	+5	-12
16								--	-5	+12	-1	-11
17								--	+27	+13	+4	--
18								--	-17	+28	+8	--
19								-33	+6	--	+22	--
20								+1	+7	+17	-2	--
21								+27	0	+8	+7	--
22								+22	+21	+13	-17	--
23								+54	-40	+15	-22	--
24								+67	+7	+10	-13	--
25								+10	-35	+15	-4	--
26								+40	-6	+16	-1	--
27								+59	-19	+7	+4	--
28								+69	-30	+15	+12	--
29								+18	+3	+11	+24	--
30								-46	+16	+18	+2	--
31								-27	--	+18	-40	--
SUMS								+261	-35	+231	+105	-271
MEANS								+20	-1	+8	+4	-17

TABLE B-8

DAILY WIND MOVEMENT, MILES

Thompson Watershed, Moscow Idaho (1970-71)

*Daily measurements were not made during this period and therefore average values for the period are shown.

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1								--	53	40*	32	53*
2								--	15	40*	23	53*
3								--	33	33	32	52*
4								--	45	41	27	57
5								--	21	51	11	59
6								--	10	51	28	59
7								--	46	64	26	23
8								--	20	30	5	57
9								--	14	68	39	37
10								--	29	33*	30	72
11								--	16	33*	32	109
12								--	15	33*	43	54
13								--	29	33*	30	80
14								--	28	33*	56	49
15								--	36	33*	28	40
16								--	55	31*	53	123
17								--	32	13	34	80
18								--	40*	28	27	45
19								--	40*	27	33	65
20								--	40*	25	66	55
21								--	40*	18	18	55
22								--	40*	21	71	128
23								--	40*	3	30	63
24								--	40*	11	38	36
25								--	40*	33*	30	42
26								--	40*	33*	29	59
27								--	40*	33*	42	41*
28								--	40*	33*	28	41*
29								98	40*	33*	34	41*
30								59	40*	35*	71	41*
31								15	--	38*	55	--
SUMS								172	1014	1031	1101	1770
MEANS								57	34	33	36	59

TABLE B-8 (Continued)

1969-70

Y	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1											--	86
2											--	86
3											--	99
4											65	81
5											56	102
6											49	161
7											101	132
8											108	156
9											47	62
10											45	97
11											41	108
12											60	113
13											99	77
14											56	50
15											44	58
16											96	84
17											65*	112
18											65*	75*
19											65*	75*
20											49	38
21											45	71
22											52*	--
23											52*	--
24											47	--
25											58	--
26											59	--
27											49	--
28											92*	--
29											92*	--
30											92*	--
31											91*	--
AVG											65.7	91.6

*Total miles for this period was distributed uniformly over these days.

TABLE B-9

DAILY PAN EVAPORATION, INCHES

Thompson Watershed, Moscow Idaho (1970-71)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1								--	.00	.24	.29	.01
2								--	.03	.19	.25	.00
3								--	.00	.22	.21	.00
4								--	.03	.20	.22	.18
5								--	.13	.16	.21	.29
6								--	.12	.24	.16	.03
7								--	.19	.21	.29	.11
8								--	.08	.24	.26	.21
9								--	.16	.13	.37	.19
10								--	.00	.09	.33	.29
11								--	.05	.16	.29	.26
12								--	.20	.20	.38	.22
13								--	.03	.30	.29	.24
14								--	.20	.25	.29	.19
15								--	.16	.20	.22	.19
16								--	.14	.24	.18	.28
17								--	.25	.20	.29	.20
18								--	.04	.33	.25	.19
19								--	.13	.26	.30	.19
20								--	.16	.26	.30	.20
21								--	.26	.33	.25	.17
22								.22	.24	.29	.05	.22
23								.24	.07	.26	.13	.21
24								.17	.12	.30	.24	.16
25								.09	.00	.30	.29	.00
26								.13	.17	.33	.25	.00
27								.25	.08	.28	.24	.00
28								.34	.04	.26	.28	.01
29								.22	.19	.29	.30	.00
30								.04	.20	.29	.36	.00
31								.00	--	.33	.05	--
SUMS								1.70	3.47	7.58	7.82	4.24
MEANS								.17	.12	.24	.25	.14

TABLE B-9 (Continued)

1969-70

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
										--	.35	.19
										--	.19	.30
										--	.24	.05
										--	.42	.00
										--	.34	.11
										--	.35	.12
										--	.31	.05
										--	.33	.21
										--	.27	.15
										--	.29	.27
										--	.15	.24
										--	.14	.25
										--	.32	.13
										--	.31	.13
										--	.34	.18
										--	.41	.15
										.35	.33	.19
										.26	.30	.01
										.41	.30	.13
										.38	.33	.14
										.33	.33	.07
										.29	.37	*
										.26	.46	--
										.42	.31	--
										.07	.40	--
										.18	.33	--
										.13	.25	--
										.08	.42	--
										.30	.27	--
										.21	.33	--
										.26	.36	--
S										3.93	9.85	3.07
NS										.26	.32	.15

vaporation pan was emptied for winter on this day.

APPENDIX C

Computer Programs

Table C-1. Program to calculate soil moisture.

```
C THIS PROGRAM WILL CALCULATE AVERAGE AREAL SOIL MOISTURE USING COUNTS
C     FROM A NEUTRON PROBE
C IT WAS ORIGINALLY DEVELOPED FOR USE ON THE THOMPSON WATERSHED PROJECT
C BY CHANGING ONLY A FEW CARDS IT IS POSSIBLE TO ADAPT THIS PROGRAM FOR
C     USE ON OTHER WATERSHEDS AND FOR USE WITH SEVERAL NEUTRON PROBES
C DATA CARD ORDER
C   CARD 1....ID CARD 80A1
C   CARD 2....PARAMETER CARD
C      JN = NUMBER OF SITES.........................COL  1-10
C      IN = NUMBER OF DEPTHS....................... COL 11-20
C      TSTD = STANDARD COUNT FOR TROXLER.......... COL 21-30
C      CSTD = STANDARD COUNT FOR NUCLEAR-CHICAGO...COL 31-40
C   REMAINING CARDS CARRY INPUT DATA
C      COL  2-3.....CODE TO IDENTIFY PROBE USED
C         LCODE = 01 FOR NUCLEAR-CHICAGO PROBE
C         LCODE = 02 FOR TROXLER PROBE
C      COL  4-15....DATE MEASUREMENT WAS MADE
C      COL 16-18....DESIGNATION OF SITE ON FIELD
C      COL 20-68....TIME(F3.1) AND COUNTS(F4.0) AT EACH DEPTH
C DEFINITION OF VARIABLES
C   C(I,J,K)...NEUTRON COUNTS
C   T(I,J,K)...DURATION OF COUNT
C   RATE.......COUNT RATE PER MINUTE
C   RATIO......RATIO OF COUNT RATE TO STANDARD COUNT RATE
C   AM(I)......AVERAGE SOIL MOISTURE FOR ALL SITES AT EACH DEPTH
C   TM.........TOTAL AVERAGE AREAL SOIL MOISTURE IN ENTIRE ROOT ZONE
```

Table C-1. (Continued)

```
      DIMENSION ID(80),LCODE(10,20),LDATE(3,10,20),LSITE(10,20),T(10,10,
     120),C(10,10,20),AM(50),IDATE(3)
      DO 99 I=1,10
      DO 99 J=1,10
      DO 99 K=1,20
      LCODE(J,K)=0
      LDATE(I,J,K)=0
      LSITE(J,K)=0
      T(I,J,K)=0.
   99 C(I,J,K)=0.
      READ(1,1)ID
    1 FORMAT(80A1)
      WRITE(3,2)ID
    2 FORMAT(3X,80A1)
      READ 3,IN,JN,TSTD,CSTD
    3 FORMAT(2I10,2F10.0)
      DO 6 K=1,20
      DO 5 J=1,JN
      READ(1,4)LCODE(J,K),(LDATE(M,J,K),M=1,3),LSITE(J,K),(T(I,J,K),C(I,
     1J,K),I=1,IN)
    4 FORMAT(1X,I2,3A4,1X,I2,1X,7(F3.1,F4.0))
      IF(LCODE(J,K).EQ.0)GO TO 7
    5 CONTINUE
    6 CONTINUE
    7 WRITE(3,8)
    8 FORMAT(36X,'INCHES OF MOISTURE IN EACH FOOT OF SOIL     TOTAL'/12X
     1,'DATE',8X,'0-1',5X,'1-2',5X,'2-3',5X'3-4',5X'4-5',5X'5-6',5X'6-7'
     2,5X,'INCHES')
```

Table C-1. (Continued)

```
C CALCULATION OF SOIL MOISTURE
C
      DO 30 K=1,20
      IF(LCODE(J,K).EQ.0)GO TO 40
      TM=0
      DO 25 I=1,IN
      IF(T(I,J,K).EQ.0)GO TO 30
      ARATE=0
      AN=0
      DO 20 J=1,JN
      IF(T(I,J,K).EQ.0)GO TO 21
      AN=AN+1
      IF(J.NE.1)GO TO 19
      DO 98 M=1,3
   98 IDATE(M)=LDATE(M,J,K)
   19 RATE=C(I,J,K)/T(I,J,K)
   20 ARATE=ARATE+RATE
   21 BRATE=ARATE/AN
      IF(LCODE(J,K).EQ.1)GO TO 22
      RATIO=BRATE/TSTD
      IF(RATIO.LT.0.71)GO TO 23
      AM(I)=(0.66*RATIO-0.194)*12.
      GO TO 24
   23 AM(I)=0.385*RATIO*12.
      GO TO 24
   22 RATIO=BRATE/CSTD
      AM(I)=0.194*RATIO*12
   24 TM=TM+AM(I)
   25 CONTINUE
   30 WRITE(3,31)(IDATE(M),M=1,3),(AM(I),I=1,IN),TM
   31 FORMAT(8X,3A4,7(3X,F5.2),3X,F5.2)
      CONTINUE
   40 STOP
      END
```

Table C-1. (Continued)

MOISTURE CONTENT OF SEVEN FOOT SOIL LAYER AT THE THOMPSON WATERSHED NEAR MOSCOW

DATE	INCHES OF MOISTURE IN EACH FOOT OF SOIL 0-1	1-2	2-3	3-4	4-5	5-6	6-7	TOTAL INCHES
OCT 03 1970	1.69	2.02	2.71	3.54	4.00	4.15	4.19	22.31
DEC 31 1970	3.96	4.03	4.11	3.96	4.03	4.13	4.07	28.34
JAN 28 1971	4.30	4.55	4.43	4.26	4.25	4.28	4.24	30.33
MAR 04 1971	2.75	4.49	4.69	4.57	4.49	4.57	4.55	30.12
APR 02 1971	2.76	4.52	4.73	4.70	4.47	4.56	4.57	30.30
MAY 03 1971	2.95	4.48	4.75	4.65	4.53	4.62	4.61	30.58
MAY 14 1971	2.08	4.10	4.70	4.59	4.44	4.57	4.60	29.10
MAY 28 1971	2.60	4.20	4.70	4.65	4.52	4.66	4.63	29.95
JUN 11 1971	3.47	4.53	4.77	4.63	4.52	4.62	4.60	31.13
JUL 02 1971	1.95	3.82	4.45	4.59	4.51	4.64	4.60	23.96
JUL 09 1971	1.56	3.35	4.23	4.58	4.54	4.67	4.65	27.58
JUL 16 1971	1.78	3.13	3.99	4.51	4.54	4.69	4.67	27.32
JUL 23 1971	1.28	2.73	3.42	4.36	4.57	4.67	4.63	25.71
JUL 30 1971	1.04	2.44	2.99	4.05	4.49	4.60	4.67	24.28
AUG 06 1971	1.18	2.31	2.79	3.93	4.34	4.48	4.59	23.61
AUG 13 1971	1.03	2.25	2.65	3.63	4.28	4.47	4.58	22.89
AUG 20 1971	0.89	2.22	2.57	3.54	4.16	4.39	4.54	22.31
AUG 27 1971	1.34	2.23	2.56	3.49	4.18	4.42	4.48	22.69
SEP 10 1971	1.73	2.29	2.55	3.50	4.12	4.34	4.46	22.98
OCT 6 1971	1.89	2.32	2.56	3.50	4.13	4.33	4.45	23.18

On July 2, no reading at 6-7'.
∴ total depth is only 72" not 84"
Duryo estimated 4.79" in bottom foot
for total of 28.75"

Table C-2. Program to calculate potential evapotranspiration.

```
C
C         PROGRAM FOR POTENTIAL EVAPOTRANSPIRATION USING EITHER OR BOTH THE
C             PENMAN AND OR THE JENSEN-HAISE EQUATIONS.  EVAPOTRANSPIRATION
C             CAN BE COMPUTED USING THE METHOD OUTLINED BY JENSEN.
C
C         REFERENCE
C             JENSEN,ME   ROBB,DC   FRANZOY,CE
C             SCHEDULING IRRIGATIONS USING CLIMATE-CROP-SOIL DATA
C             J IRRIG DRAIN DIV, ASCE     MARCH 1970
C
C         DEFINITION OF PARAMETERS USED IN JENSEN-HAISE EQUATION
C             ELEV=ELEVATION OF FIELD ABOVE MEAN SEA LEVEL
C             E1=SATURATION VAPOR PRESSURE AT MEAN MAXIMUM TEMPERATURE
C                 DURING WARMEST MONTH
C             E2=SATURATION VAPOR PRESSURE AT MEAN MINIMUM TEMPERATURE
C                 DURING WARMEST MONTH
C             ATEMP=MEAN DAILY TEMPERATURE
C             ATMAX=MAXIMUM DAILY AIR TEMPERATURE
C             ATMIN=MINIMUM DAILY AIR TEMPERATURE
C             SRAD=SOLAR (SHORTWAVE) RADIATION
C
C         DEFINITION OF COEFFICIENTS USED IN JENSEN-HAISE EQUATION
C             CELEV=ELEVATION COEFFICIENT
C             CHUMID=HUMIDITY COEFFICIENT
C             CTEMP=TEMPERATURE COEFFICIENT
C             CTEX=BASE TEMPERATURE CORRECTION FOR ZERO EVAPOTRANSPIRATION
C             CRAD=CONVERSION FOR RADIATION COUNTS TO LANGLEYS
C             CHEAT=CONVERSION FOR  MV-HRS TO LANGLEYS
```

Table C-2. (Continued)

```
C      DEFINITION OF ADDITIONAL PARAMETERS USED IN PENMAN EQUATION
C          WIND=DAILY WIND MOVEMENT
C          HUMID=MEAN DAILY HUMIDITY
C          HEAT=DAILY SOIL HEAT FLUX
C          DTEMP=MEAN DAILY DEW POINT TEMPERATURE
C          ES=MEAN SATURATION VAPOR PRESSURE
C          ED=SATURATION VAPOR PRESSURE AT MEAN DEW POINT TEMPERATURE
C          RNET=NET RADIATION
C          A=ALBEDO
C          DEL=FRACTION OF EVAPORATION CONTRIBUTED BY RADIATION
C          GAM=FRACTION OF EVAPORATION CONTRIBUTED BY MASS TRANSFER
C          ESTAR=EVAPORATION ENERGY
C          ETP=POTENTIAL EVAPOTRANSPIRATION
C          RADO=MAXIMUM CLEAR DAY RADIATION
C
C      POSITION OF VARIABLES ON DATA CARDS
C          PARAMETER CARD
C              1- 5 LSITE, A4
C              6-10 ELEV(FEET), F5.0
C             11-15 E1(MAX MILLIBARS), F5.0
C             16-20 E2(MIN MILLIBARS), F5.0
C             21-25 CRAD, F5.0
C             26-30 A, F5.0
C             31-35 CHEAT, F5.0
C             36-40 RADO, F5.0
```

Table C-2. (Continued)

```
C        REMAINING DATA CARDS
C            1- 2 ICODE......I2
C           4- 7 LSITE...........A4
C            9-11 MONTH...........A3
C           12-14 LDAY............I3
C           15-19 LYEAR...........I5
C           21-25 ATEMP, DEG FAHR.F5.0
C           26-30 HUMID, PERCENT..F5.0
C           31-35 WTEMP, DEG FAHR.F5.0
C           36-40 WIND, MILES.....F5.0
C           41-45 EVAP, INCHES....F5.2
C           46-50 SRAD, COUNTS....F5.0
C           51-55 HEAT, MV-HRS....F5.1
C           56-60 ATMAX,DEG FAHR..F5.0
C           61-65 ATMIN,DEG FAHR..F5.0
C        LAST CARD
C                 LEAVE BLANK TO TERMINATE PROGRAM
C
C     DEVELOP CLIMATIC COEFFICIENTS
C
      READ(1,1)ELEV,E1,E2,CRAD,A,CHEAT,RADO
    1 FORMAT(5X,7F5.0)
      CELEV=68.-3.6*ELEV/1000.
      CHUMID=50./(E1-E2)
      CTEMP=1./(CELEV+13.*CHUMID)
      CTEX=27.5-0.25*(E1-E2)-ELEV/1000.
```

Table C-2. (Continued)

```
C     READ DATA FROM CARDS
C
      I=0
    2 READ(1,3)MONTH,LDAY,LYEAR,ATEMP,HUMID,WTEMP,WIND,EVAP,SRAD,HEAT,
     *ATMAX,ATMIN
    3 FORMAT(8X,A3,I3,I5,1X,9F5.0)
      I=I+1
      IF(LDAY.EQ.0)GO TO 12
      IF(I.EQ.1.OR.I.EQ.51.OR.I.EQ.101.OR.I.EQ.151)GO TO 4
      GO TO 6
C
C     WRITE HEADINGS
C
    4 WRITE(3,5)
    5 FORMAT('1',28X,'POTENTIAL EVAPOTRANSPIRATION'
     *//28X,'BARLEY ON THOMPSON WATERSHED'
     *//15X,'DATE',15X,'PET(JENSEN)',15X,'PET(PENMAN)'
     *//36X,'INCHES',20X,'INCHES')
C
C     TEST FOR MISSING DATA
C
    6 IF(SRAD.NE.0.AND.ATMAX.NE.0.AND.ATMIN.NE.0)GO TO 8
      WRITE(3,7)MONTH,LDAY,LYEAR
    7 FORMAT(12X,A3,I3,I5,10X,'DATA MISSING',14X,'DATA MISSING')
      GO TO 2
C
C     CALCULATE PET USING JENSEN-HAISE
C
```

Table C-2. (Continued)

```
    8 ATEMP=(ATMAX+ATMIN)*0.5
      RAD=SRAD*CRAD
      EJ=CTEMP*(ATEMP-CTEX)*RAD
      ETPJ=EJ*0.000673
C
C     TEST FOR MISSING DATA
C
      IF(HUMID.NE.0.AND.WIND.NE.0.AND.HEAT.NE.0)GO TO 10
      WRITE(3,9)MONTH,LDAY,LYEAR,ETPJ
    9 FORMAT(12X,A3,I3,I5,13X,F5.3,16X,'DATA MISSING')
      GO TO 2
C
C     CALCULATE PET USING PENMAN
C
C     DEVELOP MASS TRANSFER TERM
C
   10 HUMID=HUMID*0.01
      DTEMP=(173.+0.9*ATEMP)*HUMID**0.125-173.+0.1*ATEMP
      BTEMP=(ATEMP-32.)*0.556
      ETEMP=(DTEMP-32.)*0.556
      B=(17.27*BTEMP/(BTEMP+238.3))
      E=(17.27*ETEMP/(ETEMP+238.3))
      ES=6.108*EXP(B)
      ED=6.108*EXP(E)
      GAM=0.80-0.007*ATEMP
      ADVECT=15.36*GAM*(1.0+0.0138*WIND)*(ES-ED)
```

Table C-2. (Continued)

```
C     DEVELOP RADIATION TERM
C
      BTMAX=((ATMAX-32.)*0.556+273)*0.01
      BTMIN=((ATMIN-32.)*0.556+273)*0.01
      BT=(BTMAX**4+BTMIN**4)*0.5
      RLO=(0.31-0.044*SQRT(ED))*11.71*BT
      IF(I.GT.31)GO TO 100
      F=I
      RADO=620.+6.2*F
      GO TO 200
  100 IF(I.GT.61)GO TO 101
      F=I-31
      RADO=810.+2.5*F
      GO TO 200
  101 IF(I.GT.92)GO TO 102
      F=I-61
      RADO=885.-2.8*F
      GO TO 200
  102 IF(I.GT.153)GO TO 12
      F=I-92
      RADO=795.-6.5*F
  200 RL=(1.35*RAD/RADO-0.35)*RLO
      RNET=(1.-A)*RAD-RL
      G=HEAT*CHEAT
      DEL=0.20+0.007*ATEMP
      ENERGY=DEL*(RNET-G)
   50 FORMAT(10X,F20.10)
```

Table C-2. (Continued)

```
C      CALCULATE PET USING PENMAN
C
       EP=ENERGY+ADVECT
       ETPP=EP*0.000673
C
C      WRITE PROGRAM OUTPUT
C
       WRITE(3,11)MONTH,LDAY,LYEAR,ETPJ,ETPP
    11 FORMAT(12X,A3,I3,I5,13X,F5.3,20X,F5.3)
       GO TO 2
C
C      END OF PROGRAM COMPILATION
C
    12 STOP
       END
```

Table C-2. (Continued)

DATE	PET(JENSEN) INCHES	PET(PENMAN) INCHES
MAY 1 1971	0.174	DATA MISSING
MAY 2 1971	0.177	DATA MISSING
MAY 3 1971	0.183	DATA MISSING
MAY 4 1971	0.081	DATA MISSING
MAY 5 1971	0.083	DATA MISSING
MAY 6 1971	0.117	DATA MISSING
MAY 7 1971	0.217	DATA MISSING
MAY 8 1971	0.100	DATA MISSING
MAY 9 1971	0.187	DATA MISSING
MAY 10 1971	0.204	DATA MISSING
MAY 11 1971	0.255	DATA MISSING
MAY 12 1971	0.189	DATA MISSING
MAY 13 1971	0.148	DATA MISSING
MAY 14 1971	0.103	DATA MISSING
MAY 15 1971	0.080	DATA MISSING
MAY 16 1971	0.040	DATA MISSING
MAY 17 1971	0.051	DATA MISSING
MAY 18 1971	0.143	DATA MISSING
MAY 19 1971	0.052	DATA MISSING
MAY 20 1971	0.090	DATA MISSING
MAY 21 1971	0.198	DATA MISSING
MAY 22 1971	0.186	DATA MISSING
MAY 23 1971	0.187	DATA MISSING
MAY 24 1971	0.204	DATA MISSING
MAY 25 1971	0.145	DATA MISSING
MAY 26 1971	0.163	DATA MISSING
MAY 27 1971	0.233	DATA MISSING
MAY 28 1971	0.153	DATA MISSING
MAY 29 1971	0.116	0.152
MAY 30 1971	0.073	0.119
MAY 31 1971	0.087	0.110
JUN 1 1971	0.077	0.100
JUN 2 1971	0.100	0.104
JUN 3 1971	0.103	0.108
JUN 4 1971	0.111	0.129
JUN 5 1971	0.202	0.192
JUN 6 1971	0.230	0.200
JUN 7 1971	0.207	DATA MISSING
JUN 8 1971	0.210	0.207
JUN 9 1971	0.176	0.171
JUN 10 1971	0.116	0.126
JUN 11 1971	0.224	0.204
JUN 12 1971	0.231	0.195
JUN 13 1971	0.188	0.184
JUN 14 1971	0.212	0.218
JUN 15 1971	0.220	0.224
JUN 16 1971	0.207	0.216
JUN 17 1971	0.221	0.207
JUN 18 1971	0.133	0.137
JUN 19 1971	0.241	0.222

Table C-2. (Continued)

DATE	PET(JENSEN) INCHES	PET(PENMAN) INCHES
JUN 20 1971	0.240	0.214
JUN 21 1971	0.293	DATA MISSING
JUN 22 1971	0.305	0.252
JUN 23 1971	0.167	0.189
JUN 24 1971	0.195	0.196
JUN 25 1971	0.174	0.189
JUN 26 1971	0.184	0.203
JUN 27 1971	0.126	0.158
JUN 28 1971	0.090	0.127
JUN 29 1971	DATA MISSING	DATA MISSING
JUN 30 1971	DATA MISSING	DATA MISSING
JUL 1 1971	DATA MISSING	DATA MISSING
JUL 2 1971	0.254	0.243
JUL 3 1971	0.239	0.235
JUL 4 1971	0.243	0.234
JUL 5 1971	0.185	0.189
JUL 6 1971	0.183	0.213
JUL 7 1971	0.216	0.234
JUL 8 1971	0.267	0.239
JUL 9 1971	0.224	0.213
JUL 10 1971	0.176	0.184
JUL 11 1971	0.181	0.191
JUL 12 1971	0.281	0.261
JUL 13 1971	0.267	0.255
JUL 14 1971	0.295	0.268
JUL 15 1971	0.303	0.261
JUL 16 1971	0.349	0.286
JUL 17 1971	0.376	0.297
JUL 18 1971	0.302	0.251
JUL 19 1971	0.340	0.277
JUL 20 1971	0.305	0.250
JUL 21 1971	0.332	0.273
JUL 22 1971	0.337	0.276
JUL 23 1971	0.315	0.252
JUL 24 1971	0.272	0.234
JUL 25 1971	0.361	0.296
JUL 26 1971	0.326	0.274
JUL 27 1971	0.326	0.277
JUL 28 1971	0.332	0.280
JUL 29 1971	0.315	0.270
JUL 30 1971	0.319	0.272
JUL 31 1971	0.328	0.278
AUG 1 1971	0.344	0.280
AUG 2 1971	0.341	0.280
AUG 3 1971	0.303	0.271
AUG 4 1971	0.317	0.277
AUG 5 1971	0.267	DATA MISSING
AUG 6 1971	0.179	0.179
AUG 7 1971	0.336	0.268
AUG 8 1971	0.328	0.247

Table C-2. (Continued)

DATE	PET(JENSEN) INCHES	PET(PENMAN) INCHES
AUG 9 1971	0.333	DATA MISSING
AUG 10 1971	0.331	DATA MISSING
AUG 11 1971	0.331	0.270
AUG 12 1971	0.327	0.278
AUG 13 1971	0.309	0.258
AUG 14 1971	0.252	0.256
AUG 15 1971	0.263	0.235
AUG 16 1971	0.253	0.249
AUG 17 1971	0.204	0.204
AUG 18 1971	0.169	0.183
AUG 19 1971	0.274	0.235
AUG 20 1971	0.200	0.221
AUG 21 1971	0.189	0.177
AUG 22 1971	0.028	0.078
AUG 23 1971	0.156	0.162
AUG 24 1971	0.197	0.201
AUG 25 1971	0.205	0.202
AUG 26 1971	0.199	0.196
AUG 27 1971	0.193	0.202
AUG 28 1971	0.202	0.187
AUG 29 1971	0.216	0.193
AUG 30 1971	0.183	0.215
AUG 31 1971	0.063	0.107

APPENDIX D

Development of Crop Coefficients

Development of Crop Coefficient

The potential evapotranspiration derived from the Jensen-Haise and Penman equations will give a rough estimate of evapotranspiration for some crops under special circumstances. Two of the more important circumstances requires that full crop cover exist and that soil moisture be non-limiting. Most of the time these conditions do not exist and it is therefore necessary to adjust the value of potential evapotranspiration to account for their effect on evapotranspiration of the crop.

An expression has been developed to account for the factors, other than climatic demand, that can effect evapotranspiration (Jensen, Robb and Franzoy 1970). This expression is

$$Kc = Kco\ (Ka) + Ks.$$

The term Kc is the coefficient used to adjust the potential evapotranspiration. The crop coefficient Kco accounts for the effects of crop development when soil moisture is non-limiting. To adjust the crop coefficient for the effect of soil moisture limitations the term Ka is used, and can be determined by

$$Ka = \ln AM/\ln TAM$$

where AM is the existing available soil moisture and TAM is the total possible available moisture that the soil can hold. The term Ks is used to account for the increase in surface evaporation immediately after an irrigation or rain storm.

The following example calculation (for the period June 11 to July 2, 1971) will illustrate the procedure used to develop crop coefficients for the Thompson watershed.

The following assumptions were made:

1. The effective root zone is contained in the upper 4-feet of the soil mantle.
2. Each foot of soil contains 1.5 inches of moisture that the plant is unable to remove.
3. Each foot of soil can hold a maximum of 4.5 inches of moisture against gravitational forces.
4. The value of Ks is small by comparison to the value Kco Ka.

The average crop coefficient for June 11 to July 2 is obtained from Figure 7:

Kco = 0.96 (average between 65 and 100% effective cover)

The adjusting factor for soil moisture limitations is based on data for in the computer printout of soil moisture content for this period and for the 4-foot upper soil layer:

On June 11 AM=(3.47+4.53+4.77+4.63)-6.00 = 11.4 inches
On July 2 AM=(1.95+3.82+4.45+4.59)-6.00 = 8.8 inches

$\overline{AM}$ = 1/2 (11.4 8.8) = 10.1 inches

ln $\overline{AM}$ = 2.31
TAM = (3.0 inches/foot) (4.0 feet) = 12.0 inches
ln TAM = 2.49
Ka = 2.31/2.49 = 0.93

Assuming Ks = 0 the value of the adjusted crop coefficient can be determined:

$$Kc = Kco\ (Ka) = 0.96 \times 0.93 = 0.89$$

Table D-1 summarizes the calculations of the crop coefficients for all the short periods during the 1971 growing season.

TABLE D-1

Crop coefficients to use with the Jensen-Haise and Penman equations for potential evapotranspiration.

Date	%	AM	$\overline{AM}$	ln$\overline{AM}$	Ka	Kco	Kc
May 3	0	10.8					
			10.15	2.32	0.93	0.19	0.18
May 14	18	9.5					
			9.85	2.29	0.92	0.25	0.23
May 28	42	10.2					
			10.8	2.38	0.96	0.54	0.52
Jun 11	65	11.4					
			10.1	2.31	0.93	0.96	0.89
Jul 2	100	8.8					
	Days		8.25	2.11	0.85	1.04	0.88
Jul 9	7	7.7					
			7.55	2.02	0.81	1.02	0.83
Jul 16	14	7.4					
			6.6	1.89	0.76	0.97	0.74
Jul 23	21	5.8					
			5.15	1.64	0.66	0.87	0.57
Jul 30	28	4.5					
			4.35	1.47	0.59	0.72	0.42
Aug 6	35	4.2					
			3.9	1.36	0.55	0.49	0.27
Aug 13	42	3.6					
			3.4	1.22	0.49	0.22	0.10
Aug 20	49	3.2					
			3.4	1.22	0.49	0.15	0.07
Aug 27	56	3.6					