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Calibration of a Temperature-Radiation Evapotranspiration Equation for Utah

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CALIBRATION OF A TEMPERATURE-RADIATION EVAPOTRANSPIRATION EQUATION FOR UTAH

by

Payam Foroughi

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

of

MASTER OF SCIENCE

in

Irrigation Science

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1985

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I wish to express my deepest gratitude towards my parents for their emotional and financial support during my long stay in graduate school. I also thank my advisor Dr. R. W. Hill for his academic assistance. My appreciation also goes to the many new friends from Utah and around the globe that I was fortunate to meet while attending Utah State University.

This work is dedicated to the oppressed people of Iran and others in the world living under dictatorial regimes.

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ABSTRACT

Calibration of a Temperature-Radiation Evapotranspiration Equation for Utah

by

Payam Foroughi, Master of Science
Utah State University, 1985

Major Professor: Dr. Robert W. Hill
Department: Agricultural and Irrigation Engineering

Two reference crop evapotranspiration (ETr) equations were calibrated to the reference crop of alfalfa using 45 meteorological datafiles from 13 scattered sites in Utah and four sites in the neigboring states of Idaho and Wyoming.

The calibrations were done against the Kimberly version of the Penman ETr formula. The first equation required measured inputs of mean air temperature and solar radiation. It was referred to as the Temperature- Radiation ETr equation (ETr= CT x T x Rs). The second equation required measured inputs of mean minimum and mean maximum air temperatures. It was referred to as the New Hargreaves equation (ETr= K x T x $TD^{0.5}$ x Ra). CT and K coefficients were found by minimizing a certain objective function which took into account 5-day sums and seasonal sums of ETr. General formulas were derived for estimating CT and K coefficients for any site in the intermountain west area for which the longitude, latitude, elevation, mean longterm July minimum temperature and mean longterm July maximum termperature were known. The average CT and K found for the study sites in Utah were 0.00999 and 0.001074 respectively.

(108 pages)

INTRODUCTION

Need for Study

Expanding world population and constant depletion of world resources forces planners and agriculturalists to find more efficient and productive methods of agriculture and water utilization. As a result crop irrigation requirements have been scientifically scrutinized and various methodologies have been proposed.

In Utah, methods of estimating agricultural crop water requirements have been introduced to the farmers through the Utah State University Extension Service. The two most recent estimating techniques have been the usage of 1) an Apple micro-computer program model for prediction of 7 and 14 day water use for crops dominant in various areas of Utah, and 2) a miniature, battery operated, field evapotranspiration computer called the "Datapod" (model DP219, Omnidata International, Logan, Utah).

The Datapod is useful for remote sites in Utah and possibly throughout the world for calculation of potential or reference evapotranspiration, where daily weather data are not available. It can store up to 255 days of data without any monitoring by an operator. Figure 1 shows a picture of the Datapod.

The formula used by the Datapod for the calculation of reference evapotranspiration is a version of the Jensen-Haise equation:

$ETr = CT(T - TX)Rs \times CF$, where

ETr is an alfalfa reference crop evapotranspiration (inches/day). T is the average air temperature (degrees F). Rs is incoming shortwave solar radiation ($cal/cm^2/day$). CF is the necessary factor for converting ETr from units of cal/cm^2 to inches and is equivalent to 0.000673 at 68 ^{o}F. CT and TX are formula coefficients which can vary from place to place.

The above formula is very simple to use since it only requires the measurement of temperature and solar radiation. However the question can arise as to the reason for calibrating such an equation which may at times not give as accurate a result as more complex methods such as the Penman ETr equation.

Usage of a simple method of ETr estimation is justifiable under the following arguments:

—Simpler methods are much more feasible for rural areas and developing nations because of: a) less financial burdens on the farmer or the extension

FIG. 1.- Datapod models Similar in Configuration to the DP219 Model which Requires a TP10v Temperature Probe and a Licor Pyranometer. From Ominidata International (27).

agency, b)possible lack of technical and scientific know-how which more complex methods require, and c)ease in availability of simple meteorological data. In short, a simple method of ETr estimation provides a methodology which is "user" oriented rather than "research" oriented (22).

— The estimation of ETr is recommended for decision making in irrigation scheduling. The risk of missing data increases with complexity of method and instrumentation, and can lead to incorrect decision making in water management.

Objectives

The objectives of this study are :

1) To calibrate a temperature-radiation ETr formula to the reference crop evapotranspiration of Alfalfa at selected sites in the intermountain west area. This will be done by finding appropriate CT and TX coefficients for various sites throughout Utah and some sites in the neighboring states of Idaho, and Wyoming.

2) To analyse the meteorological and site factors among the study sites which can cause distinct pairs of CT and TX coefficients for each site. This can tenatively lead to a generalized procedure for finding appropriate coefficients for any site in Utah and surroundings.

3) To test a method of ETr estimation for agricultural locations in Utah whose only available meteorological parameters are maximum and minimum temperatures. The method to be tested is the New Hargreaves ET equation developed at the Utah State University International Irrigation Center.

LITERATURE REVIEW

A general estimation is that 80% of water consumed worldwide is attributable to irrigation (18). The increasing demand for irrigation water has caused engineers and planners to come up with ingenius methods of water utilization. In California, giant canals have been constructed for water delivary to the fertile soils of the San Joaquin valley. Soviet planners are considering the construction of a huge network of dams and canals to reverse the flow of the Pechora and Ob rivers that now rush uselessly into the Arctic sea. The potential waters are to be made available for irrigation in southern Russia (11). In a similar effort, the Chinese gvernment is building canals to divert the Chang Jiang river 750 miles to the North China Plain (36). Cost has been estimated at $13.2 billion. Scientists at the University of California, Davis, have developed strains of wheat, barley and tomatoes which can be irrigated by up to 70% pure seawater. The strains may be capable of creating productive agricultural regions out of millions of acres of the world's sandy deserts (34).

Water consumption by man and by nature through a variety of means are identified by specific terminologies. The combination of the evaporation of water from soil and crop surfaces and the transpiration through crop stomates is termed "evapotranspiration". Penman (28) initiated the term "ET", but for it not to mean evapotranspiration, rather to indicate "evaporation from turf". He writes:

> Many find it helpful to give a special name to the combined effect, referring to it as 'evapotranspiration'. ...it is presumably a useful term, but it is rather ugly[!], and it hardly seems necessary, as there are few situations in which the use of 'evaporation' or 'transpiration' is not entirely adequate (37, p.54).

Contemporary irrigation engineers and agriculturalists, however, refer to "ET" as an abbreviation for evapotranspiration. Many use the term "potential evapotranspiration", ETp, or "reference crop evapotranspiration", ETr. The term ETp is usually used in conotation with the amount of water evapotranspired in a unit of time by a green crop, completely shading the ground, of unifrom height and never short of water (28).

The actual bio-physical process of ET cools the crops and protects them from overheating. This is done by the transfer of 85 calories to the surrounding air for every gram of water evaporated. Dew formation at night and early morning is the reverse process in that it acts as insulation for crop surfaces by making available to the crop the energy resulting from water vapor condensation (37). The ET process also helps in conducting the nutrient solution necessary for crop growth and development to various parts of the crop. Studies show that ET is directly related to crop yields. The majority of yield-ET studies have found a linear relationship between the two (10,15); for example, Hill (15) found the following yield-ET relationship for southern Utah: $Y = 0.243(ET) - 0.765$ where Y is alfalfa yield in tons/acre, and ET is in inches.

ET and crop growth are known to be regulated by plant, soil, and climatic factors. With a relatively constant effect by the plant and soil factors, one should be able to estimate ET through climatic data. Historically scientists have not been easily convinced of the close relation among ET, yield, and meteorological parameters. In 1871 Koppen referred to the relation between climatic factors and crop development as:

> ..the beautiful illusion that it is possible to represent the development of plants, even those of a single species, by means of a general formula which contains temperature, light, humidity and other external agents as factors. But, to be sure, whoever finds illusion more pleasant than sober knowledge is not disturbed by such considerations; so he goes on his way in peace and it is no fault of his if others can not follow him (38, p.459).

Abbe wrote in 1905:

> Ofcourse, hydraulic and irrigation engineers need to know the loss of water by evaporation, but in nature this is so mixed up with seepage, leekage, and consumption by animals and plants that our meteorological data are of comparatively little importance (1, p.254).

With more scientific scruitiny the relationship of ET with meteorological factors became more clear. In 1915 at Akron, Colorado, Briggs (5) conducted a thorough study to determine the relationship of ET from a variety of crops to different weather factors. For most crops he found a high degree of correlation between ET and wet-bulb temperature followed by air temperature and solar radiation. Since then a plethora of methods, models, and equations for the quantitative estimation of evapotranspiration have been proposed. Usage of any specific method will depend on the type of meteorlogical data available and the accuracy of that method in estimating ET. The following describes some ET estimation methods and the research done by scientists in testing those methods. Emphasis is put on the temperature-radiation methods and the Penman combination equation.

Temperature-Radiation Methods

In 1961, the French scintist Turc (39) proposed an equation for estimation of ETp with the only inputs of mean air temperature and solar radiation. He worked with data from France, Denmark, Ireland, Morocco, Tunisia, Congo, Iraq, and Ceylon to derive the following formula:

$$ETp=0.013[T/(T+15)](Rs+50) \qquad (1)$$

where ETp is in mm/day, T is mean air temperature in degrees C, and Rs is the incident solar radiation in equivalent units of mm/day. The above equation is claimed by its author to give satisfactory results for areas with mean relative humidities (RH) of 50% or higher. For more arid regions with RH values less than 50%, Turc offers the following:

$$ETp=0.013[T/(T+15)](Rs+50)[1+(50-RH)/70] \qquad (2)$$

In 1963 Jensen and Haise (19) studied the evapotranspiration process based on the energy balance concept. The following relationship was proposed:

$$Rs(1-r)-Ret-ET-G-A \simeq 0 \qquad (3)$$

where, Rs = shortwave solar radiation flux,
r = crop reflectance or albedo,
Ret= effective or net thermal longwave radiation,
ET = rate of evapotranspiration,
G = sensible heat flux to or from the ground, and
A = sensible heat flux to or from the air.

Equation (3) was expressed in dimensionless form when divided by Rs:

$$ET/Rs = 1-r - Ret/Rs - G/Rs - A/Rs \qquad (4)$$

The ratio ET/Rs was said to represent the combined effects of net thermal radiation, heat flux to or from soil and air, and other minor components. Because of the non-linear relationship between saturated vapor pressure and air temperature and its effect on thermal radiation, air temperature was to have a direct effect on the ET/Rs ratio provided adequately irrigated crops, where evaporating and transpiring surfaces donot limit the vaporization of water. Working with data of approximately 1000 individual sampling periods during the growing season of fifteen crops obtained within a span of 35 years from four different climatic regions in the U.S., Jensen and Haise found a general linear relationship with good regression coefficient between the ET/Rs ratio and mean air temperature. Figure 2 shows the regression line and the data points used (19). The relationship found came to be known as the original Jensen-Haise evapotranspiration equation and is as below:

ETp=0.014(T-26.4)Rs...................................(5)

where, ETp = potential evapotranspiration (in/day),

T = mean air temperature (deg. ^{o}F), and

Rs = incident solar radiation (equivalent of in/day).

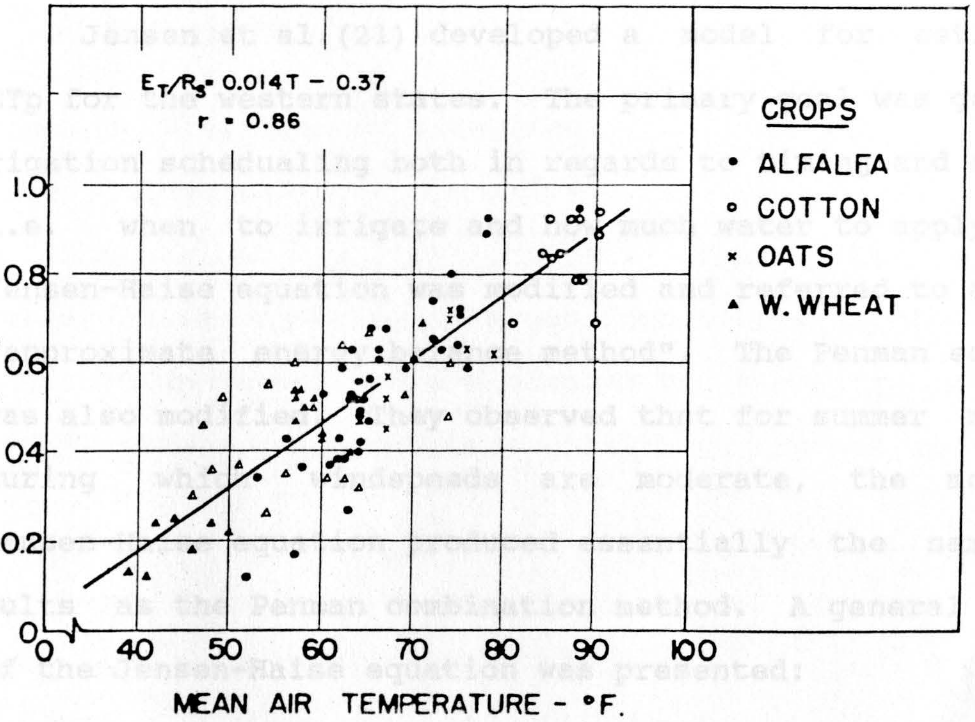

FIG. 2.- The Original Jensen-Haise Linear Regression Between ET/Rs and Mean Air Temperature, T. From Jensen and Haise (19).

Equation (5) was claimed by its authors to estimate good results of ETp for arid and semiarid areas.

Jensen et al.(21) developed a model for estimating ETp for the western states. The primary goal was good irrigation schedualing both in regards to timing and amount, i.e. when to irrigate and how much water to apply. The Jensen-Haise equation was modified and referred to as the "approximate energy balance method". The Penman equation was also modified. They observed that for summer months, during which windspeeds are moderate, the modified Jensen-Haise equation produced essentially the same results as the Penman combination method. A general format of the Jensen-Haise equation was presented:

$ETp = CT(T - TX)Rs$ ....(6a)

The CT and TX coefficients were proposed to be derived for specific sites as so:

$CT=1/(C_1+13C_h)$ ....(T in deg. ^{o}F)............(6b)

$CT=1/(C_1+7.3C_h)$ ....(T in deg. ^{o}C)............(6c)

where C_h is a humidity index and C_1 is an elevation index.

$C_h=[37.5\ mmHg\ /(e_1-e_2)]=[50\ mb\ /(e_1-e_2)]$ ....(6d)

e_1 and e_2 are saturation vapor pressures (mmHg or mb) during the warmest month of the year at the mean maximum and minimum air temperatures respectively.

$C_1 = 68 - 3.6E/1000$ ....(6e)

where E= elevation of site (feet),

$TX = 27.5 - 0.25(e_1 - e_2) - E/1000$ ....(6d)

Jensen et al.(22) indicate that the modified Jensen-Haise equation is a good substitute for the Penman combination method where windspeed and humidity data are not available, and advective conditions are not severe.

In 1965 Stephens (35) worked with ET data from Florida, North Carolina and Davis, California. He came up with four regression equations of ET/Rs vs. T for different climatic regions depending on their average July local noon relative humidity. Figure 3 shows a U.S. map as it was divided into four different areas based on mean RH values corresponding to Stephens' classification. Stephens took the original Jensen-Haise coefficients to represent the western and mid-western U.S. with average July noon RH of less than 40%. Table 1 shows his results.

Grabow (9) did regression analysis of measured ET over solar radiation vs. the average temperature for different sites. He found large negative X-intercepts which

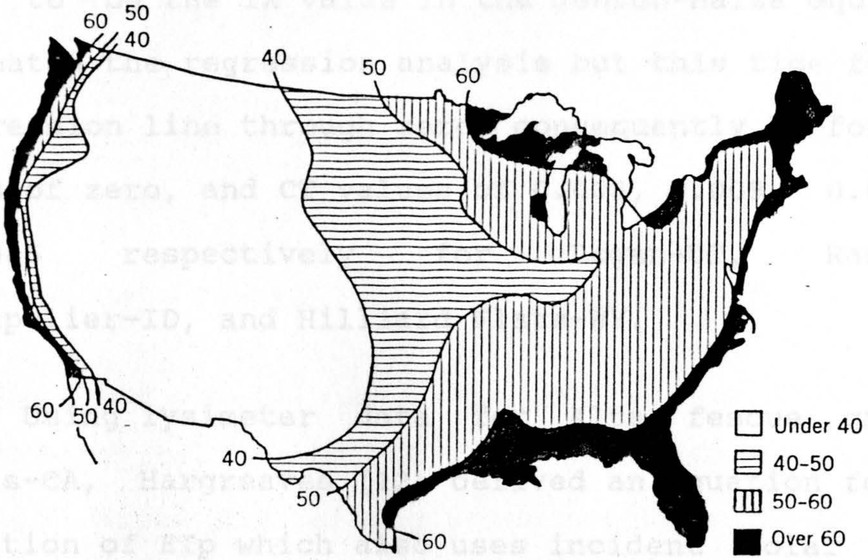

FIG. 3.- U.S. Map as Divided by Stephens into Four Areas of Similar Mean Relative Humidity Values. From Stephens (35).

Table 1.- Stephens' Proposed ET Equations for the Continental U.S. Based on Relative Humidity (RH) Values. From Stephens (35).

Average RH	Regression Equation	CT	TX
RH > 60%	ET/Rs = 0.00820(T) - 0.1900	0.00820	23.2
50% < RH < 60%	ET/Rs = 0.00868(T) - 0.1938	0.00878	22.1
40% < RH < 50%	ET/Rs = 0.01067(T) - 0.2256	0.01067	21.1
RH < 40%	ET/Rs = 0.01400(T) - 0.3700	0.01400	26.4

are to be the TX value in the Jensen-Haise equation. He repeated the regression analysis but this time forcing the regression line through zero; consequently he found TX values of zero, and CT values of 0.008, 0.009, 0.0085, and 0.0085 respectively for Logan-UT, Randolph-UT, Montpelier-ID, and Hilliard Flats-WY.

Using lysimeter data for Alta fescue grass from Davis-CA, Hargreaves (12) derived an equation for the estimation of ETp which also uses incident solar radiation and mean temperature:

$$ETp = 0.0075(Rs)T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where, ETp = potential grass ET (in/day),

Rs = incident solar radiation in equivalent depth of water evaporation,

T = average daily temperature (deg. $^{\circ}$F).

Assuming an alfalfa-grass ETp conversion factor of 1.2, the 0.0075 in the Hargreaves equation would change to 0.0090; notice that this would be a version of the Jensen-Haise equation for a reference crop of alfalfa with CT of 0.009 and TX of zero.

Hargreaves and Samani (13) estimated the incident solar energy, Rs, as a function of extraterrestrial radiation, Ra, and difference of maximum to minimum temperatures, TD. The resulting equation was as follows:

$Rs = K \times Ra \times TD^{0.50}$ ....(8)

K is a calibration coefficient. Equation (8) was combined with eqaution (7), resulting in the relationship below:

$ET_o = K (Ra \times T \times TD^{0.50})$ ....(9)

If the above equation be valid, and if the coefficient K is lacally calibrated, it would have very practical usage in rural areas and farming communities, since the only measurements required are maximum and minimum temperatures.

Doorenbos and Pruitt (8) present an ET estimation method in the FAO Irrigation and Drainage Paper #24. It looks as below:

$ET_o = c(W.Rs)$...(10)

where ET_o is the reference crop ET in mm/day. It was defined as:

> ...the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (8, p.9).

Rs is incident solar radiation in equivalent of water evaporation.

W is a weighing factor depending on the temperature and altitude.

c is an adjustment factor depending on the mean humidity and daytime wind conditions.

Doorenbos and Pruitt present tables and graphs to determine specific W and c values which depend on the altitude, mean temperature, mean RH, and mean wind movement of an area.

Penman Combination Equation

Aristotle is known to have contempolated whether the sun or the wind is the most important factor influencing evaporation. He is known to have chosen wind for he said it carried the vapor away (28). In 1948 Penman (29) indicated that in order for evaporation to happen, there are two necessary requirements. One is the supply of energy better known as the latent heat of vaporization, and the other is a mechanism for removing the water vapor or a sink for vapor. These two processes are known as the "energy balance" and the "turbulant transfer" concepts, and form the bases of the Penman combination equation. Penman's equation in 1948 had the following format:

$E_o = (Rn \Delta + 0.27E_a)/(\Delta + 0.27)$.......................(11)

where, E_o = evaporation from open water (mm/day),

Rn = net radiant energy available at the surface in evaporation equivalent (mm/day),

Δ = slope of the saturation vapor pressure and temperature (^oF) curve (de_a/dT),

$E_a = 0.35(1+0.0098U_2)(e_a - e_d)$,

U_2 = mean wind velocity at 2 meter height (miles/day),

e_a = saturation vapor pressure at the air temperature (mmHg), and

e_d = saturation vapor pressure at the dew-point temperature (mmHg).

Penman observed that crop ET averaged about $0.75E_o$.

Later Penman (30,31) modified his equation of open water evaporation to represent evapotranspiration as such:

$$ET = [(\Delta / \gamma)Rn+E_a] / [(\Delta / \gamma)+1] \quad \text{.................(12)}$$

where, ET = potential crop evapotranspiration (mm/day),

γ = wet and dry-bulb psychrometric equation constant,

E_a is an expression for the "drying power" of the air involving windspeed and saturation deficit:

$E_a = 0.35(1 + U_2/100)(e_a - e_d)$, and

Δ, u_2, e_a, and e_d are as defined earlier.

Penman (28,31) indicated that since the main source of energy for ET is radiant sunshine, the heat or energy reaching the vegetation would be:

$$H=Rs(1-r)-Rb \quad \text{...(13)}$$

where, H=heat budget or net radiation, Rn,
Rs=shortwave incomming radiation,
r=reflection coefficeint or albedo,
Rb=net longwave outgoing or back radiation.

He also states that the expenditures for the heat budget are mainly dual. One being ET, and the other being sensible heat transfer to the air A, i.e.: H = ET + A. If the condition of adequate water supply to vegetation is met, the ratio of A/ET can be a small and constant value. Since the effect of sensible heat transfer, A, is to raise the surrounding air temperature, air temperature measurements can serve as good indicators of A and ET. Under conditions of adequate water supply (or water non-limiting), higher air temperatures can be directly associated with higher ET. However if the condition of adequate water supply is not met, the reverse can be true, i.e. more energy is used for sensible heat, and less for ET. This can cause higher crop canopy and soil temperatures, and lower ET, hence creating an indirect relationship between air temperature and ET. In such conditions air temperature measurement used as a parameter in ET formulas can be misleading, and will over-estimate ET.

Jensen et al.(21) using lysimeters in Kimberly, Idaho, modified and calibrated the Penman equation. The current version of the modified Penman equation which is used extensively throughout the intermountain U.S. stands as such (16):

$$ETr = [\Delta/(\Delta + \gamma)](Rn+G) + [\gamma/(\Delta + \gamma)]15.36(W_1 + W_2U_2)(e_s - e_a) \ldots\ldots\ldots (14)$$

where, ETr = reference crop ET for "...well watered actively growing alfalfa with sufficient growth for near maximum ET in arid, irrigated regions" (40). ETr is in units of langleys/day or in/day if multiplied by 1/(585 x 2.54) = 0.000673,

Δ and γ are as defined previously,

Rn = net radiation (langleys/day),

G = soil heatflux (langleys/day),

W_1 and W_2 are empirical wind parameters dependent on location and type of crop grown,

U_2 = wind movement at 2 meters height (miles/day),

e_s = saturation vapor pressure at mean air temperature (mmHg) as in the mean of saturation vapor pressures at mean daily maximum and minimum air temperatures,

e_a = mean actual vapor pressure (mmHg) to be equivalent to the saturation vapor pressure at mean daily dewpoint temperature, Td. Td can be approximated from a single morning dewpoint temperature determination.

The above inputs required for the modified Penman ETr equation can be empirically determined leaving only the following required meteorological measurements:

1. maximum daily air temperature Tmx,
2. minimum daily air temperature Tmn,
3. early morning dew-point temperature Td,
4. incomming solar radiation Rs,
5. daily wind travel U_z, measured at height z.

For a description and format of the empirical formulas used in the modified Penman combination ET estimation equation, refer to Appendix I.

Estimation of ETr is one of the steps necessary for finding the amount of water lost by field crops or the actual crop ET. Usually a crop factor, Kc, is multiplied by ETr to arrive at the actual ET. Figure 4 from Burman et al.(6) demonstrates a systematic approach of estimating ET and irrigation water requirements through different methods.

Wright (40) developed improved crop coefficients for various irrigated crops at southern Idaho. Initially, measured daily alfalfa ET, using lysimeters, were to be used as reference ET in Wright's research for calculation of crop coefficients, while estimated ETr from the modified Penman combination method were to be used only when the alfalfa was not at full cover. However, for the eight years of lysimeter data at Kimberly-ID, measured ET was not at a maximum level during much of the growing season. The reasons sited were the time required for the alfalfa to reach full cover in the spring and after each cutting, and the lodging caused by wind and rain. Hence Wright used the modified Penman combination method to find a procedure for calcutating the final ET. The Penman method provided a continuous and consistant data base for obtaining kc for the entire growing season.

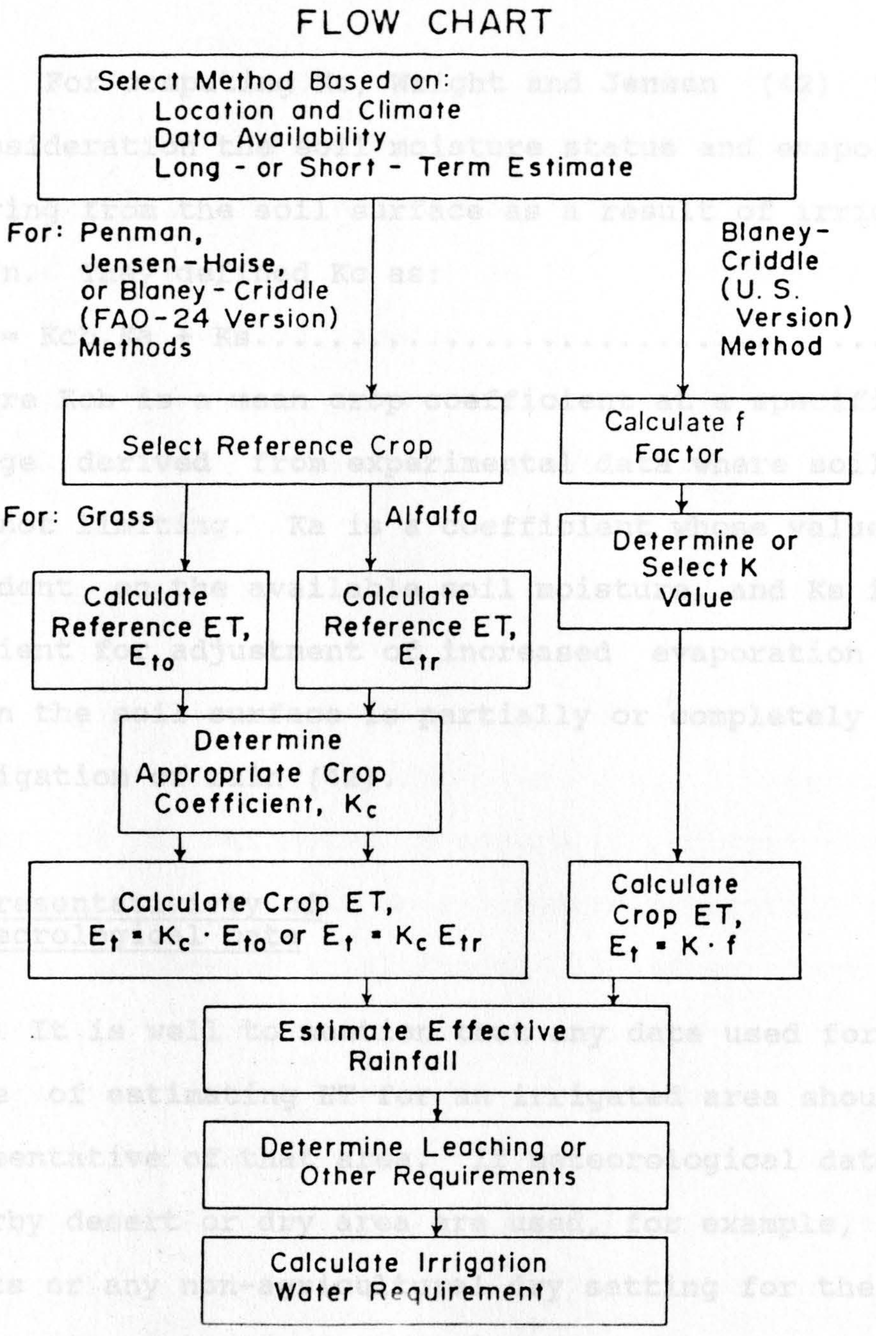

FIG. 4.- Flow Chart Demonstrating the Steps Necessary for the Calculation of Crop ET and Irrigation Water Requirements. From Burman et al. (6).

For computing Kc, Wright and Jensen (42) took into consideration the soil moisture status and evaporation occuring from the soil surface as a result of irrigation or rain. They defined Kc as:

Kc = Kcb.Ka + Ks.......................................(15)

where Kcb is a mean crop coefficient at a specific growth stage derived from experimental data where soil moisture is not limiting. Ka is a coefficient whose value is dependent on the available soil moisture, and Ks is a coefficient for adjustment of increased evaporation accuring when the soil surface is partially or completely wetted by irrigation or rain (42).

Representativivty of Meteorological Data

It is well to mention that any data used for the purpose of estimating ET for an irrigated area should be representative of that area. If meteorological data from a nearby desert or dry area are used, for example, from airports or any non-agricultural dry setting for the purpose of estimating ET of an irrigated zone, the corresponding ET values can be misleading. Studies done on this topic (3,7,14) show that introducing irrigation to a previously non-irrigated dry area creates lower day and night time temperatures, higher humidity, and lower windspeeds.

Allen et al.(3) compared the meteorological differences of an irrigated as compared to a non-agricultural setting in an area in southern Idaho. They found that an overestimation of as much as 19% over the season can occure if the weather parameters used for the ETr estimation are not measured in midst of an irrigated area of adequately watered and actively growing crops.

ET Estimation for High Altitudes

The difference in vapor pressure between the crop moist surfaces and the surrounding air increases with decrease in the barometric pressure at constant temperature (24). Since changes in barometric pressure are directly related to changes in altitude, all other factors being constant, one would expect an increase in ET with an increase in altitude. Longacre and Blaney (24) observed this effect by measuring pan evaporations at various locations in California ranging in altitude from 150 meters (500 ft) to 2800 meters (9200 ft). It was observed that as the elevation increased the rate of annual evaporation also increased.

Allen and Brockway (2) and Pochop et al.(32) tried to calibrate versions of the Blaney-Criddle ET equation with temperature as its only measured parameter for high elevations of Idaho. It was found that without an adjustment of 6-10% increase per 1000 m of elevation increase, ET would be underestimated for high elevations. The reason cited was the increased relative cooling of the air during night hours at high altitudes due to decreased density of the atmosphere. This creates low night time temperatures which in turn lower the mean 24 hour air temperature and do not reflect the net effect of daytime temperature and solar radiation available for the ET process.

Johns et al.(23) compared the alfalfa ET estimates obtained from various methods for ten scattered sites in the western U.S.. They found no single equation to function adequately for all ten sites and consequently recommended the usage of correction factors for estimation of field-obtained crop ET. The correction factor found for the Jensen- Haise equation with the elevation correction (JHE) correlated well with changes in altitude. Hence they conclude that out of the seven equations used, "...the JHE equation [with a second correction factor] seems to come closest to being... [a] generallly applicable ET method for the sites used" (23, p.20).

Evapotranspiration is just one of several important factors which combine to influence total irrigation water requirements. Water is lost during the process of delivery to farms and application to fields in the form of evaporation and seepage from canals, laterals, and ditches. Irrigation water is also used for leaching salts, easing tillage or harvest operations, protection against frost, and cooling of plants. Conservation in the use of irrigation water supplies can make available more irrigated agricultural lands. For example, Israel has been able to increase its irrigated lands by 25% without increasing its irrigation water supplies (20). Therefore, if the aim is to conserve water in an arid area, efforts should also be directed toward minimizing losses and increasing efficiencies of use of water other than that of evapotranspiration, otherwise

> ...there is little reason for insisting upon a method which will give estimates of consumptive use within close limits of accuracy if procedures for estimating the remainder of the water which comprises the total [irrigation] requirements are not of comparable accuracy (33, p.181).

PROCEDURE

Calibration of the Temperature-Radiation Equation

Ideally, any calibration of an equation which is to be used as a quantitative estimation of a natural phenomenon, such as evapotranspiration, should be done directly against measured values of that phenomenon. Although sensitive measuring devices, such as various types of lysimeters and neutron probes are available, the use of any of these devices does not necessarily provide the researcher with a reliable longterm data-base. With the main purpose of this study being the calibration of an ETr equation, the subject matter becomes even more complicated since ETr, being an "alfalfa reference evapotranspiration rate" can be hard to measure . In order to measure ETr, a sensitive alfalfa lysimeter would be required with the alfalfa being always at a constant state of full growth and water being non-limiting. Also the lysimeter should be located at a representative site, i.e. it should be located within a large irrigated alfalfa field.

The measured data available for this study were obtained by Grabow (9) using neutron probes and water-table lysimeters. Unfortunately these data were not considered as reliable data-base for the calibration of the Temperature-Radiation equation for a number of reasons: 1)Often high water tables within the lysimeters created erroneous ET values, particularly with a 7 day interval between readings. 2)The lysimeters were not always at a representative setting. For example, a grass lysimeter located at Utah State University's north experimental farm in Logan had only a very small area of grass surrounding it, and a weather station, a tree, and a road were within steps of the lysimeter. 3)There were no alfalfa lysimeters in Utah. 4)The data were scattered, and often did not cover all the growing season. Where measured data for more than one growing season were available for a site, the ET values for different years were not consistent, that is, the measured ET values fluctuated considerably from one year to another, making them appear unreliable. However, the meteorological data available for this study were generally daily, consistent, continuous (covering all the growing season), and longterm (more than one growing season).

A version of the Penman ET equation (equation 14 of the Literature Review) was calibrated by J. L. Wright at the University of Idaho Agricultural Research Center in Kimberly, Idaho. The data-base used for the Kimberly calibration were derived from several years of measured alfalfa ET using weighing lysimeters at Kimberly (22,42).

Alfalfa has been considered to serve as a good reference crop for a variety of reasons. It is widely grown in arid and semi-arid irrigated areas; 40% of Utah's irrigated acreage is in alfalfa (17). Alfalfa has a long growing season, and produces sufficient canopy thickness in a short period of time. This provides for good absorption of solar radiation above the ground surface. Also, alfalfa has low leaf resistance to water vapor diffusion and has a large root system, especially as compared to grass. Alfalfa produces relatively high ET rates under arid conditions where there are advective sensible heat input available from the air, and its ET rate is little affected by decreasing soil moisture (4,41). The combination of these factors provide the irrigation engineer with a reliable reference crop evapotranspiration rate.

With consideration of the above, the Kimberly Penman method of estimating ETr with the 100 mile wind limit, which has been tested as being an accurate method of alfalfa ETr estimation for Utah (9,17) and Southern Idaho (4,22,40,42), was considered as the best alternative to be used for the calibration of the Temperature-Radiation ETr equation.

The Kimberly Penman ETr equation requires five discrete meteorological measurements. They are: 1) maximum daily temperature Tmx, 2) minimum daily temperature Tmn, 3) early morning dew-point temperature Tdw, 4) incoming daily solar radiation flux Rs, and 5) daily wind travel. Eighteen sites were selected for which the above data were available. A list of the study sites is shown in Table 2 with their state, county, latitude, longitude, elevation, and years of available data. Among the eighteen sites, there was a total of 45 meteorological datafiles. Figure 5 shows a map of Utah and the relative position of the study sites in the state of Utah.

A version of the FORTRAN program named CRPSIM developed at Utah State University, department of Agricultural and Irrigation Engineering was utilized to read the meteorological datafiles of our study sites and to generate discrete 5-day sum Penman ETr values needed for the calibration process of the Temperature-Radiation equation. For a listing of the CRPSIM program, refer to Appendix II.

The original Jensen-Haise equation had CT and TX values equal to 0.014 and 26.4 respectively. Jensen and Haise estimated these values by simple linear regression (19). In order to come up with coefficients for the Tem-

TABLE 2.- List of the Study Sites with their State, County, Latitude, Longitude, Elevation, and Years of Available Data.

SITE	COUNTY	LATITUDE	LONGITUDE	ELEVATION	YEARS
UTAH					
St. George	Washington	37.08	113.68	2800	1984
Enterprize	Washington	37.57	113.70	5300	1984
Parowon	Iron	37.85	112.83	5930	1980
Flowell	Millard	38.98	112.42	4702	1980,81
Delta	Millard	39.33	112.59	4623	1983
Park City	Summit	40.72	111.52	6740	1982-84
SLC AP	Salt Lake	40.78	111.95	4267	1970-81
Kaysville	Summit	41.07	111.18	4267	1980-82
Paradise	Cache	41.58	111.60	5000	1984
Thornack	Rich	41.75	111.13	6280	1983
Randolph	Rich	41.75	111.13	6280	1982-84
Logan	Cache	41.75	111.82	4580	77,80-82
Garland	Cache	41.75	112.19	4400	1984
IDAHO					
Kimberly	Cassia	42.19	114.12	3960	69-75,80-82
Mont Pelier	Bear Lake	42.32	111.26	5000	1984
Talmage	Caribou	42.70	111.77	5600	1982
WYOMING					
Hilliard Flats	Unita	41.08	111.01	7550	1982-84

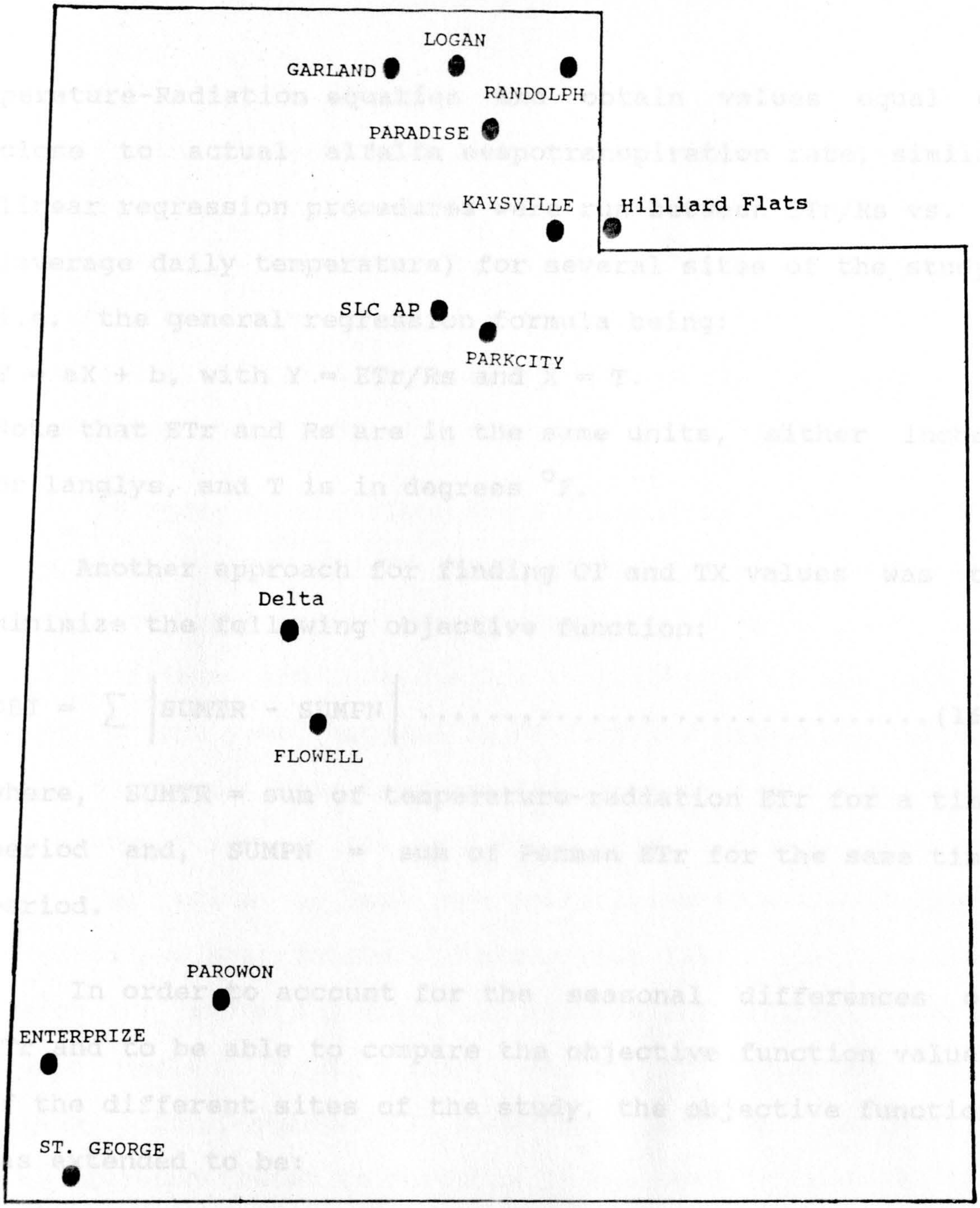

FIG. 5.- Map of Utah and the Relative Position of the Study Sites in the State of Utah.

perature-Radiation equation and obtain values equal or close to actual alfalfa evapotranspiration rate, similar linear regression procedures were run between ETr/Rs vs. T (average daily temperature) for several sites of the study; i.e. the general regression formula being:

$Y = aX + b$, with $Y = ETr/Rs$ and $X = T$.

Note that ETr and Rs are in the same units, either inches or langlys, and T is in degrees ^{o}F.

Another approach for finding CT and TX values was to minimize the following objective function:

$$OBJ = \sum \left| SUMTR - SUMPN \right| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

where, SUMTR = sum of temperature-radiation ETr for a time period and, SUMPN = sum of Penman ETr for the same time period.

In order to account for the seasonal differences of ETr and to be able to compare the objective function values of the different sites of the study, the objective function was extended to be:

$$OBJ = \left(\sum \left| SUMTR-SUMPN \right| + \left| SEASTR-SEASPN \right| \right) x100/SEASPN\ldots\ldots (17)$$

where, SEASTR = seasonal sum of ETr using the Temperature-Radiation method,

SEASPN = seasonal sum of ETr using the Kimberly Penman method,

OBJ is in units of inches/inches and represented as a % value.

A FORTRAN computer program, named TEMPRAD, was written to find the lowest objective function for every data file. Appendix II contains the FORTRAN program listings used for this study and a sample of a typical data-file used.

In order to calculate the Jensen-Haise 1970 equation coefficients CT and TX, the elevation of the site and the saturated vapor pressures corresponding to the long term mean maximum and mean minimum temperatures of the warmest month of the year (assumed to be July for the study sites) were required. Mean longterm July maximum and minimum temperatures for the sites were found from isolines outlined for the state of Utah in a publication from the National Oceanic and Atmospheric Administration (25). The isolines were the average normal July maximum and minimum temperatures derived from twenty years of recorded data (1932-1952). Appendix III shows such isolines. An empirical equation (refer to Appendix I) was used to derive the saturated vapor pressure as a function of temperature. Values for the coefficients CT and TX were obtained for the Jensen-Haise 1970 equation using eq.s 6b-6f of Chapter 1. Table 3 contains the mean long term July maximum and minimum temperatures, and the CT and TX coefficients for all the sites in this study.

When trying to find the lowest OBJ function for the Temperature-Radiation equation, TEMPRAD went through a simple do-loop, each time using a distinct pair of CT and TX. Figure 6 shows a 3-dimensional graph with changes of CT and TX, and the corresponding change in the objective function OBJ for Logan 1982 growing season's data.

TEMPRAD was modified to find the CT values for each site while holding TX equal to zero. Holding TX as zero transferred the temperature-radiation equation into a version of the Hargreaves equation. It was found that by doing so, the OBJ values did not increase considerably. The final calibration results and the corresponding coefficients to be used in the Datapod field computer are stated in the Results section.

General Method for Determining CT

Equations 6b-6f of the Literature Review section were proposed by Jensen et al.(21) for determining CT and TX of the Jensen-Haise equation. Jensen et al. took CT and TX as functions of elevation and saturation vapor pressure de-

TABLE 3.- Mean Long Term July Maximum and Minimum Temperatures, and the CT and TX Coefficients of the 1970 Jensen-Haise ET Eqaution.

SITE	July long term average temperatures (F) Max.	Min.	CT	TX
St. George	101.0	68.6	0.0138	13.60
Enterprize	90.0	57.2	0.0145	14.08
Parowon	88.0	56.0	0.0147	14.03
Flowell	90.0	60.0	0.0136	15.10
Delta	94.0	60.0	0.0145	13.55
Park City	79.4	41.4	0.0144	14.39
Kaysville	92.3	60.8	0.0139	14.75
SLC AP	92.3	60.8	0.0139	14.75
Paradise	83.0	53.4	0.0131	16.31
Thornack	80.6	43.8	0.0142	14.72
Randolph	81.1	44.2	0.0143	14.61
Logan	87.5	56.0	0.0136	15.56
Garland	87.3	58.4	0.0132	16.16
Kimberly	84.0	54.0	0.0123	17.11
Mont Pelier	81.9	45.8	0.0135	15.80
Talmage	84.0	49.0	0.0141	14.87
Hilliard flts	74.7	45.3	0.0134	15.18

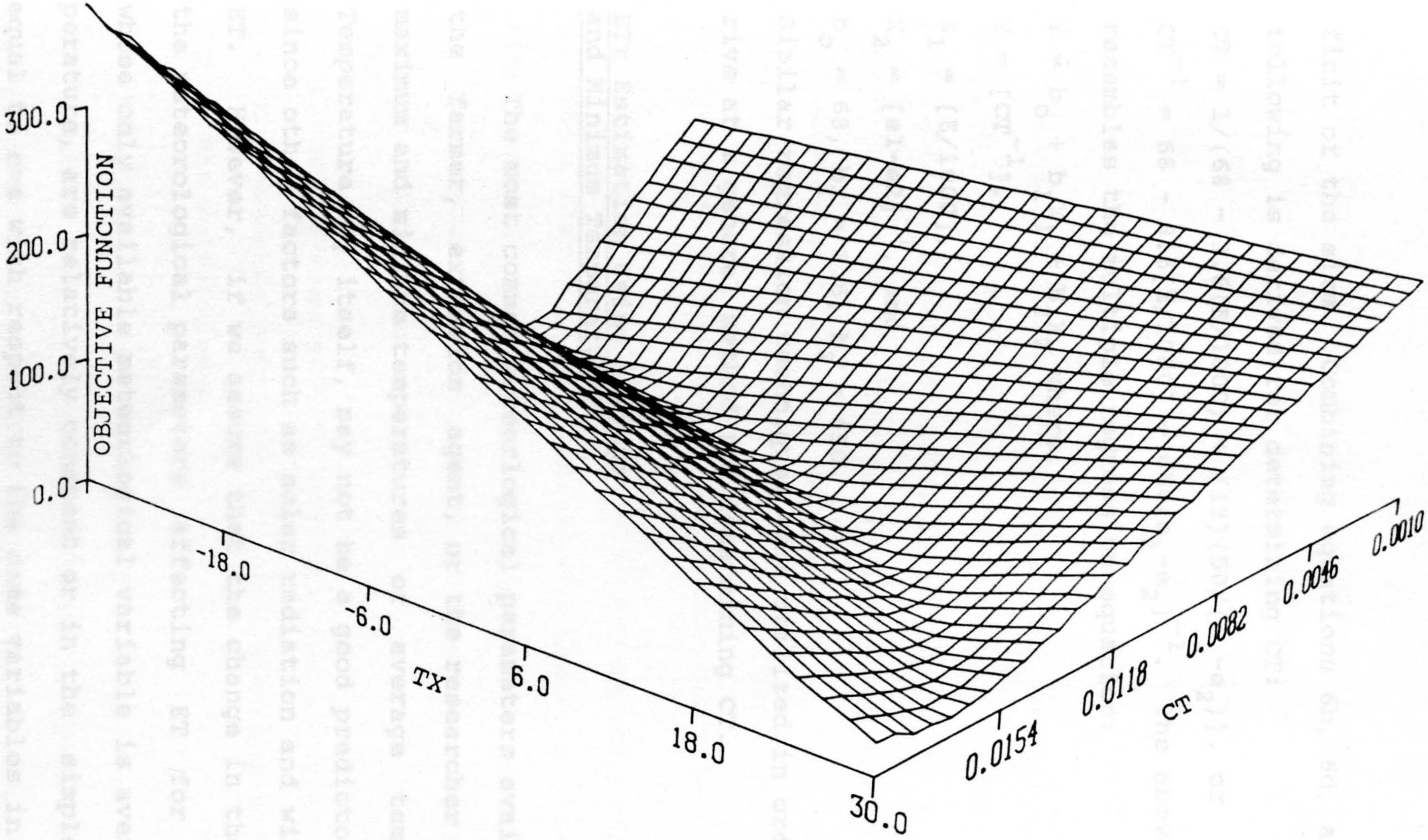

FIG. 6- Three Dimensional Graph Showing the Objective Function with Changes in CT and TX Coefficients Using the Logan 1982 Meteorological Data.

ficit of the site. Combining equations 6b, 6d, and 6e, the following is derived for determining CT:

$CT = 1/(68 - 3.6(E/1000) + (13)(50/(e_1-e_2))$, or

$CT^{-1} = 68 - 3.6[E/1000] + 650[e_1-e_2]^{-1}$. The above equation resembles the multiple regression equation:

$Y = b_o + b_1X_1 + b_2X_2$ where,

$Y = [CT^{-1}]$,

$X_1 = [E/1000]$,

$X_2 = [e1-e2]^{-1}$, and

$b_o = 68$, $b_1 = 3.6$, $b_2 = 650$.

Similar regression techniques were utilized in order to arrive at a general method for determining CT.

ETr Estimation Using Maximum and Minimum Temperatures

The most common meteorlogical parameters available to the farmer, extension agent, or the researcher are daily maximum and minimum temperatures or average temperature. Temperature, by itself, may not be a good predictor of ETr, since other factors such as solar radiation and wind affect ET. However, if we assume that the change in the rest of the meteorological parameters affecting ET for site A, whose only available meteorlogical variable is average temperature, are relatively constant or in the simplest case equal to one with respect to the same variables in a nearby site B, that is to say, if we assume that site A and B's weather parameters, i.e. vapor pressure, dew point, solar radiation, wind,...etc. are the same except for daily maximum and minimum temperatures, theoretically we could estimate ETr for site A by using ETr values of site B.

In order to see what effect temperature change alone has on ETr, TEMPRAD was modified to calculate Penman ETr while changing maximum and minimum temperatures within the range of $\pm$ 10 ^{o}F. It was found that if all other factors are held constant, temperature change in the Penman equation would be linearly related to ETr. Figure 8 of the next chapter shows this linear relationship.

Assuming Kaysville is the site B we were referring to, ETr for a nearby site A can be equivalent to the product of ETr of site B, ETr_B, and a multipler "m". m would simply be the ratio of ETr_B with a temperature change to ETr_B without a temperature change.

Attempts were made to derive a single equation relating the average temperature T, and the temperature change ΔT to the multiplier m.

As stated in the Literature Review section, Hargreaves and Samani (13) proposed an ET equation with the required measurements of maximum and minimum temperatures, and estimated extraterrestrial radiation. The equation is:

$ET_o = K \times (T \times TD^{0.05} \times Ra)$ where,

ET_o=grass reference evapotranspiration rate (in/time period),

Ra=extraterrestrial radiation (same units as ET_o),

TD=difference of mean maximum and mean minimum temperatures (°F).

The above equation was calibrated against eight years of Alta fescue grass ET from lysimeters at Davis-CA (13). The K found was 0.00094. Hargreaves and Samani suggested this K for places where local calibration is not possible. Assuming a 1.2 factor of conversion between grass ET and alfalfa ET, the suggested K for the reference crop of alfalfa would be 0.001128 (1.2 x 0.00094).

In order to find locally calibrated K values for the sites of this study, TEMPRAD was used to minimize the same objective function, OBJ, as was utilized for the Temperature-Radiation equation. These and other results are stated in the next chapter.

RESULTS

Calibration of the Temperature-Radiation Equation

Table 4 shows the linear regressions between ETr/Rs and T for several years of growing season's data from Flowell, Kaysville, Kimberly, and Logan-Utah. As can be seen from the low correlation coefficients R^2, such linear regression, a technique used by Jensen and Haise (19) was not a good strategy for the calibration of the Temperature-Radiation equation with the meteorological data available for the sites of this study.

Seasonal data were reduced to the months of May through September wherever possible. The objective function as stated by equation 17 was used in the TEMPRAD program. TEMPRAD was run with the datafiles available. The values for CT and TX were restricted to 0.005 to 0.020, and -30 to +30 respectively. Consequently the objective functions were minimized and distinct pairs of CT and TX were derived for each datafile. The initial calibration of the Temperature-Radiation method against the Penman method are shown in Table 5. Table 5 contains all the study sites and

TABLE 4.- Results of the Regression Between ET/Rs and Average Temperature, T, for Several Datafiles.

SITE	YEAR	PERIOD	REGRESSION EQUATION	R Squared
FLOWELL	1980	5/01-09/30	(ET/RS)=.0099 + .0672(T)	45.0%
FLOWELL	1981	4/08-10/31	(ET/RS)=.0100 + .2527(T)	10.0%
KAYSVILE	1980	4/01-10/03	(ET/RS)=.0055 + .3900(T)	5.4%
KAYSVILE	1981	4/01-10/04	(ET/RS)=.0050 + .3959(T)	3.8%
KAYSVILE	1982	4/06-10/20	(ET/RS)=.0069 + .2369(T)	19.7%
KIMBERLY	1980	4/01-09/30	(ET/RS)=.0076 + .2122(T)	7.8%
KIMBERLY	1981	4/01-09/30	(ET/RS)=.0046 + .4617(T)	4.9%
KIMBERLY	1982	3/16-09/30	(ET/RS)=.0053 + .2704(T)	14.8%
LOGAN	1981	4/01-10/30	(ET/RS)=.0055 + .1915(T)	10.9%
LOGAN	1982	4/01-09/30	(ET/RS)=.0041 + .3138(T)	5.4%

the initial CT, TX, and OBJ values obtained. As can be seen no site produced the same CT and TX coefficients for all years of data available for that site.

In order to avoid negative TX values, and to attempt to reduce the coefficients pertaining to each site from two (CT and TX) to one (CT), TEMPRAD was modified to find the CT coefficient while holding TX at zero. By doing this, CT values of the different years for the same site tended to take the same value. Table 6 shows the CT coefficients when TX is held at zero and the corresponding OBJ functions obtained. The OBJ functions of Table 6 are on the average only 2.25% higher than their corresponding values in Table 5.

For sites for which only one growing season's meteorological data were available, the CT values obtained were considered as final and are recommended as the coefficients to be used by the Datapod field computer. However, for sites which had more than one growing season's data available, and different CT coefficients were obtained corresponding to each year's data, a method was utilized to find the best CT to be used by the Datapod at those sites.

TABLE 5.-Initial Calibration Results of the Temperature-Radiation Equation with Distinct Pairs of CT and TX for Each Datafile.

SITE	YEAR	GROWING SEASON	CT	TX	OBJ
St. George	1984	5/ 1- 9/30	0.0080	-25.0	5.62%
Enterprize	1984	5/ 1- 9/30	0.0075	-30.0	4.19%
Parowon	1980	5/ 1- 9/30	0.0095	- 1.0	3.65%
Flowell	1980	5/ 1- 9/30	0.0130	12.0	4.74%
Flowell	1981	5/ 1- 9/30	0.0080	-29.0	11.83%
Delta	1983	5/ 1- 9/30	0.0100	5.0	4.63%
Park City	1982	5/27-10/ 9	0.0070	-27.5	5.17%
Park City	1983	5/ 5-10/ 5	0.0070	-24.5	5.56%
Park City	1984	5/ 4- 9/30	0.0070	-29.5	4.44%
SLC AP	1972	5/ 1- 9/30	0.0090	2.0	5.53%
SLC AP	1973	5/ 1- 9/30	0.0080	- 7.5	5.56%
SLC AP	1974	5/ 1- 9/30	0.0070	-19.0	3.93%
SLC AP	1975	5/ 1- 9/30	0.0085	- 1.5	4.20%
SLC AP	1976	5/ 1- 9/30	0.0075	-11.0	3.92%
SLC AP	1977	5/ 1- 9/30	0.0070	-17.0	6.04%
SLC AP	1978	5/ 1- 9/30	0.0085	- 2.5	5.36%
SLC AP	1979	5/ 1- 9/30	0.0065	-24.0	4.47%
SLC AP	1980	5/ 1- 9/30	0.0095	6.0	5.53%
SLC AP	1981	5/ 1- 9/30	0.0070	-19.0	6.39%
Kaysville	1980	5/ 1- 9/30	0.0115	9.0	6.88%
Kaysville	1981	5/ 1- 9/30	0.0065	-28.5	6.52%
Kaysville	1982	5/ 1- 9/30	0.0075	-21.0	5.92%
Logan	1980	5/ 1- 9/30	0.0075	-13.5	5.54%
Logan	1981	5/ 1- 9/30	0.0070	-20.5	4.95%
Logan	1982	5/ 1- 9/30	0.0085	- 8.0	6.29%
Paradise	1984	5/ 1- 9/30	0.0070	-29.5	4.88%
Thornack	1983	5/ 1- 9/30	0.0120	8.0	5.75%
Randolph	1982	5/26-10/22	0.0080	-15.5	5.42%
Randolph	1983	5/ 1- 9/30	0.0065	-28.5	4.02%
Randolph	1984	5/ 1- 9/30	0.0070	-26.5	4.58%

Garland	1984	5/ 1- 9/30	0.0075	-21.0	5.18%
Kimberly	1969	5/ 1- 9/30	0.0105	3.5	5.47%
Kimberly	1970	5/ 1- 9/30	0.0080	-13.5	5.32%
Kimberly	1972	5/ 1- 9/30	0.0095	- 2.5	5.82%
Kimberly	1973	5/ 1- 9/30	0.0075	-18.5	4.40%
Kimberly	1974	5/ 1- 9/30	0.0085	- 9.0	4.49%
Kimberly	1975	5/ 1- 9/30	0.0080	-13.0	5.05%
Kimberly	1980	5/ 1- 9/30	0.0100	0.5	8.65%
Kimberly	1981	5/ 1- 9/30	0.0080	-14.5	5.16%
Kimberly	1982	5/ 1- 9/30	0.0065	-23.5	5.04%
Mont Pelier	1984	5/ 1- 9/30	0.0065	-28.5	5.81%
Talmage	1982	5/ 7-10/ 7	0.0065	-26.0	6.35%
Hilliard Flts	1982	5/27-10/22	0.0075	-18.5	6.03%
Hilliard Flts	1983	5/ 6-10/ 6	0.0080	-15.0	5.06%
Hilliard Flts	1984	5/ 4-10/ 2	0.0070	-29.0	4.71%

Average OBJ: 5.42%

TABLE 6.- CT Coefficients when TX is Held at Zero and the Corresponding OBJ Function Values Obtained.

		TX=0	
SITE	YEAR	CT	OBJ
St. George	1984	0.01054	6.40%
Enterprize	1984	0.01092	6.22%
Parowon	1980	0.00966	5.12%
Flowell	1980	0.01069	7.00%
Flowell	1981	0.01131	15.42%
Delta	1983	0.00923	7.50%
Park City	1982	0.01045	7.41%
Park City	1983	0.01016	8.83%
Park City	1984	0.01081	8.48%
SLC AP	1972	0.00874	8.37%
SLC AP	1973	0.00886	7.67%
SLC AP	1974	0.00889	5.44%
SLC AP	1975	0.00868	6.71%
SLC AP	1976	0.00867	6.48%
SLC AP	1977	0.00869	8.58%
SLC AP	1978	0.00879	8.45%
SLC AP	1979	0.00868	6.73%
SLC AP	1980	0.00865	7.19%
SLC AP	1981	0.00887	8.30%
Kaysville	1980	0.00997	7.04%
Kaysville	1981	0.00922	9.01%
Kaysville	1982	0.00986	7.95%
Logan	1980	0.00953	6.07%
Logan	1981	0.00916	6.95%
Logan	1982	0.00906	6.62%
Paradise	1984	0.01026	8.01%
Thornack	1983	0.01035	7.31%
Randolph	1982	0.01017	8.13%
Randolph	1983	0.00982	8.60%
Randolph	1984	0.01040	7.99%
Garland	1984	0.00992	7.20%
Kimberly	1969	0.00994	6.11%
Kimberly	1970	0.00974	8.00%

Kimberly	1972	0.00999	7.51%
Kimberly	1973	0.00970	6.74%
Kimberly	1974	0.00970	6.58%
Kimberly	1975	0.00969	7.25%
Kimberly	1980	0.00992	9.46%
Kimberly	1981	0.00983	7.40%
Kimberly	1982	0.00898	6.67%
Mont Pelier	1984	0.00971	9.86%
Talmage	1982	0.00950	7.04%
Hilliard Flts	1982	0.01013	8.55%
Hilliard Flts	1983	0.01026	8.35%
Hilliard Flts	1984	0.01077	8.50%
		Average OBJ:	7.67%

If the OBJ function of a site be plotted against the changes of the CT coefficient, a "V" shaped graph will be created for every year. The method used for finding a single CT for a site was to sum up the OBJ values corresponding to distinct CT values for the years of data available for that site. The CT corresponding to the lowest sum of OBJs was taken as the Datapod's CT coefficient for that site. This is the same as drawing an average-fit graph. The lowest point of the graph represents the final CT coefficient for that site. Figure 7 shows the average of the three year OBJ sum as plotted against CT and compares it to the Hilliard Flats' 1982, 83, and 84 OBJ functions.

Table 7 contains all the study sites with the final CT coefficients that were recommended to be used by the Datapod field computer. The CT values can be round off to four decimal digits to match the Datapod specifications.

The Temperature-Radiation equation which was calibrated here is actually a version of the Jensen-Haise eqauation. It was found that out of the 45 datafiles used, 42 produced a smaller OBJ function corresponding to the final CT coefficient as compared to the OBJ obtained when using the 1970 Jensen-Haise coefficients.

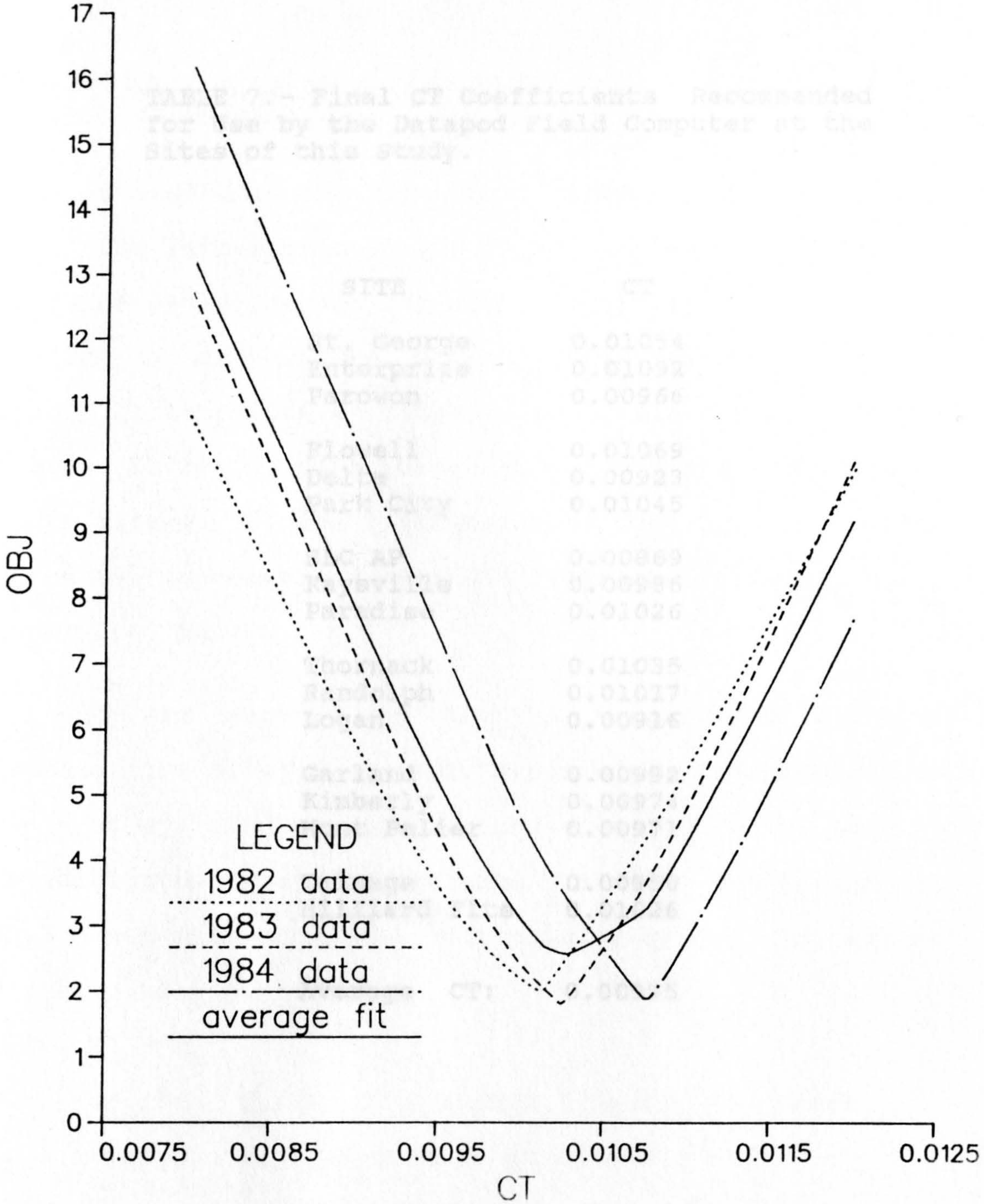

FIG. 7.- Hilliard Flats, Wyoming's 1982, 83 and 84 Objective Functions as Plotted Against a Range of CT Values, and the Average-Fit Curve Obtained.

TABLE 7.- Final CT Coefficients Recommended for Use by the Datapod Field Computer at the Sites of this Study.

SITE	CT
St. George	0.01054
Enterprize	0.01092
Parowon	0.00966
Flowell	0.01069
Delta	0.00923
Park City	0.01045
SLC AP	0.00869
Kaysville	0.00986
Paradise	0.01026
Thornack	0.01035
Randolph	0.01017
Logan	0.00916
Garland	0.00992
Kimberly	0.00974
Mont Pelier	0.00971
Talmage	0.00950
Hilliard Flts	0.01026
Average CT:	0.00995

ETr Estimation Using Maximum and Minimum Temperatures

As stated in the Procedure, TEMPRAD was modified to vary the temperature in the Penman ETr equation within ±10 °F. The ratio between ETr with a temperarure change to ETr without a temperature change was designated as "m". For specific temperature ranges, the relationship between change in the average temperature, $\triangle T$, and the multiplier m was linear. Figure 8 demonstrates such linear relationships for the combined 1981 and 1982 meteorological data of kaysville, UT.

$\triangle T$ was assumed to be the temperature difference between site A, with the only available meteorological variable of average temperature, and site B, with available meteorological data to estimate ETr using the Penman method. m was assumed as the multiplier required to estimate ETr at site A, that is:

$\triangle T = T_A - T_B$

$m = [ETr_B(T+ \triangle T)/ETr_B(T)] \approx [ETr_A(T)/ETr_B(T)]$ where,

T_A = average daily temperature at site A (^oF),

T_B = average daily temperature at site B (^oF),

$ETr_B(T)$ = daily ETr at site B with the actual temperarture of that day,

$ETr_B(T+ \triangle T)$ = daily ETr rate at site B with theoretical temperature $T+ \triangle T$. $ETr_B(T+ \triangle T)$ is assumed to be equiva-

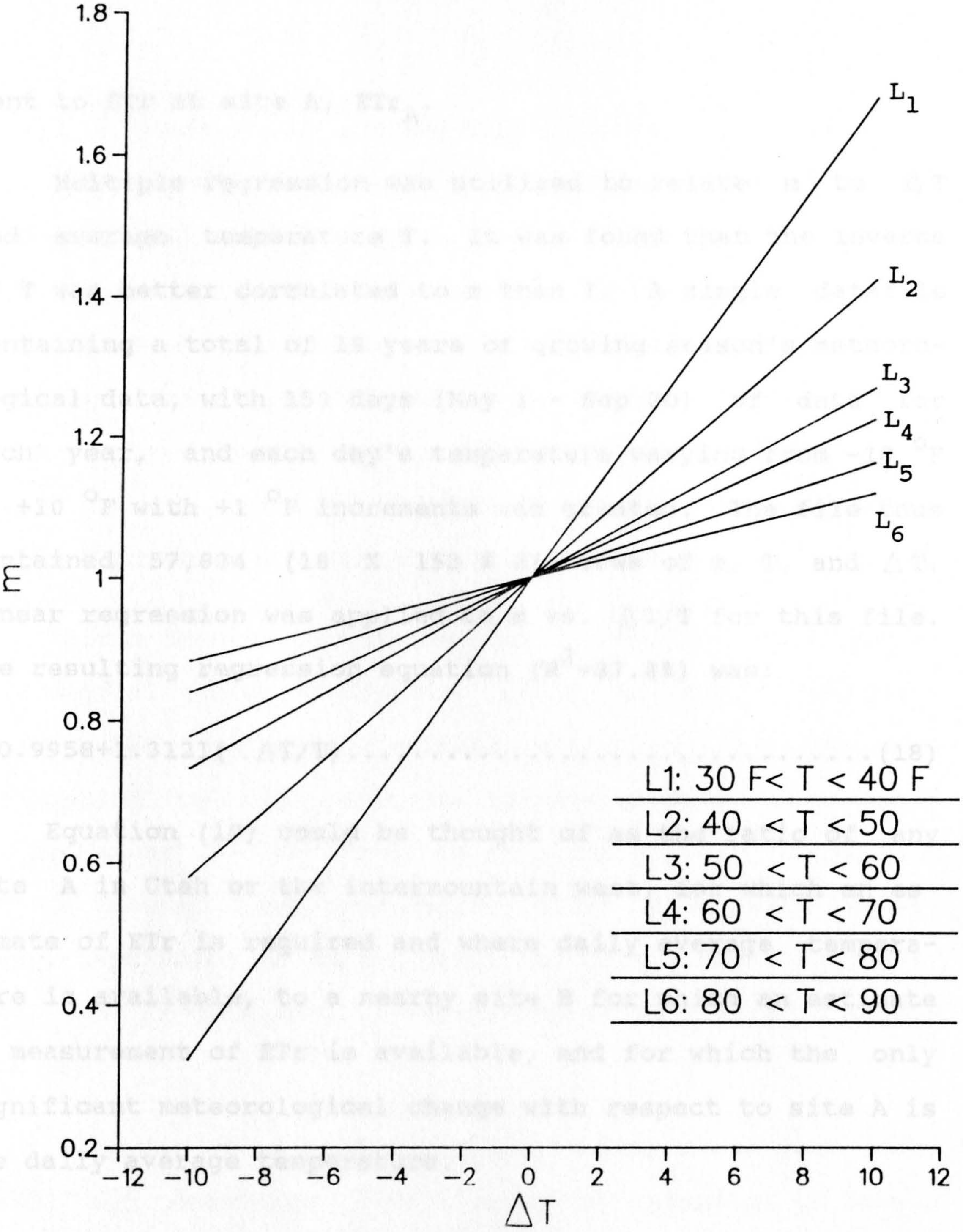

FIG. 8.-Linear Regression Lines Between Multiplier "m", and Change in Temperatrue ΔT, for Specific Temperature Ranges of Kaysville 1981, and 1982 Meteorological Data (Penman ETr Used).

lent to ETr at site A, ETr_A.

Multiple regression was utilized to relate m to ΔT and average temperature T. It was found that the inverse of T was better correlated to m than T. A single datafile containing a total of 18 years of growing season's meteorological data, with 153 days (May 1 - Sep 30) of data for each year, and each day's temperature varying from -10 °F to +10 °F with +1 °F increments was created. The file thus contained 57,834 (18 X 153 X 21) rows of m, T, and ΔT. Linear regression was applied to m vs. $\Delta T/T$ for this file. The resulting regression equation (R^2=87.8%) was:

$$m=0.9958+1.3121(\Delta T/T) \qquad (18)$$

Equation (18) could be thought of as the ratio of any site A in Utah or the intermountain west, for which an estimate of ETr is required and where daily average temperature is available, to a nearby site B for which an estimate or measurement of ETr is available, and for which the only significant meteorological change with respect to site A is the daily average temperature.

Calibration of the New Hargreaves Equation

Another way to estimate ETr using temperature data alone is by an ETr equation with the only required measurements of maximum and minimum temperatures. As stated in the Procedure, the New Hargreaves equation was calibrated using TEMPRAD and the same objective function as was for the Temperature-Radiation equation. Table 8 shows the initial calibration results and the minimum OBJ functions achieved for the New Hargreaves equation. The same procedure was used to arrive at a single coefficient for each site as was used for the Temperature-Radiation equation. Table 9 presents the final calibration results.

Since the New Hargreaves equation requires the extraterrestrial solar radiation, Ra, as an input, Appendix V was created. Appendix V contains a list of Ra values corresponding to Utah latitudes for the growing season April 1- September 30. The formulas required for the estimation of Ra were acquired from Andrew Keller, Utah State University, department of Agricultural and Irrigation Engineering. The program used in estimating Ra is listed in Appendix II.

Five-day ETr values for all the study sites were combined and datafiles were created corresponding to Penman ETr, Jensen-Haise 1970 (J-H 70) ETr, Temperature-Radiation (T-R) ETr, New Hargreaves with fixed K (Har-fK) ETr, and Calibrated New Hargreaves (Har-calK) ETr equations. The four equations stated were regressed against the Penman

TABLE 8.-Initial Calibration Results of the New Hargreaves ETr Equation with K Coefficients and Minimum Objective Functions Found.

SITE	YEAR	K	OBJ
St. George	1984	0.001057	5.69%
Enterprize	1984	0.001133	7.34%
Parowon	1980	0.001161	5.37%
Flowell	1980	0.000998	4.99%
Flowell	1981	0.000937	16.47%
Delta	1983	0.001069	7.46%
Park City	1982	0.001009	8.21%
Park City	1983	0.001038	9.22%
Park City	1984	0.001065	9.56%
SLC AP	1972	0.001040	6.27%
SLC AP	1973	0.001011	6.20%
SLC AP	1974	0.000999	4.36%
SLC AP	1975	0.001067	3.81%
SLC AP	1976	0.001042	4.91%
SLC AP	1977	0.001035	4.12%
SLC AP	1978	0.001031	6.25%
SLC AP	1979	0.001032	5.27%
SLC AP	1980	0.001040	5.12%
SLC AP	1981	0.001010	5.48%
Kaysville	1980	0.001076	7.88%
Kaysville	1981	0.000965	6.43%
Kaysville	1982	0.001136	5.92%
Logan	1980	0.001078	7.69%
Logan	1981	0.001094	8.21%
Logan	1982	0.001124	8.37%
Paradise	1984	0.001073	8.06%
Thornack	1983	0.001080	8.83%
Randolph	1982	0.001062	6.60%
Randolph	1983	0.001074	8.01%
Randolph	1984	0.001085	8.26%
Garland	1984	0.001081	11.99%
Kimberly	1969	0.001146	5.31%
Kimberly	1970	0.001116	5.86%

Kimberly	1972	0.001132	5.57%
Kimberly	1973	0.001155	6.10%
Kimberly	1974	0.001189	7.38%
Kimberly	1980	0.001093	6.69%
Kimberly	1981	0.001143	5.77%
Kimberly	1982	0.001017	8.67%
Mont Pelier	1984	0.001018	8.54%
Talmage	1982	0.000983	7.30%
Hilliard Flts	1982	0.001147	6.19%
Hilliard Flts	1983	0.001122	7.97%
Hilliard Flts	1984	0.001173	7.91%
		Average OBJ:	7.08%

TABLE 9.- Final Calibration Results of New Hargreaves ETr Equation for the Sites of this Study.

SITE	K
St. George	0.001057
Enterprize	0.001133
Parowon	0.001161
Flowell	0.000998
Delta	0.001069
Park City	0.001038
SLC AP	0.001032
Kaysville	0.001075
Logan	0.001094
Paradise	0.001073
Thornack	0.001080
Randolph	0.001074
Garland	0.001081
Kimberly	0.001135
Mont Pelier	0.001018
Talmage	0.000983
Hilliard Flts	0.001147
Average K:	0.001073

method. Table 10 shows the regression equations and the correlation coefficients, R^2, achieved.

In order to demonstrate how well the four equations mentioned estimate ETr, and whether or not they will underestimate or overestimate the evapotranspiration irrigation requirements, the following formula was utilized for comparison of the 5-day ETr estimate datafiles:

$$\%d = [(SUM5 - SUM5PN)/SUM5PN] \times 100 \text{ ....(19)}$$

SUM5=5 day sum of ETr using an ETr method, SUM5PN=5 day sum of ETr using the Penman ETr method, and %d=percentage of underestimation (if negative), or overestimation (if positive).

Table 11 shows the percentage of 5-day estimates by each of the four methods lying within 5%, 10%, and 15% of the Penman ETr method. Figures 9 through 12 are plots of % d vs. the frequency of occurance corresponding to the J-H 70, T-R, Har-fk, Har-fcal ETr equations respectively. As can be seen the Temperature-Radiaton equation ranks as the best estimator among the four methods with 90.9% of the 5-day ETr estimates within ±15% of Penman, followed by the calibrated New Hargreaves, Har-fK, and J-H 70 ETr equations each with 89.3%, 79.7%, and 55.1% of estimates within ±15% of Penman estimates respectively.

TABLE 10.- Regression Equations Obtained by Running 5-Day Discrete ETr Estimates Found by Jensen-Haise 1970, Temperature-Radiation, New Hargreaves, and Calibrated New Hargreaves ETr Methods Against the 5-Day Penman ETr Estimates for all Sites Combined.

	Regression Equation	R^2
Jensen-Haise	ETr=-0.2290+1.280(Penman ETr)	83.6 %
Temp.-Rad.	ETr=-0.0746+1.060(Penman ETr)	93.4 %
New Harg.	ETr= 0.0684+0.995(Penman ETr)	85.6 %
Calib. New Harg.	ETr= 0.0533+0.953(Penman ETr)	89.2 %

TABLE 11.-Percentage of 5-Day ETr Estimates Using the Temperature-Radiation, Jensen-Haise 1970, New Hargreaves, and Calibrated New Hargreaves ETr Equations within 5%, 10%, and 15% of the Penman ETr Method for all Sites Combined.

ETr Equation	Percentage of 5-day data within 5%	10%	15% of Penman
Temp.-Radiation	46.6%	78.3%	90.9%
New Har. calib.	42.1%	73.3%	89.3%
New Hargreaves	32.8%	59.4%	79.7%
Jensen-Haise	23.6%	41.1%	55.1%

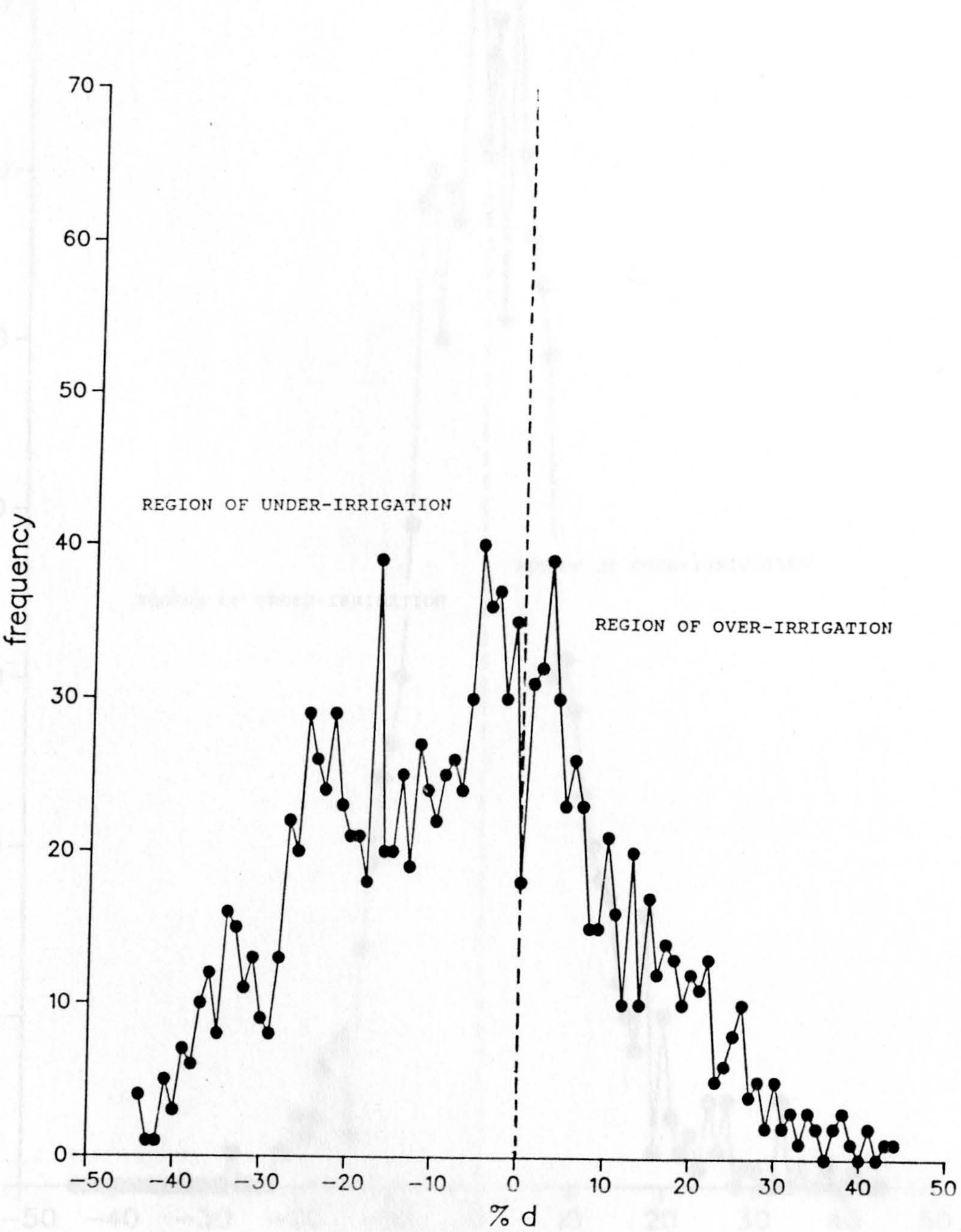

FIG. 9.- Plot of %d vs. Frequency of Occurence for the Jensen-Haise 1970 ETr Equation as Compared to Penman ETr (All Sites Combined).

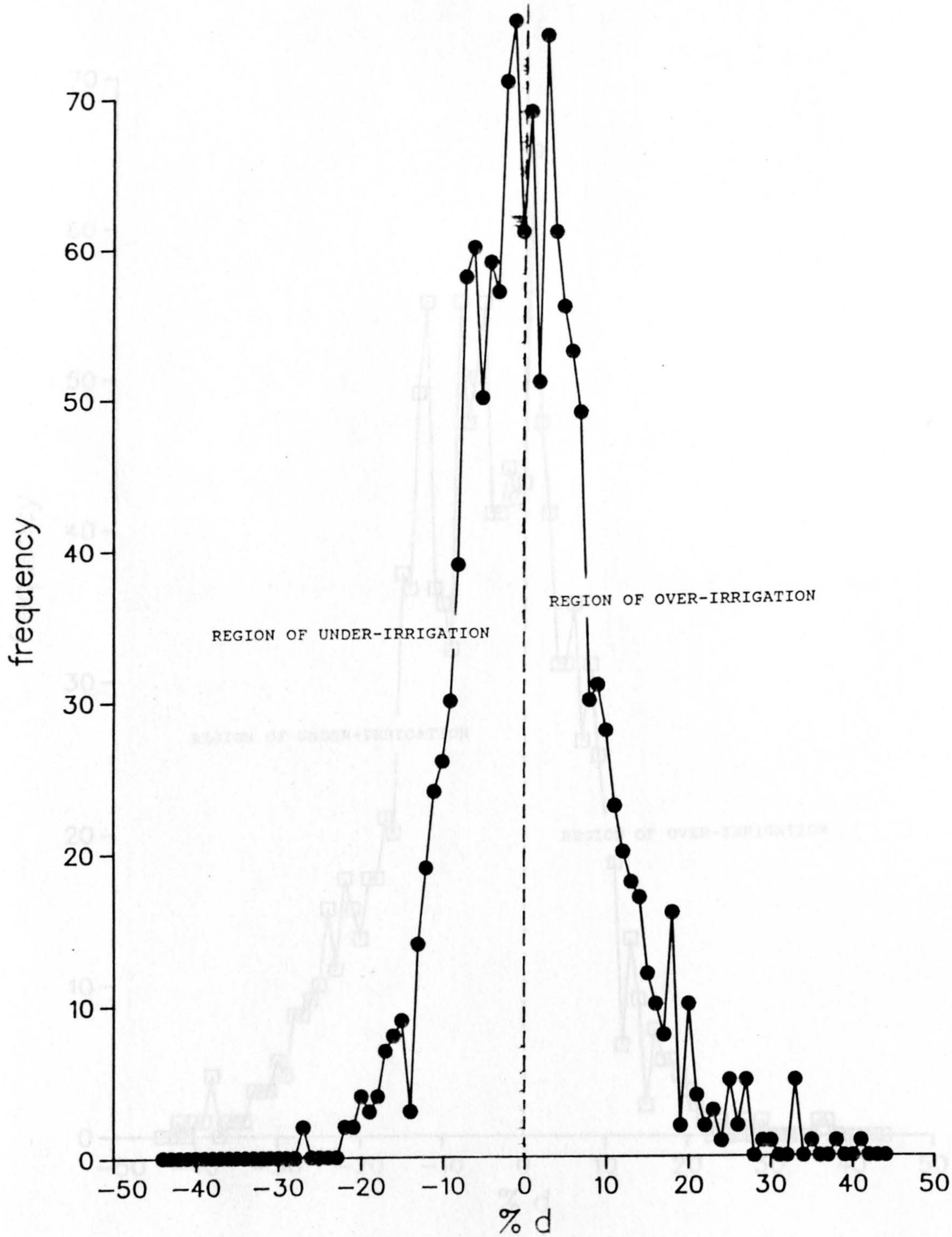

FIG. 10.- Plot of %d vs. Frequency of Occurence for the Temperature-Radiation ETr Equation as Compared to Penman ETr (All Sites Combined).

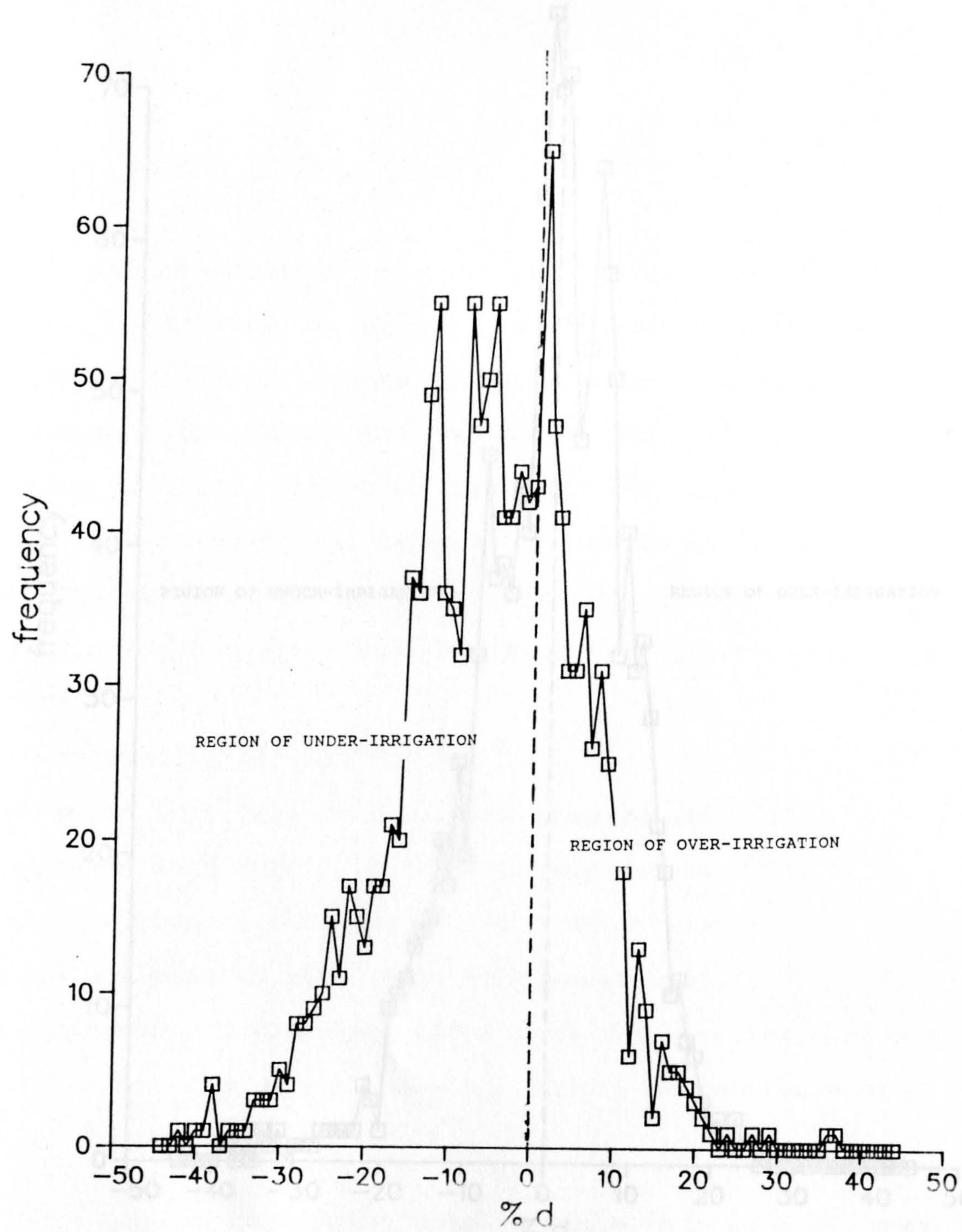

FIG. 11.- Plot of %d vs. Frequency of Occurence for the New Hargreaves ETr Equation as Compared to Penman ETr (All Sites Combined).

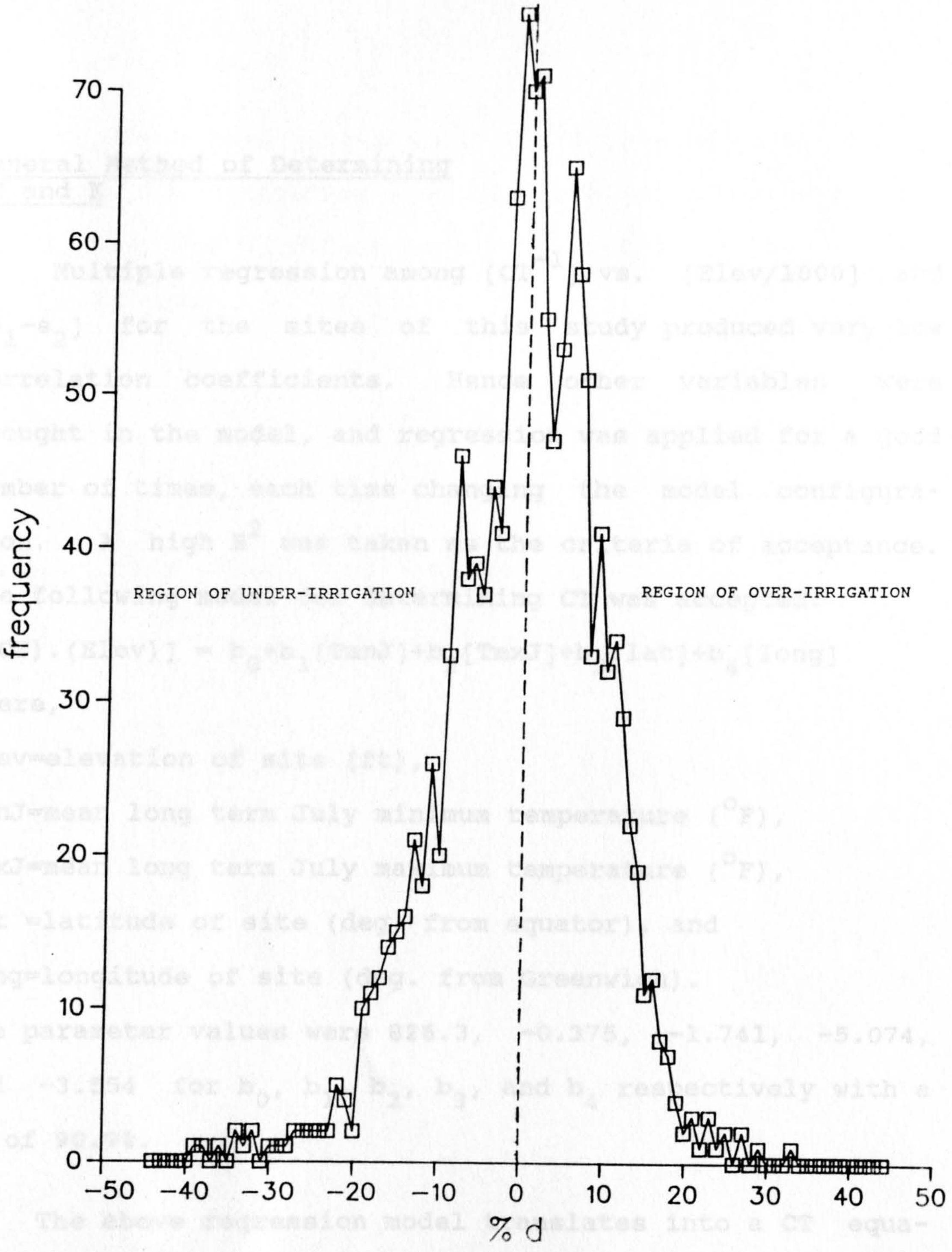

FIG. 12.- Plot of %d vs. Frequency of Occurence for the Calibrated New Hargreaves ETr Equation as Compared to Penman ETr (All Sites Combined).

General Method of Determining CT and K

Multiple regression among $[CT^{-1}]$ vs. [Elev/1000] and $[e_1-e_2]$ for the sites of this study produced very low correlation coefficients. Hence other variables were brought in the model, and regression was applied for a good number of times, each time changing the model configuration. A high R^2 was taken as the criteria of acceptance. The following model for determining CT was accepted:

$$[(CT).(Elev)] = b_0+b_1[TmnJ]+b_2[TmxJ]+b_3[lat]+b_4[long]$$

where,

Elev=elevation of site (ft),

TmnJ=mean long term July minimum temperature (^oF),

TmxJ=mean long term July maximum temperature (^oF),

Lat =latitude of site (deg. from equator), and

Long=longitude of site (deg. from Greenwich).

The parameter values were 826.3, -0.375, -1.741, -5.074, and -3.554 for b_0, b_1, b_2, b_3, and b_4 respectively with a R^2 of 90.9%.

The above regression model translates into a CT equation as such:

$$CT = (b_0 + b_1TmnJ + b_2TmxJ + b_3Lat + b_4Long)/Elev \quad .....(20)$$

The same configuration was found to work best for the K of the New Hargreaves equation also. The respective b_0, b_1, b_2, b_3, and b_4 values were 85.2, 0.005, -0.228, -0.508, and -0.353 with a R^2 of 85.2%.

SUMMARY AND CONCLUSIONS

This study, in compilance to its main objective, calibrated a Temperature-Radiation evapotranspiration equation (ETr = CT x T x Rs) for Utah and some neighboring states by finding appropriate coefficients for specific sites.

The Temperature-Radiation equation was calibrated against the Kimberly version of the Penman ETr equation. Meteorological datafiles were used for the local calibration of the equation. In addition to the above equation, the New Hargreaves equation ($ETr = K \times T \times TD^{0.5} \times Ra$) was similarly calibrated against the Kimberly version of the Penman ETr equation with the meteorological files of this study.

The accuracy of the above two equations can be understood by the fact that the Temperature-Radiation equation produced 5-day ETr estimates with 90.9% of the data lying within ±15% of the Penman method, and the calibrated new Hargreaves equation produced results with 89.3% of data lying within ±15% of the Penman method. These calibrated equations were meant for use by the Datapod field computer.

By considering the meteorological and site factors of the study sites, general methods for the estimation of the CT and K coefficients for any site in Utah and surroundings were developed. The necessary inputs were longterm July mean maximum and minimum temperatures, longitude, latitude, and elevation of sites. Appendix IV lists such inputs and the corresponding estimated CT and K coefficients, found by using equation (20), for various sites in the state of Utah.

Picking 29 farming communities in Utah, one corresponding to each county, a Datapod could be installed at representative sites for the purpose of estimating ETr. If the Temperature-Radiation ETr equation is utilized, a two channel Datapod, model DP219, would be required for each site. The cost of this particular model which comes with a TP10v temperature probe and a Licor pyranometer totals \$1,085 or \$31,465 as an initial cost for 29 sites. However if the New Hargreaves equation be substituted, a one channel Datapod model DP112 can be used instead. The DP112 comes equipped with a TP10v temperature probe and costs \$664 or \$19,256 for instrumentation of all the 29 sites; that is a savings of \$12,209 or \$421 per site. with consideration that the New Hargreaves equation produced ETr estimates within only 1.6% of the Temperature-Radiation method, usage of the DP112 Datapod model is recommended. However, since weather stations exist throughout the state of Utah with the recording of daily maximum and minimum temperatures, instalation and purchase of the Datapod model DP112 may not even be required.

RECOMMENDED FUTURE STUDIES

1) Calibration of the Penman ETr equation can be undertaken for sites in Utah against reliable measured data. This will require instalation of sensitive lysimeters or use of neutron probes with careful maintenance and daily recording of data.

2) Crop coefficient curves for specific crops dominant in Utah can be developed.

3) The empirical equation for estimation of Rs as a function of TD and Ra, needed as an input for the New Hargreaves equation, can be further researched so as to produce even more accurate ETr estimates.

4) ETr vs. Time curves for specific sites in Utah for prediction and adjustment of ETr forcasts can be developed.

5) Strategy and methodology can be thought of to gather weather information from isolated areas to a central location in Utah for analysis. There may be possibility of using a sattelite to monitor scattered stations throughout the state.

6) An implementation study can be done for utilizing the ETr equations calibrated in this study for developing

countries which have a potentially large irrigated agricultural sector and require accurate ETr estimations to assist in achieving high crop yields and in helping with water conservation.

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APPENDIXES

Appendix I: Penman ETr Equation Elaboration

A brief description of equations used for estimating the inputs required for the Kimberly version of the Penman ETr equation.

The Kimberly version of the Penman ETr equation stands as below:

$$ETr = [(\Delta/(\Delta + \gamma))(Rn + G)$$

$$(\gamma/(\Delta + \gamma))15.36(W1 + W2.U_2)(e_s - e_a)]CF$$

The following formulas can be used for the individual terms (17):

$\Delta = 2.00(0.00738(Tc) + 0.8072)^7 - 0.00116$, for $Tc>-23^{o}C$.

Δ is in mb/^{o}C and Tc is mean daily temperature in ^{o}C, or:

$\Delta = 2.00(0.0041(Tf) + 0.676)^7 - 0.00116$, for $Tf>-9.4^{o}F$.

Tf is mean daily temperature in ^{o}F.

$\gamma = Cp\ P/(\lambda(Mw/Ma))$

where Cp= Specific heat of air at constant pressure; it is taken as 0.240 Cal/gm/deg^{o}C,

P= 1013 - 0.03216(ELEV); P is air pressure in units of mb, and ELEV is site elevation is feet,

λ is the latent heat of water estimated by:

$\lambda = 595.9 - 0.305(T - 32)$, for T in ^{o}F,

Mw= Molecular weight of water equivalent to 18.016 gm/mole,

Ma= Molecular weight of air equivalent to 28.966 gm/mole, (Mw/Ma) ~0.622.

$Rn = (1 - \alpha)Rs - Rb$,

where α is crop albido. α can be taken as 0.23 on the average for a green, actively growing crop at full height, Rb is back radiation determined by:

Rb= Rbo(a(Rs/Rso) + b), Rbo is back radiation for cloudless days and is approximated by:

$$Rbo= (a1 + b1\ e_a)11.71 \times 10^{-8}(Ta^4 + Tb^4)/2.$$

a,b,a1,and b1 are empirical constants. Their recommended values for several locations are shown in Table 12.

Rso is the clear day solar radiation for a particular day and site. Rso can be obtained from standard meteorological tables. For this study, empirical polinomial curves were used which gave a good approximation of Rso for each site.

Ta and Tb are the daily maximum and minimum air temperatures in °K.

$$G= 5(Tpr - T)$$

where Tpr= mean air temperature in °F for a previous time period, usually the previous 3 days. T= mean daily air temperature in °F.

W1 and W2 are empirical wind parameters. Some suggested values for W1 and W2 are shown in Table 13.

U_2= wind movement at 2 meter height from the ground. U_2 can be approximated when the anemometer is at height x by:

$$U_2= U_x\ (2/x)^{0.2}.$$

e_s= Saturation vapor pressure taken as the mean of values obtained at the daily maximum and minimum air temperatures,

e_a= Mean actual vapor pressure taken as the saturation vapor pressure at the daily average dew point temperature. Vapor pressure at any given air temperature can be empirically appriximated by:

e_s= exp[21.3574 - 5336.0/(T^oC + 273.10)] or,

e_s= exp[21.3575 - 9604.8/(T^oF + 459.58)].

Care must be taken in using the above formulas. Where possible, local calibration should be done to determine exact figures.

TABLE 12.- The a, b, a1, and b1 Empirical Constants Used for Estimating Rbo for Several Locations. From Hill et al. (16).

a	b	a1	b1	LOCATION AND/OR SOURCE
1.35	-0.35	0.35	-0.046	Davis, CA
1.22	-0.18	0.325	-0.044	Kimberly, Idaho
1.20	-0.20	0.39	-0.05	Arid regions
1.10	-0.10	0.39	-0.05	Semihumid regions
1.00	0.00	0.39	-0.05	Humid regions
1.35	-0.35	0.34	-0.044	FAO Irrigation & Drainage paper #24

TABLE 13.- Empirical Wind Parameters W1 and W2 for Several Reference Crops.

CROP	W1	W2	LOCATION AND/OR SOURCE
Short Green Crop	1.00	0.0100	Penman (31)
Alfalfa	0.75	0.0185	Kimberly, Idaho
Clipped Grass	1.00	0.0161	FAO Irrigation & Drainage Paper #24

Appendix II: Major Programs and Sample Datafile Listings

```
************************************************************************
*                                                                      *
*                          " CRPSIM.FOR "                              *
*                                                                      *
************************************************************************
*                                                                      *
*     THIS IS A FORTRAN PROGRAM NAMED "CRPSIM.FOR". IT ESTIMATES       *
*     ALFALFA REFERENCE EVAPOTRANSPIRATION IN INCHES/DAY THROUGH       *
*     THE KIMBERLY VERSION OF THE PENMAN ETr EQUATION. THE  NECE-      *
*     SSARY INPUT DATA ARE SITE SPECIFICATIONS AND METEOROLOGICAL      *
*     DATA WHICH THE PROGRAM READS FROM A GIVEN SITE'S DATAFILE.       *
*                                                                      *
************************************************************************
*                                                                      *
*     PROGRAM WAS WRITTEN AND DEVELOPED WITHIN THE AGRICULTURAL        *
*     AND IRRIGATION ENGINEERING DEPARTMENT,                           *
*     UTAH STATE UNIVERSITY,                                           *
*     UNDER THE DIRECTION OF: DR  R. W. HILL                           *
*     MODIFIED BY: P. FOROUGHI                                         *
*     DECEMBER 1984                                                    *
*                                                                      *
************************************************************************
*                                                                      *
*                 VARIABLE AND CONSTANT IDENTIFICATION                 *
*                                                                      *
*     A,AA= VARIABLES  REQUIRED FOR THE ESTIMATION OF  NET RADIA-      *
*     TION, AN INPUT OF THE PENMAN ETr EQUATION.                       *
*     A0,A1,A2,A3,A4,A5,A6,A7= POLINOMIAL VARIABLES USED TO ESTI-      *
*     MATE THE CLEAR DAY SOLAR RADIATION (RS0) OF THE SITE.            *
*                                                                      *
*     ALAM= LATENT HEAT OF WATER, APPROXIMATELY 585 CAL/(CUBIC CM).    *
*                                                                      *
*     B,BB= SIMILAR TO A AND AA.                                       *
*                                                                      *
*     CONV= THE CONVERSION  FACTOR  REQUIRED TO CONVERT UNITS OF       *
*     GIVEN THE MONTH AND DAY.                                         *
*     LANGLEYS INTO INCHES OF EQUIVALENT WATER EVAPORATION, CONV       *
*     IS EQUAL TO 0.000673 IN/LANGLEYS FOR STANDARD CONDITIONS.        *
*                                                                      *
*     DELTA= ESTIMATE OF THE SLOPE OF SATURATION VAPOR PRESSURE-       *
*     TEMPERATURE CURVE AT THE AIR TEMPERATURE IN mb/deg C.            *
*                                                                      *
*     ELEV= ELEVATION OF SITE IN FEET.                                 *
*                                                                      *
*     E1,E2= SATURATION VAPOR PRESSURES FOR THE WARMEST MONTH OF       *
*     MONTH, ASSUMED TO BE JULY, AT THE  MEAN  MAXIMUM AND MEAN        *
*     MINIMUM TEMPERATURES OF THE SITE RESPECTIVLEY.                   *
*                                                                      *
*     FMT= THE FORMAT AT WHICH THE METEOROLOGICAL DATA FILE ARE.       *
*                                                                      *
*     IDAYB,IDAYE= BEGINNING AND ENDING JULIAN DAY OF THE DATA.        *
*                                                                      *
*     GAMA= PSYCHROMETRIC CONSTANT IN mb/deg C.                        *
*                                                                      *
*     MNB,MNE= BEGINNING AND ENDING MONTH OF THE MET. DATA.            *
*                                                                      *
*     PENET(I)= DAILY CALCULATED PENMAN ETr IN INCHES/DAY.             *
*     PENET5(I)= FIVE-DAY SUM OF PENMAN ETr READ FROM THE DATA.        *
*                                                                      *
*     P= AVERAGE AIR  PRESSURE  ESTIMATED BY THE AVERAGE TEMPERA-      *
*     TURE IN mmHg OR mb.                                              *
*                                                                      *
*     RS(I)= DAILY SOLAR RADITION DATA IN LANGLEYS.                    *
*                                                                      *
*     STNM= STATION NAME.                                              *
*                                                                      *
*     SVPAV= AVERAGE DAILY SATURATION VAPOR PRESSURE ESTIMATED BY      *
*     THE AVERAGE DAILY TEMPERATURE.                                   *
*                                                                      *
*     TMX(I)= DAILY MAXIMUM AIR TEMPERATURE IN DEG F IN DATA FILE.     *
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```
*     TMN(I)= DAILY MINIMUM AIR TEMPERATURE.                         *
*     TWB(I)= DAILY WET BULB TEMPERATURE.                            *
*     TDB(I)= DAILY DRY BULB TEMPERATURE.                            *
*     TAV(I)= DAILY AVERAGE AIR TEMPERATURE.                         *
*     TMNW,TMXW= AVERAGE LONG TERM MINIMUM AND MAXIMUM JULY TEM-     *
*     PERATURE RESPECTIVELY.                                         *
*     TEMCN= TEMPERATURE ADJUSTMENT CONSTANT.                        *
*                                                                    *
*     W1,W2= WIND PARAMETERS USED IN THE PENMAN EQUATION.            *
*     WHT= ANEMOMETER HEIGHT IN METERS.                              *
*     WIND(I)= DAILY WIND RUN IN MILES.                              *
*     WINDCN= WIND READING ADJUSTMENT CONSTANT.                      *
*     WINDLIM= WIND LIMIT SET AT 100 MILES/DAY FOR THIS STUDY.       *
*                                                                    *
*     XNDP= NUMBER OF DAY OF DATA.                                   *
*                                                                    *
**********************************************************************
*                                                                    *
      DIMENSION TMX(250),TMN(250),TWB(250),TDB(250),PPT(250),
     +WIND(250),RS(250),TAV(250),PENET(250),CONV(250)
      CHARACTER STNM*25,FMT*50
      OPEN(5,FILE='PENINP',STATUS='OLD')
      OPEN(8,FILE='PEN',STATUS='NEW')
*
****  SITE SPECIFICATIONS ARE READ.
*
      READ(5,10)STNM,ELEV
   10 FORMAT(/A25,1X,F5.0/////)
      READ(5,20)TMXW,TMNW,A,B,AA,BB,W1,W2,WHT,WNDLIM
   20 FORMAT(2F10.0/3X,12F6.0)
      READ(5,30)A0,A1,A2,A3,A4,A5,A6
   30 FORMAT(5X,7E10.0)
      READ(5,40)MNB,IDAYB,MNE,IDAYE
   40 FORMAT(4I5)
      READ(5,45)RSCN,WINDCN,PPCN,PANCN,TEMCN
      IF(WINDCN.EQ.0)WINDCN=1
   45 FORMAT(5F10.0)
      READ(5,50)FMT
      WRITE(99,51)TMXW,TMNW,A,B,AA,BB,W1,W2,WHT,WNDLIM,
     +A0,A1,A2,A3,A4,A5
   51 FORMAT(1X'TXW='F5.2' TNW='F5.2' A='F5.3' B='F5.3' AA='F5.3
     +' BB='F5.3/3X'W1='F5.3' W2='F5.3' WHT='F4.2' WNDLIM='F5.1/
     +3X'A0-A6='7(E10.3,2X))
   50 FORMAT(A50)
      CALL JULDAY(MNB,IDAYB,AJDB)
      CALL JULDAY(MNE,IDAYE,AJDE)
      XNDP=AJDE - AJDB + 1.
      TMXW=(TMXW-32.)*5./9.
      TMNW=(TMNW-32.)*5./9.
      CALL SAVAPR(TMXW,SVPTXW)
      CALL SAVAPR(TMNW,SVPTNW)
      SVPDIF=SVPTXW - SVPTNW
      TAVW=(TMXW + TMNW)/2.
      CP=.240
      P=1013. - 0.03217*ELEV
      ALAM1=595.9 - .549*TAVW
      CONV1=1/(2.54*ALAM1)
      AJD=AJDB - 1.
*
****  DAILY METEOROLOGICAL DATA ARE READ.
*
      DO 80 I=1,XNDP
      READ(5,FMT)TMX(I),TMN(I),TWB(I),TDB(I),PPT(I),WIND(I),RS(I)
      TAV(I)=(TMN(I) + TMX(I))/2
      IF(TEMCN.EQ.1)GOTO 55
      TMX(I)=(TMX(I) - 32.)*5./9.
      TMN(I)=(TMN(I) - 32.)*5./9.
      IF(TDB(I).EQ.0)GOTO 52
      TDB(I)=(TDB(I) - 32.)*5./9.
   52 TWB(I)=(TWB(I) - 32.)*5./9.
```

```
      TAV(I)=(TAV(I)-32.)*5./9.
   55 DEL=0.00738*TAV(I) + 0.8072
      DEL7=DEL*DEL*DEL*DEL*DEL*DEL*DEL
      DELTA=2.00* DEL7 - .00116
      ALAM=595.9 - .549*TAV(I)
      GAMA=CP*P/(.622*ALAM)
      DELGAM=DELTA/(DELTA + GAMA)
      CONV(I)= 1/(2.54*ALAM)

      CALL SAVAPR(TWB(I),SVPWB)
      SVPDP = SVPWB - GAMA*(TDB(I)-TWB(I))
      IF(TDB(I).EQ.0)SVPDP=SVPWB
      CALL SAVAPR(TMX(I),SVPTMX)
      CALL SAVAPR(TMN(I),SVPTMN)
      SVPAV=(SVPTMX + SVPTMN)/2.

      TXK=TMX(I) + 273.1
      TNK=TMN(I) + 273.1
      TXK4=TXK*TXK*TXK*TXK
      TNK4=TNK*TNK*TNK*TNK
      TAVK4=(TXK4+TNK4)/2.
      RBO = (AA + BB*SQRT(SVPDP))*11.71E-8*TAVK4
      AJD=AJD+1
      RSO=A0+AJD*(A1+AJD*(A2+AJD*(A3+AJD*(A4+AJD*(A5+AJD*A6)))))
      RB = RBO*(B + A*RS(I)/RSO)
      RN = 0.77*RS(I) - RB

      IF(TAV(I-1).EQ.0)TAV(I-1)=TAV(I)
      IF(TAV(I-2).EQ.0)TAV(I-2)=TAV(I-1)
      IF(TAV(I-3).EQ.0)TAV(I-3)=TAV(I-2)
      TPR=(TAV(I-3) + TAV(I-2) + TAV(I-1))/3.
      TPR=32.+TPR*9./5.
      G=(TPR - 32.-TAV(I)*9./5.)*5.

      WIND(I)=WIND(I)*WINDCN
      IF(WIND(I).GT.100.)WIND(I)=100.
      IF(WHT.EQ.2)THEN
        U2=WIND(I)
      ELSE
        U2=WIND(I)*(2./WHT)**.2
      ENDIF
*
****  DAILY PENMAN ETr IS CALCULATED.
*
      PENET(I)= (DELGAM*(RN+G)  +
     +          (1-DELGAM)*15.36*(W1 +W2*U2)*(SVPAV-SVPDP) )*CONV(I)
      SUMPEN=SUMPEN + PENET(I)
      CALL ROOZ(AJD,IMN,IDAY)
   80 CONTINUE
*
****  PROGRAM RESULTS ARE PRINTED.
*
      WRITE(8,200)STNM,ELEV,SUMPEN
  200 FORMAT(5X,A25' ELEVATION=' F6.1/5X'SEASONAL PENMAN ET= 'F5.2/)
      WRITE(8,250)CTOBJ2,TXOBJ2,FIX,PFIX,SUBOBJ1,SEASOBJ2
  250 FORMAT(/5X'FOR LOWEST OBJ2: CT= 'F6.4' AND TX= 'F5.1/
     +5X'OBJ2= 'F7.4' (OBJ2/SUMPEN)*100= 'F5.2'%'/5X'OBJ1= 'F7.4/
     +5X'SUMJH= 'F5.2/)
      WRITE(8,300)CTOBJ1,TXOBJ1,HOLD,SEASOBJ1
  300 FORMAT(5X'FOR LOWEST OBJ1: CT= 'F6.4' AND TX= 'F5.1/
     +5X'OBJ1= 'F7.4/5X'SUMJH= 'F5.2/5X'SUM PENMAN    PENMANET')
      DO I=1,(XNDP+2),5
        PENET5=PENET(I)+PENET(I+1)+PENET(I+2)+PENET(I+3)+PENET(I+4)
        SPENET5=SPENET5+PENET5
        WRITE(8,500)SPENET5,PENET5
      ENDDO
      WRITE(8,400)CTZOBJ2,ZOBJ2,PZOBJ2,SEASZOBJ2
  400 FORMAT(5X'FOR TX OF ZERO: CT= 'F6.4/5X'OBJ2= 'F7.4
     +' (OBJ2/SUMPEN)*100= 'F5.2'%'/5X'SUMJH= 'F5.2/
```

```
     +5X'SUM JHET   JHET')
  500 FORMAT(7X,F5.2,8X,F5.2)
      STOP
      END
*
****  SUBROUTINE SAVAPR ESTIMATES THE SATURATION VAPOR PRESSURE
*     FOR A GIVEN TEMPERATURE.
*
      SUBROUTINE SAVAPR(TC,SVP)
      SVP= 1.3329*EXP(21.07 - 5336./(TC+273.1))
      RETURN
      END
*
****  SUBROUTINE JULDAY CALCULATES THE JULIAN DAY OF THE YEAR
*
      SUBROUTINE JULDAY(IMN,IDAY,AJD)
      DIMENSION MN(12)
      DATA MN/31,28,31,30,31,30,31,31,30,31,30,31/
      SUM=0
      DO 20 I=1,IMN
      IF(IMN.EQ.I)GOTO 10
      SUM=SUM+MN(I)
   10 AJD=SUM+IDAY
   20 CONTINUE
      RETURN
      END
*
****  SUBROUTINE ROOZ CALCULATES THE DAY AND MONTH GIVEN THE
*     JULIAN DAY.
*
      SUBROUTINE ROOZ(AJD,IMN,IDAY)
      DIMENSION MN(12)
      DATA MN/31,28,31,30,31,30,31,31,30,31,30,31/
      SUM=0
      DO 10 J=1,12
      SUM=SUM+MN(J)
      IF((AJD-SUM).LE.0)GOTO 20
   10 CONTINUE
   20 IMN=J
      IDAY=AJD - SUM + MN(J)
      RETURN
      END
*
*                          END OF PROGRAM
*
******************************************************************
```

```
************************************************************************
*                                                                      *
*                         " TEMPRAD.FOR "                              *
*                                                                      *
************************************************************************
*                                                                      *
*     THIS IS A FORTRAN PROGRAM NAMED "TEMPRAD.FOR". IT READS THE      *
*     METEOROLOGICAL  DATA OF A  SITE AND THE  PENMAN ETr  VALUES      *
*     GENERATED FOR THAT SITE FROM A DATAFILE. TEMPRAD THEN  AT-       *
*     TEMPTS TO CALIBRATE THE TEMPERATURE-RADIATION  ETr EQUATION      *
*     FOR THAT SITE.                                                   *
*                                                                      *
*     WRITTEN BY: PAYAM  FOROUGHI                                      *
*     UTAH STATE UNIVERSITY                                            *
*     DECEMBER 1984                                                    *
*                                                                      *
************************************************************************
*                                                                      *
      REAL JHET(365),JHET5
      DIMENSION TMX(365),TMN(365),TWB(365),TDB(365),PPT(365),TAVF(365),
     +WIND(365),RS(365),TAV(365),PENET(365),CONV(365),ETJH(365),
     +PENET5(365),EVAP(365)
      CHARACTER STNM*25,FMT*70
      OPEN(5,FILE='PENINP',STATUS='OLD')
      OPEN(8,FILE='JH',STATUS='NEW')
*
****  SITE SPECIFICATIONS ARE READ.
*
      READ(5,10)STNM,ELEV
 10   FORMAT(/A25,1X,F5.0/////)
      READ(5,15)TMXW,TMNW,A,B,AA,BB,W1,W2,WHT,WINDLIM
 15   FORMAT(2F10.0/3X,12F6.0)
      READ(5,20)K,A0,A1,A2,A3,A4,A5,A6
 20   FORMAT(3X,I2,7E10.0)
      READ(5,30)MNB,IDAYB,MNE,IDAYE
 30   FORMAT(4I5)
      READ(5,40)RSCN,WINDCN,PPCN,PANCN,TEMCN
      IF(RSCN.LE.0)RSCN=1.00
      IF(WINDCN.LE..001)WINDCN=1.00
 40   FORMAT(5F10.0)
      READ(5,45)FMT
 45   FORMAT(A70)
      CALL JULDAY(MNB,IDAYB,JDB)
      CALL JULDAY(MNE,IDAYE,JDE)
      XNDP=FLOAT(JDE-JDB+1)
*
****  DAILY METEOROLOGICAL DATA ARE READ.
*
      DO 50 I=JDB,JDE
      READ(5,FMT)TMX(I),TMN(I),TWB(I),TDB(I),PPT(I),WIND(I),RS(I)
      TAV(I)=(TMX(I)+TMN(I))*.5
      RS(I)=RS(I)*RSCN
      IF(TEMCN.EQ.1.)THEN
        TAV(I)=32. + TAV(I)*9./5.
        TMX(I)=32. + TMX(I)*9./5.
        TMN(I)=32. + TMN(I)*9./5.
      ENDIF
      SPPT=SPPT+PPT(I)
      STMN=STMN+TMN(I)
      STMX=STMX+TMX(I)
      CALL SAVAPR(TMX(I),SVPTMX)
      CALL SAVAPR(TMN(I),SVPTMN)
      SVPAV=(SVPTMX+SVPTMN)/2.
      SSVPAV=SSVPAV+SVPAV
      IF((I.GE.182).AND.(I.LE.212))THEN
        SJULSVP=SJULSVP+SVPAV
        SJULTMN=SJULTMN+TMN(I)
        SJULTMX=SJULTMX+TMX(I)
      ENDIF
      WIND(I)=WIND(I)*WINDCN
```

```
      IF(WHT.EQ.2.)THEN
        U2=WIND(I)
       ELSE
        U2=WIND(I)*(2./WHT)**.2
      ENDIF
      IF((I.GT.121).AND.(I.LE.151))SWMAY=SWMAY+U2
      IF((I.GT.151).AND.(I.LE.181))SWJUN=SWJUN+U2
      IF((I.GT.181).AND.(I.LE.212))SWJUL=SWJUL+U2
      IF((I.GT.212).AND.(I.LE.243))SWAUG=SWAUG+U2
      IF((I.GT.243).AND.(I.LE.273))SWSEP=SWSEP+U2
 50   CONTINUE
      READ(5,55)SUMPEN
 55   FORMAT(/5X,F5.2)
      DO 60 I=JDB,JDE,5
*
****  PENMAN 5-DAY SUM ETr VALUES ARE READ.
*
 60   READ(5,65)PENET5(I)
 65   FORMAT(5X,F5.2)
      WRITE(8,68)STNM,MNB,IDAYB,MNE,IDAYE,ELEV,SUMPEN
 68   FORMAT(5X,A25,2X,I2'/'I2'-'I2'/'I2
     +//5X'ELEVATION='F5.0/5X'SEASONAL PENMAN ET='F5.2/)
      XNDP=JDE - JDB + 1.
*
****  JENSEN-HAISE 1970 ET EQUATION CONSTANTS ARE CALCULATED.
*
      C1=68. - (3.6*ELEV/1000.)
      C2= 13.
      CALL SAVAPR(TMXW,E2)
      CALL SAVAPR(TMNW,E1)
      SVPDIF=E2-E1
      CH=50./SVPDIF
      CT70= 1./(C1 + C2*CH)
      TX70= 27.5 - .25*SVPDIF - ELEV/1000.

      TAVW=(TMXW + TMNW)/2.
      P=1013. - 0.03217*ELEV
      WRITE(91,*)STNM,' PENMAN ET'
      WRITE(92,*)STNM,'  JEN-HAS  1970  ET'
      WRITE(93,*)STNM,'  TEM-RAD  (DATAPOD)  ET'

*
****  CALIBRATION OF THE TEMPERATURE-RADIATION ETr EQUATION IS BEGUN.
*
      HOLD=1000.
      FIX=1000.
      ZOBJ2=1000.
      PRINT*,'SUMPEN=',SUMPEN
      DO 100 CT=.0005,.0200,.0005
      DO 100 TX=-30.,20.,.5
      SUMJH=0.0
      OBJ1=0.0
      JHET5=0.0
      DO 90 I=JDB,JDE
      EVAP(I)=CT*(TAV(I)-TX)*RS(I)*.000673
      SUMJH=SUMJH+EVAP(I)
 90   CONTINUE
      DO 95 I=JDB,JDE,5
      JHET5=EVAP(I)+ EVAP(I+1)+ EVAP(I+2)+ EVAP(I+3)+ EVAP(I+4)
      DIFF= ABS(PENET5(I) - JHET5)
      OBJ1= OBJ1 + DIFF
 95   CONTINUE
      SEADIF= ABS(SUMPEN - SUMJH)
      OBJ2 = OBJ1 + SEADIF
      POBJ2=(OBJ2/SUMPEN)*100.
      IF(OBJ1.LT.HOLD)THEN
        HOLD=OBJ1
        CTOBJ1=CT
        TXOBJ1=TX
        SEASOBJ1=SUMJH
```

```
      ENDIF
      IF(OBJ2.LT.FIX)THEN
        FIX=OBJ2
        PFIX=POBJ2
        SUBOBJ1=OBJ1
        CTOBJ2=CT
        TXOBJ2=TX
        SEASOBJ2=SUMJH
      ENDIF
      IF((TX.EQ.0).AND.(OBJ2.LT.ZOBJ2))THEN
        ZOBJ1=OBJ1
        ZOBJ2=OBJ2
        PZOBJ2=POBJ2
        CTZOBJ2=CT
        SEASZOBJ2=SUMJH
      ENDIF
100   CONTINUE

      PRINT*,'CT=',CTZOBJ2,' WHEN TX=0 WITH BEST OBJ'
      PRINT*,'ENTER THE CT AND TX TO BE USED IN THE DATAPOD:'
      READ*,CTB,TXB
      JIM=0
        CT=CT70
        TX=TX70
      IF(JIM.EQ.0)GOTO 120
115     CT=CTB
        TX=TXB
120   DO 125 I=JDB,JDE
125   ETJH(I)=CT*(TAV(I) - TX)*RS(I)*.000673
      DO 130 I=JDB,JDE,5
        JHET5=ETJH(I)+ETJH(I+1)+ETJH(I+2)+ETJH(I+3)+ETJH(I+4)
        IF(JIM.EQ.0)THEN
          OBJ170=OBJ170+ABS(PENET5(I)-JHET5)
          SJHET70=SJHET70+JHET5
          SPENET5=SPENET5+PENET5(I)
          WRITE(91,300)I,SPENET5,PENET5(I)
          WRITE(92,300)I,SJHET70,JHET5
        ENDIF
        IF(JIM.EQ.1)THEN
          OBJ1BST=OBJ1BST+ABS(PENET5(I)-JHET5)
          SJHETZ=SJHETZ+JHET5
          WRITE(93,300)I,SJHETZ,JHET5
        ENDIF
130   CONTINUE
      IF(JIM.EQ.0)THEN
        DIFF70=ABS(SUMPEN-SJHET70)
        OBJ270=OBJ170+DIFF70
        POBJ270=(OBJ270/SUMPEN)*100.
      ENDIF
      IF(JIM.EQ.1)THEN
        DIFFBST=ABS(SUMPEN-SJHETZ)
        OBJ2BST=OBJ1BST+DIFFBST
        POBJ2BST=(OBJ2BST/SUMPEN)*100.
        GOTO 175
      ENDIF
      IF(CTB.EQ.9)THEN
        CONTINUE
      ELSE
        JIM=1
        GOTO 115
      ENDIF
175   TMXWC=(TMXW-32.)*5./9.
      TMNWC=(TMNW-32.)*5./9.
*
****  PROGRAM OUTPUT IS PRINTED.
*
      WRITE(8,250)CTOBJ2,TXOBJ2,FIX,PFIX,SUBOBJ1,SEASOBJ2
250   FORMAT(5X'FOR LOWEST OBJ2: CT= 'F7.5' AND TX= 'F5.1/
     +5X'OBJ2= 'F7.4', (OBJ2/SUMPEN)= 'F5.2'%'/5X'OBJ1= 'F7.4/
     +5X'SUMJH= 'F5.2/)
```

```
300    FORMAT(1X,I3,1X,F5.2,1X,F5.2)
       WRITE(8,350)CTOBJ1,TXOBJ1,HOLD,SEASOBJ1
350    FORMAT(5X'FOR LOWEST OBJ1: CT= 'F7.5' AND TX= 'F5.1/
      +5X'OBJ1= 'F7.4/5X'SUMJH= 'F5.2)
       WRITE(8,400)CTZOBJ2,ZOBJ1,ZOBJ2,PZOBJ2,SEASZOBJ2
400    FORMAT(1X,55('*')/1X'*'53X'*'/1X
      +'*'3X'FOR TX OF ZERO: CT= 'F7.5,T56'*'/1X'*'3X'OBJ1='F7.4,T56'*'
      +/1X'*'3X'OBJ2= 'F7.4', (OBJ2/SUMPEN)= ',F6.2'%'T56'*'/1X
      +'*'3X'SUMJH= 'F5.2,T56'*'/1X'*'53X'*'/1X,55('*')/)
       IF(CTB.EQ.9)GOTO 575
       WRITE(8,550)CTB,TXB,OBJ1BST,OBJ2BST,POBJ2BST,SJHETZ
550    FORMAT(5X'DATA POD WILL USE:  CT = 'F7.5' AND TX = 'F5.1/5X'OBJ1=
      + 'F7.4/5X'OBJ2= 'F7.4', (OBJ2/SUMPEN)= 'F6.2'%'/5X'SUMJH= 'F5.2//)
575    WRITE(8,500)CT70,TX70,OBJ170,OBJ270,POBJ270,SJHET70
500    FORMAT(5X'FOR J-H 1970: CT= 'F7.5' AND TX= 'F5.2/5X'OBJ1= 'F7.4/
      +5X'OBJ2= 'F7.4', (OBJ2/SUMPEN)= 'F6.2'%'/5X'SUMJH= 'F5.2/)
       TMNAV=STMN/XNDP
       TMNAVC=(TMNAV - 32.)*5./9.
       TMXAV=STMX/XNDP
       TMXAVC=(TMXAV-32.)*5./9.
       TDF=TMXAV-TMNAV
       TDFC=TMXAVC-TMNAVC
       TAVE=(TMNAV+TMXAV)*.5
       TAVEC=(TMNAVC+TMXAVC)*.5
       AJULTMN=SJULTMN/31.
       AJULTMNC=(AJULTMN-32.)*5./9.
       AJULTMX=SJULTMX/31.
       AJULTMXC=(AJULTMX-32.)*5./9.
       AJULTAV=(AJULTMN+AJULTMX)*.5
       AJULTAVC=(AJULTMXC+AJULTMNC)*.5
       AJULTDFC=AJULTMXC - AJULTMNC
       SEASSVPD=SSVPAV/XNDP
       AJULSVPD=SJULSVP/31.
       AJULTDF=AJULTMX-AJULTMN
       WRITE(8,600)TMNAV,TMNAVC,AJULTMN,AJULTMNC,TMXAV,TMXAVC,AJULTMX,
      +AJULTMXC,TDF,TDFC,AJULTDF,AJULTDFC,TAVE,TAVEC,AJULTAV,AJULTAVC,
      +SPPT,SEASSVPD,AJULSVPD,TMXW,TMNW,(TMXW-TMNW),TMXWC,TMNWC,
      +(TMXWC-TMNWC),E2,E1,(E2-E1)
600    FORMAT(24X'S U M M A R Y'/18X'SEASONAL'13X'JULY'/5X
      +'AVE. TMN='F6.2' F, 'F6.2' C   'F6.2' C, 'F6.2' C'/5X
      +'AVE. TMX='F6.2' F, 'F6.2' C   'F6.2' F, 'F6.2' C'/5X
      +'   DIFF.='F6.2' F, 'F6.2' C   'F6.2' F, 'F6.2' C'/5X
      +'    TAV ='F6.2' F, 'F6.2' C   'F6.2' F, 'F6.2' C'/5X
      +'  PRECIP='F5.2' INCHES'/
      +'        E2-E1 ='F7.4' mb          E2-E1 ='F7.4' mb'//
      +'                  MEAN HISTORICAL JULY VALUES'/
      +'               TMX:'F6.2' - TMN:'F6.2' = 'F6.2' C'/
      +'               TMX:'F6.2' - TMN:'F6.2' = 'F6.2' F'/
      +'              E2:'F7.4' - E1:'F7.4' = 'F7.4' mb')
       WRITE(8,700)A,B,AA,BB,W1,W2,WHT,WINDLIM,
      +            K,A0,A1,A2,A3,A4,A5,A6,RSCN,WINDCN,TEMCN
700    FORMAT(/5X'PENMAN EQUATION COEFFICIENTS:'/5X'A='F6.3
      +'  B='F6.3'  A1='F6.3'  B1='F6.3/5X'W1='F6.3'  W2='F7.5
      +'  WHT = 'F7.5' WINDLIM='F4.0//5X'RSO'I2':'4(E10.4,1X)/11X
      +3(E10.4,1X)//5X'RSCN='F7.5' WINDCN='F7.5' TEMCN='F7.5/)
       WMAY=SWMAY/31.
       WJUN=SWJUN/30.
       WJUL=SWJUL/31.
       WAUG=SWAUG/31.
       WSEP=SWSEP/30.
       AVWIND=(SWMAY+SWJUN+SWJUL+SWAUG+SWSEP)/153.
       WRITE(8,800)WMAY,WJUN,WJUL,WAUG,WSEP,AVWIND
800    FORMAT(20X'W I N D'//5X'MAY: 'F6.1' MILES/DAY,  '
      +5X'JUN: 'F6.1' MILES/DAY'/5X'JUL: 'F6.1' MILES/DAY,  '
      +5X'AUG: 'F6.1' MILES/DAY'/5X'SEP: 'F6.1' MILES/DAY'/
      +5X'AVERAGE SEASONAL WIND: 'F6.1' MILES/DAY')
       STOP
       END

       SUBROUTINE SAVAPR(TF,SVP)
```

```
      TC=(TF-32.)*5./9.
      SVP= 1.3329*EXP(21.07 - 5336./(TC+273.1))
      RETURN
      END

      SUBROUTINE JULDAY(IMN,IDAY,JD)
      DIMENSION MN(12)
      DATA MN/31,28,31,30,31,30,31,31,30,31,30,31/
      SUM=0
      DO 20 I=1,IMN
      IF(IMN.EQ.I)GOTO 10
      SUM=SUM+MN(I)
 10   JD=SUM+IDAY
 20   CONTINUE
      RETURN
      END

      SUBROUTINE ROOZ(JD,IMN,IDAY)
      DIMENSION MN(12)
      DATA MN/31,28,31,30,31,30,31,31,30,31,30,31/
      SUM=0
      DO 10 J=1,12
      SUM=SUM+MN(J)
      IF((JD-SUM).LE.0)GOTO 20
 10   CONTINUE
 20   IMN=J
      IDAY=JD - SUM + MN(J)
      RETURN
      END
*
*                         END OF PROGRAM
*
********************************************************************
```

```
 100      1    2 1981
 200   GREENVILLE LOGAN UT 1981  4580.     4175       11182           7  6.5    4
 300   THC  .328 .672    1    1    1    1    1
 400   SMI%   90   82   88   90   91   85   89
 500   FC   2.1732.3042.2282.3702.4412.6422.488
 600   WP   .693 .814 .850 .949 .9881.0081.039
 700      2    2    3    1    1    1    1    0
 800     87.5      56.0
 900   CON  1.22   -.18  .325 -.044  0.75 .0185       .5 100.
1000   RSO 5-.15281E03.105439E02-.1793E-01-.1057E-03.22262E-06
1100      5    1    9   30
1200           0         0         0         0              0
1300   (15X,4F5.0,F5.2,2F5.0,F5.3)
1400   LOGANUTNF 50181   74   49   58   76            28  661  034
1500   LOGANUTNF 50281   77   49   54   68   21       45  311  293
1600   LOGANUTNF 50381   71   43   49   60            29  541  131
1700   LOGANUTNF 50481   72   40   54   70            56  679  274
1800   LOGANUTNF 50581   72   40   54   62            64  348  195
1900   LOGANUTNF 50681   48   40   39   45   36       36  360  176
2000   LOGANUTNF 50781   55   36   43   51   01       62  581  092
2100   LOGANUTNF 50881   57   36   46   56   02       36  481  101
2200   LOGANUTNF 50981   65   33   50   63            23  740  209
2300   LOGANUTNF 51081   73   37   52   71            38  607  236
2400   LOGANUTNF 51181   56   39   45   55   50       53  365  110
2500   LOGANUTNF 51281   56   31   41   50            12  575  194
2600   LOGANUTNF 51381   63   30   47   62            32  773  186
2700   LOGANUTNF 51481   77   42   58   74            17  635  148
2800   LOGANUTNF 51581   73   43   47   51   66       31  336  176
2900   LOGANUTNF 51681   52   38   44   46   01       31  218  050
3000   LOGANUTNF 51781   60   42   50   60   21       12  369  065
3100   LOGANUTNF 51881   70   32   60   67            10  614  111
3200   LOGANUTNF 51981   74   55   53   70            71  473  264
3300   LOGANUTNF 52081   50   45   49   49   24       22  225  049
3400   LOGANUTNF 52181   51   43   48   49   88       35   85  090
3500   LOGANUTNF 52281   55   46   49   54   44       28   82  048
3600   LOGANUTNF 52381   68   53   56   65            29  319  071
3700   LOGANUTNF 52481   74   42   58   70            22  673  164
3800   LOGANUTNF 52581   84   56   56   59   15       10  282  045
3900   LOGANUTNF 52681   62   55   56   57   60        8  180  263
4000   LOGANUTNF 52781   75   48   60   66   02        7  637  107
4100   LOGANUTNF 52881   76   48   64   74            12  711  243
4200   LOGANUTNF 52981   78   46   60   76             5  743  203
4300   LOGANUTNF 53081   80   55   61   77            14  660  162
4400   LOGANUTNF 53181   79   51   56   72           101  738  407
4500   LOGANUTNF 60181   78   44   58   77            34  783  138
4600   LOGANUTNF 60281   79   51   57   61            20  406  224
4700   LOGANUTNF 60381   69   52   57   68   71        7  529  135
4800   LOGANUTNF 60481   76   48   59   74            16  731  206
4900   LOGANUTNF 60581   80   65   63   80            10  769  168
5000   LOGANUTNF 60681   81   63   62   79            21  624  299
5100   LOGANUTNF 60781   81   57   58   79            18  377  179
5200   LOGANUTNF 60881   84   60   63   83            39  620  332
5300   LOGANUTNF 60981   85   54   55   71   04       30  625  106
5400   LOGANUTNF 61081   73   52   58   65   18       14  343  218
5500   LOGANUTNF 61181   81   57   58   80            13  573  107
5600   LOGANUTNF 61281   75   55   56   73            20  696  285
5700   LOGANUTNF 61381   63   41   42   45   54       35  452  237
5800   LOGANUTNF 61481   58   40   47   56   02       21  452  089
5900   LOGANUTNF 61581   66   40   49   64   08       19  818  130
6000   LOGANUTNF 61681   82   47   55   79            41  782  313
6100   LOGANUTNF 61781   70   48   48   67            42  716  239
6200   LOGANUTNF 61881   76   45   54   75            27  700  216
6300   LOGANUTNF 61981   80   47   58   76            21  670  251
6400   LOGANUTNF 62081   83   54   60   81            34  758  281
6500   LOGANUTNF 62181   82   49   58   79            27  766  422
6600   LOGANUTNF 62281   87   50   58   86            25  802  213
6700   LOGANUTNF 62381   85   60   61   82            17  720  293
6800   LOGANUTNF 62481   86   50   63   84            13  784  222
6900   LOGANUTNF 62581   92   56   70   89            10  714  217
7000   LOGANUTNF 62681   87   70   61   87            26  122  337
```

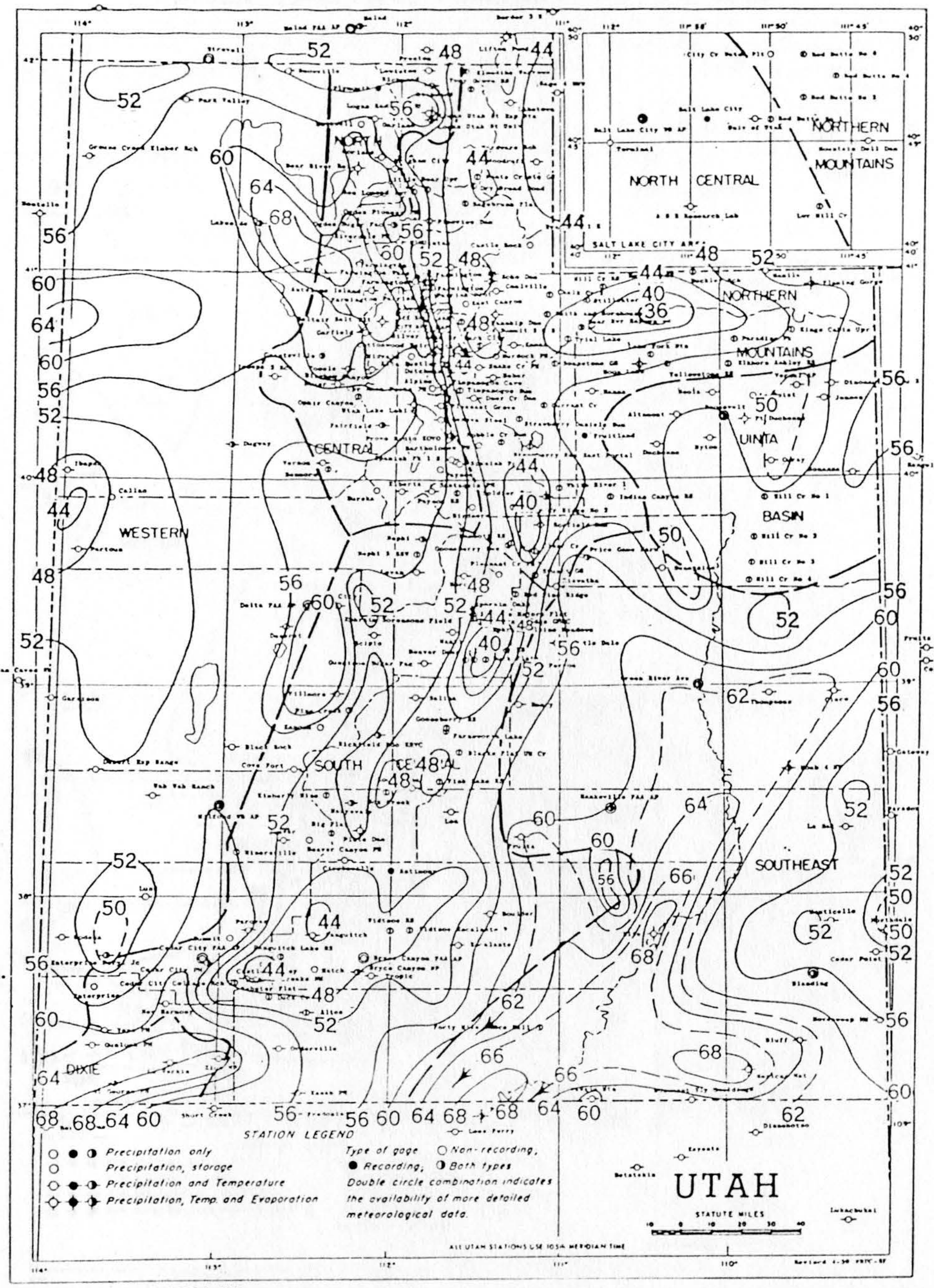
```
 7100    LOGANUTNF 62781   90   72   64   83         31  139  247
 7200    LOGANUTNF 62881   85   70   57   79         10  794  204
 7300    LOGANUTNF 62981   85   54   62   82          9  782  276
 7400    LOGANUTNF 63081   90   50   64   88          7  723  232
 7500    LOGANUTNF 70181   85   62   62   74         23  438  218
 7600    LOGANUTNF 70281   81   56   62   79   03    34  546  270
 7700    LOGANUTNF 70381   85   56   63   77   14    10  681  207
 7800    LOGANUTNF 70481   89   72   64   88         41  469  329
 7900    LOGANUTNF 70581   93   62   65   91          2  768  310
 8000    LOGANUTNF 70681   83   62   64   84         16  626  319
 8100    LOGANUTNF 70781   85   62   59   76   06    40  839  306
 8200    LOGANUTNF 70881   78   41   55   78         20  791  215
 8300    LOGANUTNF 70981   89   50   63   88         15  765  277
 8400    LOGANUTNF 71081   89   63   67   87         38  687  377
 8500    LOGANUTNF 71181   90   59   61   88   04    57  719  313
 8600    LOGANUTNF 71281   90   54   62   88         19  727  216
 8700    LOGANUTNF 71381   90   60   58   85         34  795  341
 8800    LOGANUTNF 71481   86   47   58   84         15  771  241
 8900    LOGANUTNF 71581   88   48   55   87         10  785  280
 9000    LOGANUTNF 71681   91   49   60   90         17  649  269
 9100    LOGANUTNF 71781   87   58   64   86         29  730  188
 9200    LOGANUTNF 71881   88   52   61   87         17  573  363
 9300    LOGANUTNF 71981   85   52   58   85         11  767  247
 9400    LOGANUTNF 72081   89   49   61   88         28  761  322
 9500    LOGANUTNF 72181   89   50   59   87         19  295  295
 9600    LOGANUTNF 72281   89   49   58   86         21  751  345
 9700    LOGANUTNF 72381   90   50   61   89         13  718  258
 9800    LOGANUTNF 72481   90   50   61   85         16  659  224
 9900    LOGANUTNF 72581   88   54   59   86         36  665  265
10000    LOGANUTNF 72681   72   60   55   68   25    34  424  434
10100    LOGANUTNF 72781   81   46   68   81         19  748  155
10200    LOGANUTNF 72881   88   48   59   86         15  735  278
10300    LOGANUTNF 72981   93   54   61   91         15  628  310
10400    LOGANUTNF 73081   88   58   60   87          8  695  333
10500    LOGANUTNF 73181   90   51   58   89          7  712  289
10600    LOGANUTNF 80181   92   49   63   90         19  717  402
10700    LOGANUTNF 80281   91   55   60   89         40  718  303
10800    LOGANUTNF 80381   90   50   58   88         17  716  280
10900    LOGANUTNF 80481   90   49   59   89         20  712  286
11000    LOGANUTNF 80581   92   54   60   90         14  714  319
11100    LOGANUTNF 80681   92   49   60   90         14  702  275
11200    LOGANUTNF 80781   91   59   62   90         44  685  315
11300    LOGANUTNF 80881   94   54   62   91         33  675  379
11400    LOGANUTNF 80981   86   64   62   85        126  314  456
11500    LOGANUTNF 81081   83   63   62   80   04   168  705  363
11600    LOGANUTNF 81181   86   49   60   85         65  605  264
11700    LOGANUTNF 81281   87   49   60   85          1  556  225
11800    LOGANUTNF 81381   74   50   56   73   03     3  319  280
11900    LOGANUTNF 81481   88   56   62   86         10  619  219
12000    LOGANUTNF 81581   88   54   58   70         31  578  366
12100    LOGANUTNF 81681   89   53   63   87         25  651  185
12200    LOGANUTNF 81781   91   51   61   89          4  660  259
12300    LOGANUTNF 81881   93   52   59   90         26  636  310
12400    LOGANUTNF 81981   86   58   60   86         44  622  378
12500    LOGANUTNF 82081   88   56   62   86         28  571  243
12600    LOGANUTNF 82181   88   55   59   80   26    39  645  326
12700    LOGANUTNF 82281   88   48   61   86         14  641  256
12800    LOGANUTNF 82381   91   47   61   88         11  634  232
12900    LOGANUTNF 82481   90   60   62   89         30  622  273
13000    LOGANUTNF 82581   93   58   62   91         16  615  256
13100    LOGANUTNF 82681   93   56   63   91         41  584  356
13200    LOGANUTNF 82781   92   55   57   78         48  518  333
13300    LOGANUTNF 82881   93   52   62   89          3  608  219
13400    LOGANUTNF 82981   91   58   62   88         44  571  326
13500    LOGANUTNF 83081   89   54   55   74         24  524  286
13600    LOGANUTNF 83181   78   42   51   76         11  621  188
13700    LOGANUTNF 90181   84   40   55   83         15  605  253
13800    LOGANUTNF 90281   80   53   54   79         14  518  308
13900    LOGANUTNF 90381   84   41   60   80         15  586  239
14000    LOGANUTNF 90481   88   47   60   87         15  563  101
```

```
14100     LOGANUTNF 90581  87   59   57   62   11   58  109  131
14200     LOGANUTNF 90681  87   62   56   53        21  213  200
14300     LOGANUTNF 90781  83   74   58   75        25  377  190
14400     LOGANUTNF 90881  81   78   61   78        24  508  158
14500     LOGANUTNF 90981  80   51   58   78         7  525  193
14600     LOGANUTNF 91081  82   58   61   81        16  540  202
14700     LOGANUTNF 91181  86   49   62   85        24  549  221
14800     LOGANUTNF 91281  87   50   59   77         6  541  255
14900     LOGANUTNF 91381  87   52   60   85         9  552  168
15000     LOGANUTNF 91481  86   49   58   80        11  545  214
15100     LOGANUTNF 91581  85   48   57   85         7  538  195
15200     LOGANUTNF 91681  87   49   58   86        16  531  243
15300     LOGANUTNF 91781  88   46   58   85         6  525  262
15400     LOGANUTNF 91881  88   47   59   86        15  520  201
15500     LOGANUTNF 91981  86   52   53   69        30  450  270
15600     LOGANUTNF 92081  78   41   54   76        14  516  201
15700     LOGANUTNF 92181  77   74   53   74        19  475  207
15800     LOGANUTNF 92281  77   73   52   73        14  423  198
15900     LOGANUTNF 92381  76   72   50   72        26  483  171
16000     LOGANUTNF 92481  79   50   55   75        24  482  182
16100     LOGANUTNF 92581  62   45   49   59   43   47  184  156
16200     LOGANUTNF 92681  63   32   47   62        13  349  078
16300     LOGANUTNF 92781  80   36   54   76        16  496  147
16400     LOGANUTNF 92881  78   51   54   75        60  448  227
16500     LOGANUTNF 92981  75   43   52   64        17  314  150
16600     LOGANUTNF 93081  64   38   46   62   05   22  486  134
16700               GREENVILLE LOGAN UT 1981
16800               36.01=SEASONAL PENMAN ET
16900                 1.05
17000                 0.90
17100                 0.88
17200                 0.63
17300                 0.53
17400                 0.97
17500                 1.20
17600                 1.28
17700                 1.02
17800                 1.36
17900                 1.50
18000                 1.20
18100                 1.27
18200                 1.52
18300                 1.62
18400                 1.45
18500                 1.42
18600                 1.33
18700                 1.49
18800                 1.55
18900                 1.18
19000                 1.30
19100                 1.38
19200                 1.36
19300                 1.25
19400                 0.89
19500                 1.09
19600                 1.03
19700                 0.99
19800                 0.89
19900                 0.48
```

```
************************************************************************************
*                                                                                  *
*       THIS PROGRAM ESTIMATES THE EXTRATERRESTRAIL SOLAR RADIATION               *
*       FOR THE GROWING SEASON  APRIL 1- SEPTEMBER 30  FOR THE LATI-              *
*       TUDES OF THE STATE OF UTAH.                                                *
*                                                                                  *
************************************************************************************
*                                                                                  *
        INTEGER RA(300,11)
        CHARACTER MON*3
        DIMENSION XLAT(11),K(300,11),MON(12)
        DATA XLAT/37.,37.5,38.,38.5,39.,39.5,40.,40.5,41.,41.5,42./
        DATA MON/'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG',
       +              'SEP','OCT','NOV','DEC'/
        DO 28 I=1,11
        PHI=XLAT(I)/57.2958
        DO 25 J=91,273
        D=J
        THETA=0.0172*(D-2.)
        IF(J.LT.3.)THETA=0.0172*(D+FLOAT(NDYR-2))
        RR=(1.+0.0167238*COS(THETA))/0.99986
        PC=0.0172*(D-1.)
        SIND=0.39785*SIN(PC+(279.9348+1.914827*SIN(PC)-0.079525*COS(PC)
       $+0.019938*SIN(2.*PC)-0.00162*COS(2.*PC))/57.29578)
        DER=ASIN(SIND)
        XSIN=SIN(PHI)*SIND
        XCOS=COS(PHI)*COS(DER)
        H=ACOS((-0.01454-XSIN)/XCOS)
        DL=7.63944*H
        RA(J,I)=118.5*RR*RR*(DL*XSIN+7.63944*XCOS*SIN(H))
 25     CONTINUE
 28     CONTINUE
        DOAR=49
        PAGE=0
        DO J=91,273
        CALL ROOZ(J,JMON,JDAY)
        IF((DOAR.EQ.49).AND.(PAGE.LT.2))THEN
          WRITE(90,35)
          DOAR=0
          PAGE=PAGE+1
        ENDIF
        IF((DOAR.EQ.50).AND.(PAGE.EQ.2))THEN
          WRITE(90,40)
          WRITE(90,35)
          DOAR=0
        ENDIF
        WRITE(90,30)MON(JMON),JDAY,(RA(J,I),I=1,11)
        DOAR=DOAR+1
        END DO
 30     FORMAT(14X,A3,I2,11(1X,I4))
 35     FORMAT(//14X,60('_'),//25X'EXTRATERRESTRIAL  RADIATION (LANGLEYS
       +/DAY)'//42X'LATITUDE'/14X
       +'MON DAY 37 37.5  38  38.5  39  39.5  40  40.5  41  41.5  42'/
       +14X,60('_'))
 40     FORMAT(/)
        STOP
        END
        SUBROUTINE ROOZ(JA,JAMON,JADAY)
        DIMENSION JMON(12)
        DATA JMON/31,28,31,30,31,30,31,31,30,31,30,31/
        SMON=0
        DOAR=0
        DO K=1,12
        SMON=SMON+JMON(K)
        IF((SMON.GE.JA).AND.(DOAR.EQ.0))THEN
          JAMON=K
          JADAY=JA-(SMON-JMON(K))
          DOAR=1
        ENDIF
        ENDDO
        RETURN
        END
```

Appendix III: Isolines of Mean Longterm July Maximum and Minimum Temperatures for the State of Utah

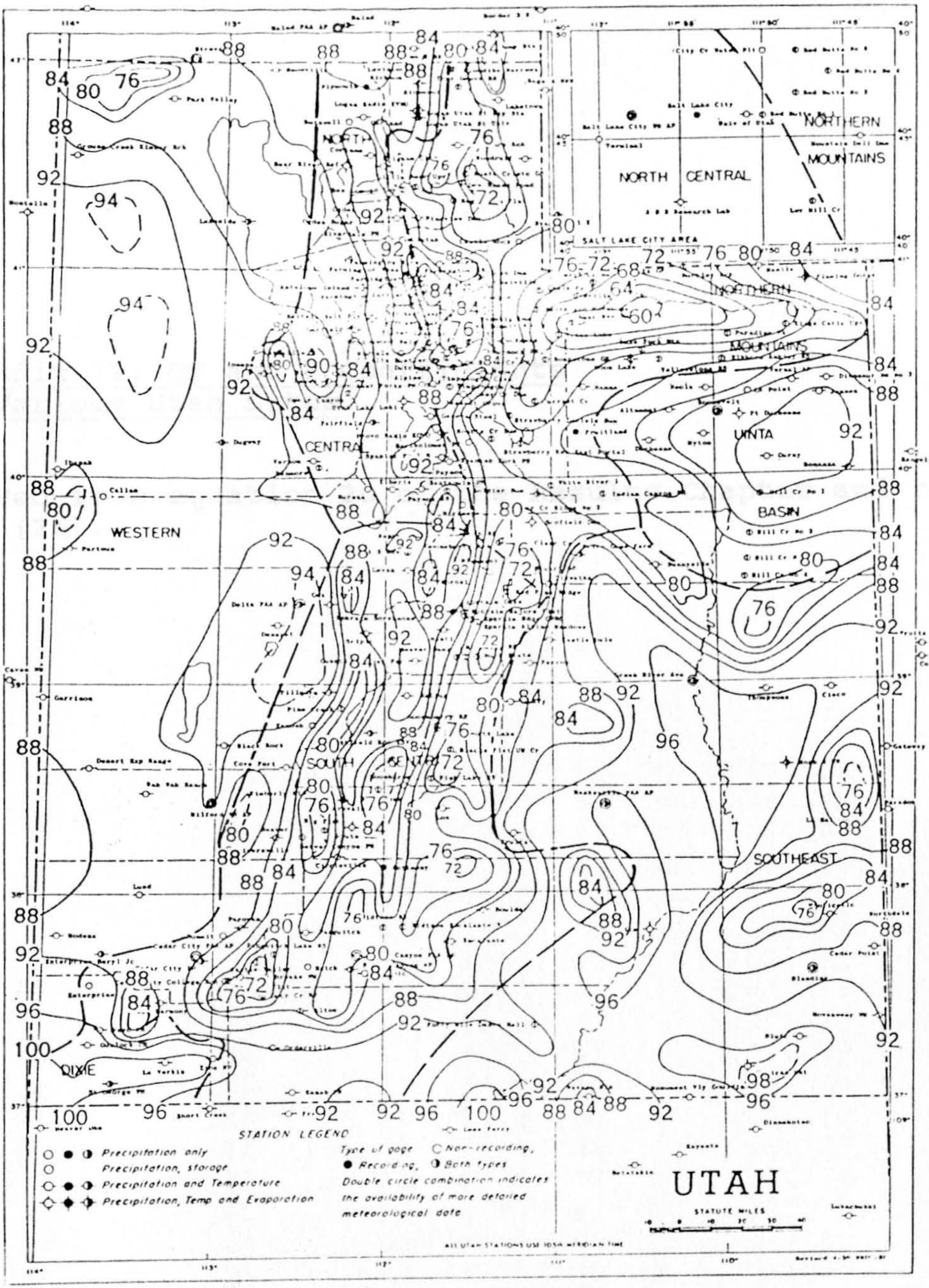
Mean Minimum Temperature (°F.), July



Based on period 1931-52

FIG. 13.- Mean Longterm July Minimum Temperature Isolines for the State of Utah. From (25).

Mean Maximum Temperature (°F.), July



Based on period 1931-52

FIG. 14.- Mean Longterm July Maximum Temperature Isolines for the State of Utah. From (25).

Appendix IV: CT and K Coefficients for Various Utah Sites

Derived from equation 20 of the Results Chapter and reference (26).

SITE	LAT	LONG	ELEV	JULY TMN	 TMX	K	CT
ALPINE	40.45	111.78	4920	50	80	.001464	.01336
ALTA	40.60	111.63	8760	58	92	.000512	.00475
ALTAMONT	40.37	110.28	6370	52	84	.001079	.01001
ALTON	37.43	112.48	7040	51	84	.001077	.01012
BEAR RIV. REF.	41.47	112.27	4208	60	92	.000910	.00813
BIRDSEYE	39.87	111.53	5740	50	88	.001004	.00970
BLACK ROCK	38.70	112.95	4895	55	92	.001015	.00975
BLADING	37.62	109.47	6130	56	90	.001176	.01121
BLUFF	37.28	109.55	4315	64	97	.001343	.01272
BONANZA	40.02	109.18	5450	56	92	.001034	.00992
BRYCE CANYON	37.65	112.17	7915	48	80	.001071	.01002
CALLAO	39.90	113.72	4330	48	88	.001147	.01120
CASTLE DALE	39.22	111.02	5660	56	84	.001275	.01158
CEDAR POINT	37.72	109.08	6760	52	88	.001143	.01103
CIRCLEVILLE	38.17	112.27	6060	49	84	.001200	.01139
CORINNE	41.58	112.13	4240	57	92	.000897	.00831
DELTA	39.33	112.59	4623	60	94	.001069	.00923
DESERET	39.28	112.65	4585	56	94	.000944	.00915
DESERT EXP RN	38.60	113.75	5250	52	89	.001030	.00985
DUCHESNE	40.17	110.40	5510	52	86	.001175	.01105
DUGWAY	40.18	112.93	4340	54	90	.001076	.01016
EMERY	38.77	111.45	7640	52	82	.001012	.00932
ENTERPRIZE	37.57	113.70	5300	57	90	.001133	.01092
ESCALANTE	37.77	111.60	5810	53	84	.001331	.01238
EUREKA	39.95	112.12	6480	56	88	.000856	.00786
FAIRFIELD	40.27	112.08	4880	56	88	.001106	.01013
FERRON	39.08	111.13	5930	52	83	.001257	.01164
FILLMORE	38.95	112.32	5120	60	92	.000994	.00914
FLAMING GORGE	40.93	109.42	6270	52	84	.001099	.01021
FLOWELL	38.98	112.42	4702	60	90	.000998	.01069
GARFIELD	40.72	112.20	4330	62	85	.001349	.01148
GARLAND	41.75	112.19	4400	58	87	.001081	.00992
GRANTSVILLE	40.60	112.45	4290	61	90	.001087	.00958
GREEN RIVER	39.00	110.17	4070	62	96	.001209	.01142
HDWARE RNH	41.60	111.57	5560	45	76	.001364	.01250
HITE STN	37.87	110.38	4000	68	96	.001363	.01231
HOVENWEEP	37.38	109.08	5240	56	92	.001337	.01293
JENSEN	40.37	109.35	4760	52	92	.001130	.01117
KAMAS	40.65	111.28	6470	47	80	.001122	.01045
KANAB	37.05	112.53	4950	56	93	.001158	.01120
KANOSH	38.80	112.43	5010	55	88	.001200	.01118
KAYSVILLE	41.07	111.18	4267	61	92	.001075	.00986
LA SAL	38.30	109.22	6720	56	88	.001102	.01036
LA VERKIN	37.20	113.27	3220	68	100	.001199	.01099
LEVAN	39.55	111.87	5315	56	88	.001098	.01013

				JULY			
SITE	LAT	LONG	ELEV	TMN	TMX	K	CT
LOA	38.40	111.65	7080	51	80	.001172	.01077
LOGAN	41.75	111.82	4580	56	88	.001094	.00916
MANILA	41.00	109.73	6440	52	80	.001189	.01079
MANTI	39.25	111.63	5740	52	88	.001054	.01005
MARYSVALE	38.45	112.23	5910	52	86	.001134	.01068
MEXICAN HAT	37.15	109.87	4120	68	98	.001345	.01243
MOAB 4 NW	38.60	109.60	3965	62	96	.001343	.01275
MODENA	37.80	113.92	5480	52	90	.001008	.00975
MONTICELLO	37.87	109.30	6820	52	84	.001245	.01173
MONUMT VALY.	37.02	110.22	5300	63	94	.001202	.01122
MORONI	39.53	111.58	5525	51	92	.000906	.00902
NEOLA	40.42	110.03	5920	51	82	.001248	.01153
NEPHI	39.70	111.83	5130	56	92	.000947	.00901
NEW HRMNY	37.48	113.30	5290	60	88	.001210	.01091
OAK CITY	39.38	112.33	5070	60	94	.000869	.00810
OURAY 4 NE	40.13	109.65	4670	50	92	.001152	.01157
PANGUITCH	37.82	112.45	6720	44	84	.001096	.01072
PARADISE	41.58	111.60	5000	53	83	.001073	.01026
PARK CITY	40.72	111.52	6740	41	79	.001038	.01045
PARK VALY	41.82	113.33	5530	56	85	.000877	.00766
PAROWAN	37.85	112.83	5930	56	88	.001161	.00966
PARTOUN	39.63	113.88	4780	47	88	.001054	.01038
PAYSON	40.03	111.72	4800	56	89	.001128	.01045
PINE VW DAM	41.25	111.83	4940	52	88	.001005	.00948
PLEASANT GV	40.37	111.72	4760	56	88	.001150	.01055
RANDOLPH	41.75	111.13	6280	44	81	.001074	.01017
RICHMOND	41.90	111.82	4680	52	88	.000991	.00932
ROOSEVELT	40.30	109.98	5104	52	89	.001150	.01107
SLC AIRPORT	40.78	111.95	4267	61	92	.001032	.00869
ST. GEORGE	37.08	113.68	2800	69	101	.001057	.01054
SALINA	38.97	111.87	5130	52	92	.001014	.01001
SNOWVILLE	41.97	112.72	4560	52	88	.000940	.00878
SUMMIT	37.80	112.93	6000	56	88	.001058	.00982
SUNNYSIDE	39.57	110.37	6780	51	88	.000934	.00899
THOMPSON	38.97	109.72	5150	62	96	.000990	.00937
THORNACK	41.75	111.13	6280	44	81	.001080	.01035
TIMPANOGAS	40.45	111.70	5640	52	88	.000961	.00911
TOOELE	40.53	112.30	5070	60	90	.000936	.00835
TROPIC	37.63	112.08	6280	50	83	.001249	.01174
UTAH LAKE	40.37	111.90	4497	56	84	.001406	.01257
VERNON	40.08	112.45	5485	56	88	.000977	.00894
WAH WAH RN	38.48	113.42	4880	54	90	.001099	.01045
WOODRUFF	41.53	111.15	6315	44	80	.001084	.01025

Appendix V: Estimated Extraterrestrial Solar Radiation for Utah Latitudes

Derived from program EXTRAD listed in Appendix II.

EXTRATERRESTRIAL RADIATION (LANGLEYS/DAY)

	LATITUDE										
MON DAY	37	37.5	38	38.5	39	39.5	40	40.5	41	41.5	42
APR 1	785	781	777	773	769	764	760	756	751	747	742
APR 2	790	786	782	778	774	770	766	761	757	753	748
APR 3	795	791	788	784	780	775	771	767	763	758	754
APR 4	800	797	793	789	785	781	777	773	768	764	760
APR 5	805	802	798	794	790	786	782	778	774	770	766
APR 6	810	807	803	799	796	792	788	784	780	776	771
APR 7	815	812	808	804	801	797	793	789	785	781	777
APR 8	820	817	813	810	806	802	798	795	791	787	783
APR 9	825	822	818	815	811	807	804	800	796	792	788
APR10	830	826	823	820	816	813	809	805	802	798	794
APR11	835	831	828	825	821	818	814	811	807	803	799
APR12	839	836	833	830	826	823	819	816	812	809	805
APR13	844	841	838	834	831	828	824	821	818	814	810
APR14	848	845	842	839	836	833	829	826	823	819	816
APR15	853	850	847	844	841	838	834	831	828	824	821
APR16	857	854	852	849	846	843	839	836	833	830	826
APR17	862	859	856	853	850	847	844	841	838	835	831
APR18	866	863	861	858	855	852	849	846	843	840	837
APR19	870	868	865	862	860	857	854	851	848	845	842
APR20	874	872	869	867	864	861	858	856	853	850	847
APR21	879	876	874	871	869	866	863	860	857	855	852
APR22	883	880	878	875	873	870	868	865	862	859	856
APR23	887	884	882	880	877	875	872	870	867	864	861
APR24	891	889	886	884	882	879	877	874	871	869	866
APR25	895	893	890	888	886	883	881	879	876	873	871
APR26	898	896	894	892	890	888	885	883	880	878	875
APR27	902	900	898	896	894	892	890	887	885	882	880
APR28	906	904	902	900	898	896	894	891	889	887	884
APR29	910	908	906	904	902	900	898	896	893	891	889
APR30	913	911	910	908	906	904	902	900	898	895	893
MAY 1	917	915	913	912	910	908	906	904	902	900	897
MAY 2	920	919	917	915	913	912	910	908	906	904	902
MAY 3	924	922	920	919	917	915	914	912	910	908	906
MAY 4	927	925	924	922	921	919	917	916	914	912	910
MAY 5	930	929	927	926	924	923	921	919	918	916	914
MAY 6	933	932	931	929	928	926	925	923	921	920	918
MAY 7	936	935	934	933	931	930	928	927	925	923	922
MAY 8	940	938	937	936	935	933	932	930	929	927	925
MAY 9	943	941	940	939	938	937	935	934	932	931	929
MAY10	945	944	943	942	941	940	938	937	936	934	933
MAY11	948	947	946	945	944	943	942	940	939	938	936
MAY12	951	950	949	948	947	946	945	944	942	941	940
MAY13	954	953	952	951	950	949	948	947	946	944	943
MAY14	956	956	955	954	953	952	951	950	949	948	946
MAY15	959	958	958	957	956	955	954	953	952	951	950
MAY16	962	961	960	959	959	958	957	956	955	954	953

EXTRATERRESTRIAL RADIATION (LANGLEYS/DAY)

	LATITUDE										
MON DAY	37	37.5	38	38.5	39	39.5	40	40.5	41	41.5	42
MAY17	964	963	963	962	961	961	960	959	958	957	956
MAY18	966	966	965	965	964	963	962	962	961	960	959
MAY19	969	968	968	967	967	966	965	964	964	963	962
MAY20	971	970	970	970	969	968	968	967	966	965	964
MAY21	973	973	972	972	971	971	970	970	969	968	967
MAY22	975	975	975	974	974	973	973	972	971	971	970
MAY23	977	977	977	976	976	975	975	974	974	973	972
MAY24	979	979	979	978	978	978	977	977	976	976	975
MAY25	981	981	981	980	980	980	979	979	978	978	977
MAY26	983	983	983	982	982	982	982	981	981	980	980
MAY27	985	985	984	984	984	984	984	983	983	982	982
MAY28	986	986	986	986	986	986	986	985	985	984	984
MAY29	988	988	988	988	988	988	987	987	987	986	986
MAY30	989	989	990	990	989	989	989	989	989	988	988
MAY31	991	991	991	991	991	991	991	991	991	990	990
JUN 1	992	992	993	993	993	993	993	992	992	992	992
JUN 2	994	994	994	994	994	994	994	994	994	994	993
JUN 3	995	995	995	995	996	996	996	996	995	995	995
JUN 4	996	996	997	997	997	997	997	997	997	997	997
JUN 5	997	997	998	998	998	998	998	998	998	998	998
JUN 6	998	999	999	999	999	999	1000	1000	1000	1000	999
JUN 7	999	1000	1000	1000	1000	1001	1001	1001	1001	1001	1001
JUN 8	1000	1000	1001	1001	1001	1002	1002	1002	1002	1002	1002
JUN 9	1001	1001	1002	1002	1002	1003	1003	1003	1003	1003	1003
JUN10	1002	1002	1003	1003	1003	1003	1004	1004	1004	1004	1004
JUN11	1002	1003	1003	1004	1004	1004	1004	1005	1005	1005	1005
JUN12	1003	1003	1004	1004	1005	1005	1005	1005	1006	1006	1006
JUN13	1004	1004	1005	1005	1005	1006	1006	1006	1006	1006	1006
JUN14	1004	1005	1005	1005	1006	1006	1006	1007	1007	1007	1007
JUN15	1004	1005	1005	1006	1006	1007	1007	1007	1007	1008	1008
JUN16	1005	1005	1006	1006	1007	1007	1007	1008	1008	1008	1008
JUN17	1005	1006	1006	1007	1007	1007	1008	1008	1008	1008	1009
JUN18	1005	1006	1006	1007	1007	1008	1008	1008	1009	1009	1009
JUN19	1005	1006	1007	1007	1007	1008	1008	1008	1009	1009	1009
JUN20	1005	1006	1007	1007	1008	1008	1008	1009	1009	1009	1009
JUN21	1005	1006	1007	1007	1008	1008	1008	1009	1009	1009	1009
JUN22	1005	1006	1007	1007	1007	1008	1008	1009	1009	1009	1009
JUN23	1005	1006	1006	1007	1007	1008	1008	1008	1009	1009	1009
JUN24	1005	1006	1006	1007	1007	1008	1008	1008	1008	1009	1009
JUN25	1005	1005	1006	1006	1007	1007	1008	1008	1008	1008	1008
JUN26	1004	1005	1006	1006	1006	1007	1007	1007	1008	1008	1008
JUN27	1004	1005	1005	1006	1006	1006	1007	1007	1007	1007	1008
JUN28	1003	1004	1005	1005	1005	1006	1006	1006	1007	1007	1007
JUN29	1003	1004	1004	1004	1005	1005	1006	1006	1006	1006	1006
JUN30	1002	1003	1003	1004	1004	1005	1005	1005	1005	1005	1006
JUL 1	1002	1002	1003	1003	1003	1004	1004	1004	1004	1005	1005
JUL 2	1001	1001	1002	1002	1003	1003	1003	1003	1004	1004	1004

EXTRATERRESTRIAL RADIATION (LANGLEYS/DAY)

	LATITUDE										
MON DAY	37	37.5	38	38.5	39	39.5	40	40.5	41	41.5	42
JUL 3	1000	1001	1001	1001	1002	1002	1002	1002	1003	1003	1003
JUL 4	999	1000	1000	1000	1001	1001	1001	1001	1001	1002	1002
JUL 5	998	999	999	999	1000	1000	1000	1000	1000	1000	1000
JUL 6	997	998	998	998	999	999	999	999	999	999	999
JUL 7	996	996	997	997	997	998	998	998	998	998	998
JUL 8	995	995	996	996	996	996	996	996	996	996	996
JUL 9	994	994	994	995	995	995	995	995	995	995	995
JUL10	992	993	993	993	993	993	993	993	993	993	993
JUL11	991	991	991	992	992	992	992	992	992	992	991
JUL12	990	990	990	990	990	990	990	990	990	990	990
JUL13	988	988	988	989	989	989	988	988	988	988	988
JUL14	987	987	987	987	987	987	987	987	986	986	986
JUL15	985	985	985	985	985	985	985	985	984	984	984
JUL16	983	983	983	983	983	983	983	983	982	982	982
JUL17	981	981	981	981	981	981	981	981	980	980	979
JUL18	980	980	980	979	979	979	979	978	978	978	977
JUL19	978	978	978	977	977	977	977	976	976	975	975
JUL20	976	976	975	975	975	975	974	974	973	973	972
JUL21	974	974	973	973	973	972	972	971	971	970	970
JUL22	972	971	971	971	970	970	970	969	968	968	967
JUL23	969	969	969	969	968	968	967	967	966	965	964
JUL24	967	967	967	966	966	965	965	964	963	962	962
JUL25	965	965	964	964	963	963	962	961	960	960	959
JUL26	963	962	962	961	961	960	959	958	958	957	956
JUL27	960	960	959	959	958	957	956	956	955	954	953
JUL28	958	957	957	956	955	954	954	953	952	951	950
JUL29	955	955	954	953	952	952	951	950	949	948	947
JUL30	953	952	951	950	950	949	948	947	946	945	943
JUL31	950	949	948	948	947	946	945	944	943	941	940
AUG 1	947	946	946	945	944	943	942	940	939	938	937
AUG 2	944	944	943	942	941	940	938	937	936	935	933
AUG 3	941	941	940	939	938	936	935	934	933	931	930
AUG 4	939	938	937	935	934	933	932	931	929	928	926
AUG 5	936	935	933	932	931	930	928	927	926	924	923
AUG 6	933	931	930	929	928	926	925	924	922	921	919
AUG 7	929	928	927	926	924	923	922	920	918	917	915
AUG 8	926	925	924	922	921	919	918	916	915	913	911
AUG 9	923	922	920	919	917	916	914	913	911	909	907
AUG10	920	918	917	915	914	912	911	909	907	905	903
AUG11	916	915	913	912	910	909	907	905	903	901	899
AUG12	913	911	910	908	907	905	903	901	899	897	895
AUG13	910	908	906	905	903	901	899	897	895	893	891
AUG14	906	904	903	901	899	897	895	893	891	889	887
AUG15	902	901	899	897	895	893	891	889	887	885	882
AUG16	899	897	895	893	891	889	887	885	883	880	878
AUG17	895	893	891	889	887	885	883	881	878	876	873
AUG18	891	889	887	885	883	881	879	876	874	871	869

EXTRATERRESTRIAL RADIATION (LANGLEYS/DAY)

	LATITUDE										
MON DAY	37	37.5	38	38.5	39	39.5	40	40.5	41	41.5	42
AUG19	887	885	883	881	879	877	874	872	869	867	864
AUG20	884	881	879	877	875	872	870	867	865	862	860
AUG21	880	877	875	873	871	868	866	863	860	858	855
AUG22	876	873	871	869	866	864	861	858	856	853	850
AUG23	872	869	867	864	862	859	857	854	851	848	845
AUG24	868	865	863	860	857	855	852	849	846	844	841
AUG25	863	861	858	856	853	850	847	845	842	839	836
AUG26	859	857	854	851	848	846	843	840	837	834	831
AUG27	855	852	850	847	844	841	838	835	832	829	826
AUG28	851	848	845	842	839	836	833	830	827	824	821
AUG29	846	843	841	838	835	832	828	825	822	819	815
AUG30	842	839	836	833	830	827	824	820	817	814	810
AUG31	837	834	831	828	825	822	819	815	812	808	805
SEP 1	833	830	827	824	820	817	814	810	807	803	800
SEP 2	828	825	822	819	815	812	809	805	802	798	794
SEP 3	824	821	817	814	811	807	804	800	796	793	789
SEP 4	819	816	812	809	806	802	798	795	791	787	784
SEP 5	814	811	808	804	801	797	793	790	786	782	778
SEP 6	810	806	803	799	796	792	788	784	780	777	773
SEP 7	805	801	798	794	790	787	783	779	775	771	767
SEP 8	800	796	793	789	785	781	778	774	770	766	761
SEP 9	795	791	788	784	780	776	772	768	764	760	756
SEP10	790	786	783	779	775	771	767	763	759	754	750
SEP11	785	781	778	774	770	766	761	757	753	749	744
SEP12	780	776	772	768	764	760	756	752	747	743	739
SEP13	775	771	767	763	759	755	751	746	742	737	733
SEP14	770	766	762	758	754	749	745	741	736	732	727
SEP15	765	761	757	753	748	744	739	735	730	726	721
SEP16	760	756	751	747	743	738	734	729	725	720	715
SEP17	755	750	746	742	737	733	728	724	719	714	709
SEP18	750	745	741	736	732	727	723	718	713	708	704
SEP19	744	740	735	731	726	722	717	712	707	703	698
SEP20	739	735	730	725	721	716	711	706	702	697	692
SEP21	734	729	725	720	715	710	706	701	696	691	686
SEP22	728	724	719	714	710	705	700	695	690	685	680
SEP23	723	718	714	709	704	699	694	689	684	679	674
SEP24	718	713	708	703	698	693	688	683	678	673	668
SEP25	712	707	703	698	693	688	682	677	672	667	662
SEP26	707	702	697	692	687	682	677	671	666	661	655
SEP27	701	696	691	686	681	676	671	666	660	655	649
SEP28	696	691	686	681	676	670	665	660	654	649	643
SEP29	691	685	680	675	670	664	659	654	648	643	637
SEP30	685	680	675	669	664	659	653	648	642	637	631