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IRRIGATION SCHEDULING

A Review of Techniques and Adaption of the USDA Irrigation Scheduling Computer Program for Swedish Conditions

Joseph Matthew Erpenbeck

Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

Swedish University of Agricultural Sciences
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PREFACE

Since the beginning of the seventies the area of irrigated land in Sweden has increased considerably. This has led to a demand for good water management. For irrigation application of proper amounts of water with proper intervals is desired in order to meet the requirements for optimum crop growth.

Irrigation scheduling deals with this problem. Soil water measurements and computed soil water balance are two general approaches for scheduling. On several farms in Sweden tensiometers have been useful tools in order to record the soil moisture status. To provide evaporation data for soil water balance calculations, small evaporimeters have been set up on different sites in the country.

This paper begins with a review of irrigation scheduling techniques. Then the model of the United States Department of Agriculture (USDA) computer program for water balance computations is presented. In the proceeding of the text an adaption of the USDA model to Swedish climatological and agricultural conditions is worked out.

The work was carried out at the Division of Agricultural Hydrotechnics by M.Sc. Joseph M. Erpenbeck. He was staying as a visiting scientist during the winter 1981/82. Erpenbeck has earlier carried out research on estimating crop water requirements and irrigation scheduling. Professor Waldemar Johansson provided data from his work with a model for soil water balance computations. He also assisted in the preparation of the report.

Available climatological and soil physical data from two sites were utilized in order to test the proposed program. The next step ought to be a test in field trials for eventual modification.

August Håkansson
Uppsala, 1982

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ABSTRACT

Irrigation scheduling is deciding when to irrigate and how much water to apply. The objective is maximum crop production for the farmer but other benefits are possible toward better management of water resources. This report reviews soil water depletion measurement and computation approaches. Examples are given of how these irrigation scheduling methods are used in practice in the western United States. The USDA irrigation scheduling computer program is adapted for Swedish conditions. Model theory and program usage is discussed to provide the basis for establishment of an irrigation scheduling service in Sweden. The scheduling program is run for two potato fields near Ultuna to illustrate program operation. Recommendations are made toward improvement of the scheduling computer program. The development of an irrigation scheduling service in Sweden based on United States experience is also briefly discussed.

SAMMANFATTNING

Bevattningsstyrning är att bestämma när bevattning skall ske och hur mycket vatten som skall tillföras. Syftet är hög produktion och god skördekvalitet samt god hushållning med tillgängliga vattenresurser. I denna rapport ges inledningsvis en översikt över metoder för bevattningsstyrning baserade på mätning av vattenhalt eller vattnets bindning i jord samt på beräkning av markvattenunderskott med hjälp av väderleksdata. Exempel ges på praktisk användning av sådana metoder i de västra delarna av USA.

Ett dataprogram för bevattningsstyrning utarbetat vid USDA (United States Department of Agriculture) har anpassats för svenska förhållanden. De teoretiska modellerna i detta program redovisas och diskuteras i rapporten. Dess användning illustreras med två exempel för potatis. Möjligheter till förbättring och förenkling av programmet diskuteras. Avslutningsvis diskuteras också kortfattat utvecklingen av en bevattningsstyrningsservice i Sverige.

CHAPTER 1

INTRODUCTION

Determination of when to irrigate and the amount of water to apply defines *irrigation scheduling*. The goal for irrigation scheduling is to maximize crop production. An irrigation scheduling computer program has been developed and put into practical use in the western United States. The program makes use of climatic data to estimate current and expected soil water conditions. This information assists the farmer in irrigation management.

This paper reviews irrigation scheduling techniques which are either soil water measurements or soil water balance computations. Computational methods are discussed for use by farmers or by a scheduling service. An attempt is made to explain the theory behind the scheduling techniques and to discuss applications.

The USDA irrigation scheduling program is given as adapted to Swedish conditions. Example runs are shown to facilitate further use of the program. Suggestions are made as to the additional work which may be needed to apply the program for irrigation scheduling in Sweden.

Soil-Plant-Atmosphere-Water System

A growing plant utilizes radiant energy from the sun by the photosynthetic process which converts the energy into the chemical components needed by the plant. Excess energy is prevented from increasing the plant's temperature by being used in evaporation of water from the leaves. Transpiration is also responsible for providing a mechanism by which water moves from the soil, through the plant, and to the leaves carrying needed nutrients.

The dynamic nature of the soil-plant-atmosphere-water system has been represented by mathematical models. The movement of water is a response to a potential energy gradient, as follows:

$$q = \frac{\Psi_2 - \Psi_1}{r}$$

where q is the water flow (cm/hr), Ψ is the water potential at specified points 1 and 2 in the system (cm), and r is the resistance to flow (hr). Soil water potential is the work required to move a volume of water from a reference state to the conditions of the soil water. The reference state or zero potential is pure water with a flat air-water interface at a given elevation, temperature, and air pressure. If energy must be added to remove water, as in the case of soil water under unsaturated conditions, then the water potential has a negative sign. The potential gradient, which is the change in water potential with distance, is the driving force causing soil water flow (Skaggs et al., 1980).

Using terminology common in system modelling, the water potential is a state variable which characterizes the current condition of the system. State variables are acted on by external factors (model inputs) which may be controllable as in the case of irrigation amount or uncontrollable as with precipitation.Resistances are rate variables which control the change of the system. Evaporation or drainage amounts are examples of response variables (model outputs) which are dependent on the resistances and water potential gradients (Hillel, 1977).

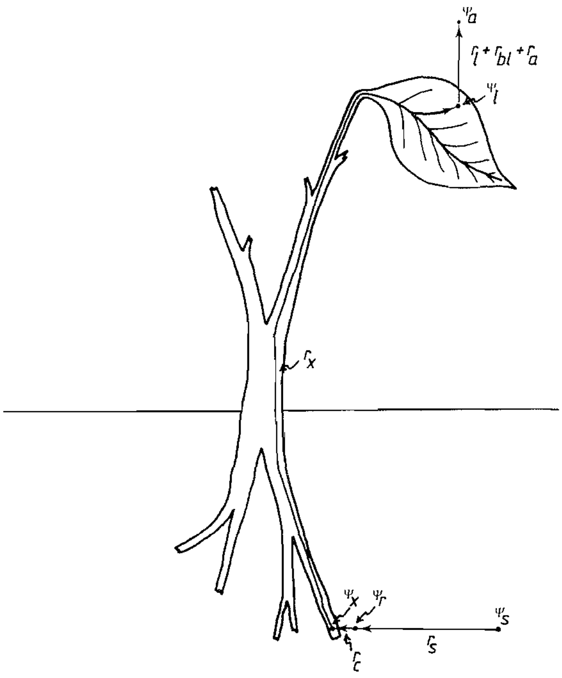


Fig. 1.1. The path of water through the soil-plant-atmosphere-water system as given by Hillel (1980b). The symbol Ψ represents the water potential at the specified point in the system. The symbol r represents the resistance to water flow over the illustrated path. The subscripts are defined as follows: s - soil, r - root, c - root cortex, x - xylem, l - leaf, bl - boundary layer, and a - atmosphere.

The system along with its components is illustrated in Figure 1.1. The water potential decrease from the soil to the root cortex can be up to 10 to 15 bars*. A similar drop can occur from the root cortex through the

---

* Water potential is presented in terms of energy per unit volume with dimensions of pressure which in this case is bars. The water potential can also be expressed as energy per unit weight. The units then become cm for an equivalent column of water. A water column of 1020 cm exerts a pressure of 1 bar at the bottom (Skaggs et al., 1980).

xylem to the leaves. The major water potential decrease is from the leaves to the air which can be 1000 bars or more under arid conditions. For steady-state flow through the plant, the water withdrawl rate from the soil is equal to the transpiration rate. The flow rate through the plant is given by the following:

$$q = -\frac{\Psi_s - \Psi_r}{r_s} = -\frac{\Psi_r - \Psi_x}{r_c} = -\frac{\Psi_x - \Psi_l}{r_x} = -\frac{\Psi_l - \Psi_a}{r_l + r_{bl} + r_a}$$

where the subscript s represents the soil, r the root, c the root cortex, x the xylem, l the leaf, bl the boundary layer, and a the atmosphere. The leaf resistance consists of the parallel combination of stomatal and cuticle resistances. The transfer of water from the leaf to the atmosphere is also influenced by the supply of energy from radiation and heat.

As the soil water decreases, the soil resistance increases and the gradient from the soil to the root must increase to maintain the same flow rate. When the soil water uptake falls below the transpiration rate then the plant will lose water and turgor, causing the stomates to close which affects plant growth. The major objective of irrigation scheduling is to minimize the reduction in transpiration due to decreasing soil water.

CHAPTER 2

IRRIGATION SCHEDULING TECHNIQUES

Soil water measurements and computed soil water balance are two general approaches to irrigation scheduling. Techniques are usually taken from both groups to balance the accuracy desired and the time required in determining the actual field soil water condition. The use of computer calculated soil water depletions has helped to lessen the number of visits required to a field. Experience with actual field conditions must be gained, so soil water measurements are still essential.

Soil Water Measurements

Soil water measurements can be used when plotted as a function of time to predict the next irrigation date. The allowable depletion needs to be determined for use with the specific measurement approach. The total measurement depth must be chosen so as to include the effective rootzone. Figure 2.1 illustrates the use of linear interpolation and extrapolation to determine daily soil water content.

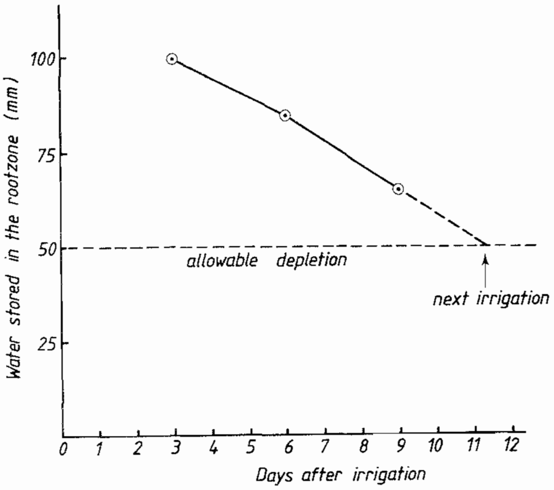


Fig. 2.1. Soil water content of the rootzone as a function of days after irrigation. Circled points indicate measured values.

This section will cover five measurement methods: 1) appearance and feel, 2) gravimetric, 3) neutron scattering, 4) tensiometer, and 5) electrical resistance blocks. Principles of measurement, field installation, calibration, and consideration of advantages and disadvantages are covered where applicable. For tensiometers and electrical resitance blocks, some examples of irrigation scheduling are given. One special topic, the conversion of soil matric potential to soil water content, is discussed.

Appearance and Feel

This method is simple and requires only a hand soil probe. Skill in judging the soil water content develops after practice. The texture of the soil sample is first identified, then the appropriate test is done to determine the soil water depletion. Table 2.1 shows the tests to perform on the soil and the results depending on the depletion. Depending on the texture of the soil, considerable practice may be needed with the soil to use this method.

Gravimetric Method

This is the traditional method and consists of using a soil probe or auger to remove samples for weighing. The weighing is done before and after drying in an oven at $105^{o}C$ for twenty-four hours or longer. The volumetric water content of the soil is computed as follows:

Table 2.1. Guide for judging of soil water depletion by the feel and appearance method (Source: Stegman et al., 1980).

Soil water depletion	Feel or appearance of soil and water depletion in centimeters of water per meter of soil			
	Coarse texture	Moderately coarse texture	Medium texture	Fine and very fine texture
0 % (Field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 0.0	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand 0.0
0-25 %	Tends to stick together slightly, sometimes forms a very weak ball under pressure 0.0 to 1.7	Forms weak ball, breaks easily, will not slick 0.0 to 3.4	Forms a ball, is very pliable, slicks readily if relatively high in clay 0.0 to 4.2	Easily ribbons out between fingers, has slick feeling 0.0 to 5.0
25-50 %	Appears to be dry, will not form a ball with pressure 1.7 to 4.2	Tends to ball under pressure but seldom holds together 3.4 to 6.7	Forms a ball somewhat plastic, will slick slightly with pressure 4.2 to 8.3	Forms a ball, ribbons out between thumb and forefinger 5.0 to 10.0
50-75 %	Appears to be dry, will not form a ball with pressure[a] 4.2 to 6.7	Appears to be dry, will not form a ball[a] 6.7 to 10.0	Somewhat crumbly but holds together from pressure 8.3 to 12.5	Somewhat pliable, will ball under pressure[a] 10.0 to 15.8
75-100 %	Dry, loose single-grained, flows through fingers 6.7 to 8.3	Dry, loose, flows through fingers 10.0 to 12.5	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition 12.5 to 16.7	Hard, baked, cracked, sometimes has loose crumbs on surface 15.8 to 20.8

[a] Ball is formed by squeezing a handful of soil very firmly.

$$\theta = \frac{w_w - w_d}{w_d} \cdot \frac{\rho_b}{\rho_w}$$

where θ is the soil water content (cm^3/cm^3), w_w is the weight of the soil sample at wet or field condition (g), w_d is the weight of the soil sample after drying (g), ρ_b is the dry bulk density of the soil (g_s/cm^3), ρ_w is the density of water (1.0 g_w/cm^3).

When using this method, it is necessary to know the bulk density of the soil. The size and number of samples affect the final result. The method is laborious and time consuming (Hillel, 1980a).

Neutron Scattering Method

This instrument, commonly referred to as a *neutron probe*,consists of a source of fast neutrons, a detector of slow neutrons, and a scaler which monitors the flux of slow neutrons as scattered by the soil. One commercial unit has battery powered electronics and shielding to contain the neutron source together in a compact, portable unit. It is lightweight to make carrying over a rough field to an access tube site possible.

The access tubes are commonly aluminum and consistency of material and construction is required as this may affect the conversion of the reading to the soil water content. The access tubes are installed tight fitting after a slightly undersized hole is made with a hand or power auger and are usually placed in the crop row to allow field cultivations. The access tube needs to extend above the soil surface for instrument support. The extension should be standardized so that rapid soil water measurements can be taken at the required soil depths. If the soil surface is difficult to define then a definite reference level should be assigned to each site. Soil depth increments of 15 cm are adequate as the neutron probe measurements can not distinguish soil layers of less than 30 cm (Hooli and Kasi, 1975).

Fast neutrons are emitted radially into the soil. The volume of soil measured, known as the sphere of influence, depends on the soil water content, soil type and the particular instrument used. This may vary from a radius of 10 cm in a wet soil to 25 cm or more in a dry soil. The neutron probe can not be used closer than 20 cm to the surface because of the loss of fast neutrons (Hillel, 1980a).

Hydrogen nuclei are most effective in slowing the speed of neutrons. Boron, cadmium, and chlorine may absorb slow neutrons decreasing the count. Generally the density of slow neutrons around the detector is most related to hydrogen in the soil, mainly in water but also in organic matter. For this reason universal calibration is not possible for determination of absolute soil water contents. Field or laboratory calibration is required for each soil type. The relation for soil water content is as follows:

$$\theta = a + b\ (N_w / N_s)$$

where a and b are linear regression coefficients, N_w is the slow neutron count rate in the soil, and N_s is the count rate in a standard absorber, usually the protective shield. Hillel (1980a) estimates that a boron concentration greater than 10 ppm (parts per million) and a total chlorine concentration greater than 1000 ppm could affect the calibration significantly. The use of a standard count eliminates systematic errors which vary day to day, and also prevents the need for recalibration after repairs. The calibration of the neutron probe is done by volumetric or gravimetric soil water measurements. A single or universal calibration curve usually supplied by the manufacturer can be used if only the change in soil water is desired rather than absolute values (Skaggs et al., 1980). Fereres and Puech (1981) have shown that calibration lines for various soils are not necessarily parallel to the factory calibration, so that field calibration is preferred. This has also been the author's experience with Portneuf silt loam in southern Idaho. Danfors and Rydén (1975) state that theoretical calibration can be made from knowledge of bulk density and chemical composition of the soil with the method of Ølgaard (1965). Bulk density measurements can be taken with a gamma probe unit which may be attached to the end of the neutron probe. This is a feature of the Danish BASC combined moisture and density gauge. The components of this gauge are illustrated by Danfors (1975, p. 116).

Statistical analysis of the variation in the standard count at the start and end of a series of measurements will check the functioning of the neutron probe. A mean standard count for the day can be used in the calibration equation. Care must be taken that the standard count is taken under reproducible conditions.

The neutron probe has the advantage of providing measurements that can be repeated at a given location and soil depth. This minimizes the effects of soil variability on sequential soil water measurements. The large volume of soil measured also has the advantage of providing a field representative value of soil water. Still whether the access tube is located in a site typical of the field needs consideration. But once calibration is completed, the soil water content is determined on a volumetric basis and non-destructively.

The cost of the equipment is high and trained personal are required. In the United States it is required that a licensed radiation safety officer supervise neutron probe use with periodic safety checks. New employees need a safety course and the wearing of radiation badges have become widespread to help keep awareness of the radiation exposure hazard. This is important since after extended use of the probe safety precautions tend to become routine. The equipment with proper safety can be used without excessive risk (Hillel, 1980a).

Installation of access tubes can be difficult and definite procedures have yet to be specified. It is necessary to wait until the field is planted and even better until the crop has emerged before installing the access tubes. The crop stand near the site must be representative of the field. Extreme care may be needed when measurements are taken in dense planted crops to avoid affecting the crop condition near the site.

Partial wetting of the soil after an irrigation, especially in alternate row furrow irrigation, makes interpretation of the neutron probe readings difficult. Another difficulty previously mentioned is that neutron probe measurements can not be taken near the soil surface. Attempts have been made to develop special surface calibration equations. Holmes et al. (1967) mention use of "reflectors" placed over the surface. This technique has not been used in practice. Hooli and Kasi (1975) mention that "special corrections" are made to shallow measurements of 10 cm. As one final point, the dependability of available commercial instruments as far as necessary repairs needs to be considered. Also the accuracy of the new lightweight units should be noted during calibration. This information is presently not available in the literature.

Tensiometers

A tensiometer is a tube filled with water with a ceramic porous tip in contact with the soil. The tube is closed at the top with a vacuum gauge which provides a measurement of the soil matric potential. A partial vacuum is created in the tensiometer as the soil dries, drawing water through the porous tip. After an irrigation, water flows back into the tensiometer. The tensiometer functions up to soil matric potentials of about -0.8 bar at which the partial vacuum is lost as air is drawn from the water in the tensiometer (Skaggs et al., 1980).

Installation of the tensiometer should be made by using a soil probe or auger to reach the desired depth. Some loose soil should be placed in the bottom before placing the tensiometer in the hole. A small amount of soil and water poured around the tensiometer will provide good contact between the ceramic tip and the soil (Hagood, 1969). If in fine-textured soils silt clogging of the tip is a problem, then setting the tensiometer in sand may help (Hooli and Kasi, 1975). The tensiometer may need to be shielded from the sun (Holmes et al., 1967).

The tensiometer can generally be read twenty-four hours after installation. A portable type, known as a rapid tensiometer, can be read in one or two minutes (Marsh, 1978).

The tensiometer is best suited for irrigation scheduling on coarse-textured soils where the range of available water is to a great extent covered. The soil water characteristic curve (soil matric potential as a function of soil water content) is needed to convert the tensiometer readings to soil water content. The main advantages of using a tensiometer is its simplicity to construct and use. Costs for the tensiometer are low (Schmugge et al., 1980).

Marsh (1978) gives some general recommendations of when to irrigate based on tensiometer readings. The tensiometer tip should be placed at the midpoint of the effective rootzone. Crops grown on coarse textured soils or those with shallow root systems may need irrigation at readings of 25 to 40 centibars. Crops with rootzones greater than 45 cm will not require irrigating before 40 to 50 centibars. In medium textured soils with rootzone depths greater than 75 cm, readings of 70 to 80 centibars will indicate when to irrigate. Marsh (1978) later states that the tensiometer reading at which to irrigate depends on the crop, soil, climate, and irrigation method, and is in the range of 25 to 75 centibars. It is best if each user determines the reading at which to irrigate for the specific field conditions. Marsh (1978) suggests that one or two tensiometers be installed for each area of the field that differs in soil texture and depth, crop, slope, method of irrigation, and time of irrigation if greater than a two or three day difference.

Hagood (1969) recommends that two tensiometers located at one-third and two-thirds of the effective rootzone best indicate average wetting and drying trends. On shallow rooted crops that require frequent irrigation, such as potatoes in central Washington state, then one tensiometer at the 20 to 30 cm depth is adequate. Tensiometer readings indicating when irrigation is required are given for various crops by Hagood (1969). These are based on research in Washington state and the depth of tensiometer installation is also specified. Tensiometer stations should be located where the irrigation sequence starts and ends for fields requiring several days to irrigate. The number of stations depends on field size and soil differences. Two stations for up to 4 hectares, four for up to 16 hectares, and eight for up to 65 hectares are recommended by Hagood (1969).

Simplicity in installing and using the tensiometer does not appear to insure its performance in scheduling irrigations. Local experience appears necessary. The depth at which to install the tensiometer and the recommendations on the reading at which to irrigate are related. Each crop, soil, and climate condition requires specifications for proper use of the tensiometer in scheduling irrigations.

Electrical Resistance Blocks

This method measures the electrical resistance of a moisture absorbent block, which is a function of the soil water content. The electrical resistance is also a function of the salts in the block. The blocks can be calibrated against either soil water content or matric potential. The latter is preferred since block measurements will then complement tensiometers. The resistance readings change very slowly in wet soil conditions making the blocks insensitive. This limits use to the -0.5 to -15 bar soil water potential range (Holmes et al., 1967).

The blocks consist of two electrodes surrounded by gypsum. The use of gypsum eliminates the influence of soil salinity on electrical resistance, since the electrodes are placed in a saturated solution of calcium sulfate. The electrical resistance measurement is made with an alternating current Wheatstone bridge of 1K Hertz. Selection and handling of the material for the blocks must be standardized for reproducible results. Consideration should be given to how long the material can withstand the soil environment. Commercial blocks and meters are available.

Before installation the blocks should be thoroughly soaked with water. After using a soil probe or auger to bore a hole to the desired depth, the last 5 cm of soil is replaced and water added. The block is inserted into this slurry firmly so that good soil contact is made. This is an important step and soil probes have been designed to facilitate placement of the block without interference from the wires. The hole is then refilled 5 cm or so at a time and repacked. The wire leads should be staked and coded by knotting the wires to indicate the block depth (Fischbach, 1971).

Fischbach (1971) recommends following the conversions of meter readings to soil water as given with the particular commercial unit. Hooli and Kasi (1975) state that calibration for each resistance block and soil type is necessary. Calibration of readings are preferably done against soil matric potential in the laboratory (Skaggs et al., 1980). Temperature corrections may also be needed (Cary, 1981). It is not necessary to calibrate individual blocks if construction is nearly identical. Uniformity can be improved by selecting blocks with similar resistances when saturated. The calibration often changes with successive wetting and drying (Skaggs et al., 1980). This is due to hysterisis in the block. The relation between water potential and water content of the block is affected by the history of wetting and drying.

Problems occur in coarse textured soils because of poor soil to block contact and the resultant delay in response to soil water potential changes in the soil (Haise and Hagan, 1967). Problems with poor soil to block contact also occur in fine textured soils which shrink and swell. Besides this, in sandy soils a block is needed which is more responsive to soil water potentials in the -0.1 to -0.3 bar range (Cary, 1981). Hooli and Kasi (1975) indicate that nylon, gypsum-fiberglass, and monel-fiberglass units are available which perform at above -0.5 bars. Skaggs et al. (1980) indicate that these are sensitive to salinity. Resistance blocks need improvements in reliability, precision, construction, and calibration (Hooli and Kasi, 1975).

Advantages of resistance blocks are ease of use, low costs, and repeated measurements at the same site. The method is also suited for automatic recording.

Soil osmotic potentials can also be determined from electrical resistance measurements. The block is different from the normal one in that it must consist of small pores which remain saturated throughout the range of soil matric potentials in the field. The salinity of the water in the ceramic block is in equilibrium with the soil water. Resistance of the block is only affected by the salinity. A thermistor is needed to measure the soil temperature and apply a correction for the effect on resistance.

Cary (1981) placed the blocks in the most active part of the rootzone and shallow to keep in the dry range of readings in scheduling irrigations. Fischbach (1971) gives depths for shallow and deep blocks which are set at 40 percent and 70 percent of the effective rootzone, respectively.

Fischbach (1971) outlines a method of using resistance blocks to schedule irrigations for Nebraska conditions. Two shallowed and one deep blocks are used for each station with four stations per field for furrow irrigated crops. The stations are placed at the upper and lower ends of the field, in the same row, and in both the first and last irrigation sets. The mean of the shallow readings in the first irrigation set are used to start the irrigation sequence. Early in the season the irrigation should be stopped when the shallow blocks indicate a wet condition. Later in the season the deep blocks should be used. Having stations at the first and last irrigation sets help to determine where to start after a rain has interrupted the irrigation sequence.

Fischbach (1971) gives meter readings and associated soil matric potentials which indicate when to irrigate for corn and sorghum. These apply to Nebraska climatic conditions and to the normal irrigation sequence of 5 to 8 days. Resistance blocks have been recommended for irrigation scheduling in Nebraska since 1965 and have had success on fine-textured soils. Computer programs have been available in recent years at extension offices which predict the irrigation date from resistance block readings.

Conversion of Soil Matric Potential to Soil Water Content

The relation between the soil matric potential and the soil water content is known as the soil water characteristic curve. Because of the so called hysterisis, field determined values of matric potential give imprecise values of soil water content. Thus the conversion in the field between soil matric potential and water content can only be used with reservation. The wetting history needs to be known. Skaggs et al. (1980) state that the amount of error due to hysterisis is relatively small when compared to variations in the soil, crop, and climate.

Holmes et al. (1967) state that attempts to correlate tensiometer readings in the field with soil water content measurements have not always worked well, due to hysterisis. Local variability in soil texture and structure will also cause variability in the calibration curves. The recommendation is given that direct measurements of the desired value be made, whether it is soil water content or matric potential.

Computed Soil Water Balance

The soil water depletion in the rootzone can be calculated as follows:

$$W_J = W_{J-1} + (ET - P_e - I_n + D)_J$$

where W is the soil water depletion on day J (mm), P_e is the effective precipitation (mm), I_n is the net irrigation amount (mm), and D is the drainage loss from the rootzone or the capillary rise from a water table. The drainage and capillary rise term is usually neglected. Since P_e and I_n are usually known, the ET amount must be estimated to compute the daily soil water depeltion. Soil water balance calculations that can be performed by a farmer or by an irrigation scheduling service are discussed in this section.

For farmers

A soil water accounting procedure is given by Stegman et al. (1980). For a farmer's use, a tabular computational format is usually followed with column heading of the date, precipitation amount, net irrigation, ET estimate, and soil water depletion. Important considerations in using this computational procedure are shown in Figure 2.2. The first point is that an initial estimate of the soil water depletion is required near planting or crop emergence. Second, the soil water depletion increases by daily calculation of ET. Third, the soil water depletion is reduced by precipitation or irrigation. The depletion is set to zero if precipitation or irrigation is excessive. Fourth, an irrigation is often planned so as to not fill the soil reservoir completely but maintain space for future rainfall. The fifth point is that an allowable depletion is selected by considering management objectives such as maximum crop production or net profit. The operation practices of the irrigation system and the maximum available water for the coarser soils in the field also need consideration.

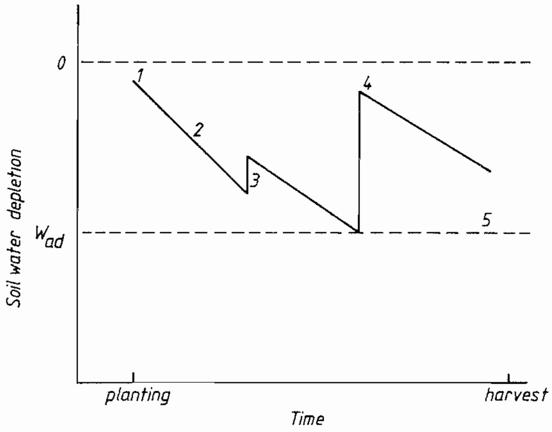


Fig. 2.2. Soil water depletion as a function of time to illustrate special points concerning the soil water accounting technique for irrigation scheduling. The symbol W_{ad} is the allowable depletion.

ET estimates are generally based on locally calibrated methods (Stegman et al., 1980). One illustration of this is the "water accounting board" developed by Pruitt (1956) for use in Washington state. ET was computed by using pan evaporation as a climatic standard which was then adjusted by a seasonal crop coefficient. Jensen and Middleton (1970) stated that scheduling is simplified by the near constant relation between crop ET and the class A pan evaporation, once the crop is near full ground cover. Hagood

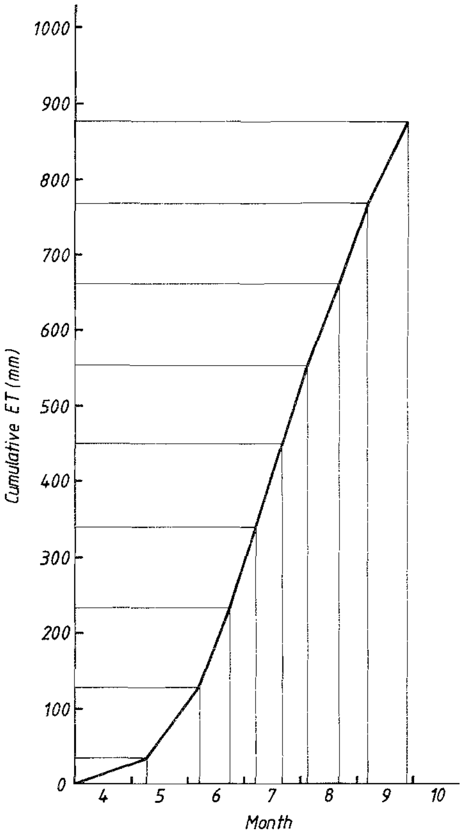
(1964) presented the details of this scheduling technique so it is usable by farmers. The ET estimation procedure depends on the crop coefficient values developed for Washington state. Extension to another area may require new values for the crop coefficients or even questioning of the use of pan evaporation as a climatic standard.

Scheduling techniques have also been developed using historic weather records to determine long-term ET values. Black and Brosz (1972) described a soil water accounting procedure for South Dakota. The long-term ET values appear to be computed from a standard ET method, usually referred to as potential ET method, dependent on temperature and radiation. The details of the ET estimation procedure are not revealed as the farmer would be given the daily calculated values. Wilcox and Sly (1974) present a similar approach for Canada but recommend long-term standard ET values that are measured by a Bellani plate evaporimeter. If measurements are not available, then a multiple regression formula requiring air temperature and sunshine is used. This method was developed for Canada by Baier and Robertson (1965). For irrigation scheduling in Iowa, Mather and DeNardo (1978) used the Thornthwaite equation, which needs only air temperature, to calculate ET.

It is suggested that if long-term standard ET is acceptable for scheduling, then actual precipitation values be used. Long-term precipitation data gives an incorrect soil water condition for a region especially in extreme wet or dry periods. The use of crop coefficients is implied by Black and Brosz (1972), and by Wilcox and Sly (1974) to convert the standard ET to crop ET.

For scheduling in California, Fereres et al. (1981a) use crop ET for a normal year. This is also taken from historic records as the long-term fifty percent probable value. The scheduling technique only works with no rainfall and when the ET rates vary little from year to year. In the Central Valley of California during 90 percent of the irrigation season, 10 to 14 day normal ET are within 10 percent of measured ET. Availability of long-term ET records and accurate crop coefficients are necessary for this normal year irrigation schedule (Fereres et al., 1981b).

An irrigation schedule for a specific crop, soil, and location can be presented as graphical or tabular irrigation dates, as shown in Figure 2.3. The ET curve can be updated with actual values. Pan evaporation and crop coefficients can be used to compute crop ET. Periodic checks of field soil water is recommended for early and late in the season when weather and subsequently ET rates are more variable.



Normal year irrigation date	Net irrigation amount (mm)
May 8	36
June 6	91
June 22	107
July 6	107
July 20	107
August 4	107
August 20	107
Sept. 6	107
Sept. 26	107

Fig. 2.3. A normal year irrigation schedule for a given crop, soil, and location. The example is for sugar beets planted on April 1 on a medium textured soil in the Sacramento Valley, California (Fereres et al., 1981a). The thick line is the cumulative ET as a function of time and the thin lines indicate irrigation dates as also given in the table.

It is not expected that a farmer should develop this normal year irrigation schedule. Fereres and Puech (1981) describe how an Irrigation Management Program (IMP) is developed by farm advisors, Soil Conservation Service engineers, private consultants, or other trained personnel. An IMP for a field is defined as to crop, location, planting date, soil depth, and allowable depletion. A computer program is available at the California Department of Water Resources and a farmer can request an IMP for a field.

For Scheduling Services

USDA Irrigation Scheduling Program

Most irrigation scheduling services use or have adapted the USDA (United States Department of Agriculture) computer program (Jensen, 1978a). The program was developed in southern Idaho from 1966 to 1969 to supplement a water use study by the United States Bureau of Reclamation (USBR), now called the Water and Power Resources Service (WPRS). Evaluation was done during 1968 and

1969 in Idaho and the Salt River Project in Arizona (Jensen et al., 1970). The computer program was released for use in 1970 and modified slightly in 1971 (Jensen et al., 1971). Most likely each user adapts the program to meet specific needs. The program was revised for use in Nebraska with a microcomputer by Kincaid and Heermann (1974). Heermann et al. (1976) adapted the USDA scheduling program for use with center pivots. The Nebraska AGNET irrigation scheduling program was developed from the Kincaid and Heermann (1974) version (Jensen, 1978a). The WPRS Irrigation Management Service (IMS) computer program can also be traced back to the USDA model.

Jensen (1976) makes the following important statement: "The computer program is only a tool used by technical service groups to estimate the current soil water status and predict future irrigations for individual fields." The soil water balance calculations are modelled at a simple level so that the input data requirements are reasonable. The program users must understand how to make adjustments for abnormal conditions.

The soil water status needs to be monitored to adjust the computer results to actual field conditions. Precipitation and irrigation amounts may also need to be measured. Local calibration of the water balance models may need to be done (Jensen, 1976). Fereres et al. (1981b) gives the following reasons as to why field verification of computer predictions is necessary:

1) uncertainty about the depth of water actually applied at each irrigation
2) uncertainties in evaluating the crop rooting depth
3) soil water storage capacity is estimated
4) soil water allowable depletion is estimated
5) spatial variability of soil water holding characteristics within each field
6) uncertainties in computations of crop ET, especially in early growth stages
7) need to evaluate effective rainfall on each farm.

The variation of soil properties that affect the soil water characteristic curve and the bulk density are one aspect of field variability. The field variation of soil water content complicates irrigation scheduling in general. How representative is the measurement site of the general field condition? This question can only be answered by additional measurements. In addition the uncertainty of the irrigation scheduling method will be at least as great as the spatial variation of the soil water on a field basis (Cary, 1981).

Schmugge et al. (1980) give the following relation to determine the number of samples required in a field to give an estimate of the mean soil water content with a specified accuracy:

$$n = 4(\sigma / a_d)^2$$

where n is the number of samples required, σ is the standard deviation of the soil water content (%), and a_d is the desired accuracy (%). For irrigation scheduling a practical limit of about two to four measurements per field is assumed. The standard deviation of the soil water content in the field is about 4 to 6 percent. The required accuracy as given by the preceeding equation is then given in Table 2.2. Jensen and Wright (1978) indicate prediction confidence of plus or minus one day using the computer scheduling program when the soil water content has been measured after an irrigation. This may increase to several days if the amount of irrigation is less certain. Cary (1981) gives an example for neutron probe and gravimetric measurements that also have minimum prediction uncertainties of plus or minus one day.

Table 2.2. Accuracy of the mean soil water content for a field in relation to the number of soil water measurement sites (n) and the standard deviations of the measurements (σ).

n	σ (%)		
	4	5	6
2	5.6	7.1	8.5
4	4.0	5.0	6.0

CHAPTER 3

IRRIGATION SCHEDULING IN PRACTICE

The history of irrigation scheduling in the western United States parallels the increasing pressures on water resources. As irrigation scheduling has spread so has knowledge of the benefits possible.

The United States Bureau of Reclamation (USBR) in 1964 started a study that collected and analyzed information on how irrigation waters were actually used on federal irrigation projects. The observations of low farm irrigation efficiencies relate to the irrigator's inability to judge the current soil water depletion. Application of the correct amounts of water at the proper intervals was not possible. In 1968, the USBR began its Irrigation Management Service (IMS) program to direct and assist irrigation projects in establishing programs to improve the effectiveness of irrigation (Buchheim, 1976).

Benefits of irrigation scheduling are presented by Buchheim (1976) with respect to three groups: 1) irrigators, 2) irrigation districts, and 3) regions. A list of possible benefits are as follows:

1) benefits for the irrigator

    increased crop yields in quantity and quality
    better use and/or reduction of labor
    better use and/or reduction of water
    reduced leaching of soil nitrogen or other soluble plant nutrients
    reduced drainage requirements and problems
    better water management during peak water use periods

2) benefits for the irrigation district

    better use of reservoir storage
    reduced demand on delivery system during peak water use periods
    reduced water use
    capability to forecast water deliveries
    reduced drainage problems
    reduced maintenance requirements
    computer records of water storage and delivery
    improved economics of irrigation enterprises

3) benefits for the region

    improved economics of irrigated agriculture
    reduced adverse environmental effects by irrigated agriculture
    improved use of the natural resources
    improved planning and operation criteria for irrigation.

Water and Power Resources Service

The Water and Power Resources Service's (WPRS), formerly USBR, Irrigation Management Service (IMS) has two phases, an initial one of better farm water management and a second one of improving distribution and storage system water management.

The WPRS irrigation management program gives a unique possibility to observe the application of irrigation scheduling techniques over a wide geographical area. Also the experience of the WPRS is illustrated by flexibility in providing different irrigation scheduling approaches or intensities, in modification of the computer water budget model, and in the use of soil water measurements. It is important to observe how reference fields and neutron probe measurements are use to gain knowledge of conditions in a new project area. One example of IMS program development is also discussed in this section.

Irrigation Scheduling Approaches

The WPRS provides three levels of irrigation scheduling to the farmer. The first approach, "irrigation guide", relies on area computations of crop water use. The second, "neutron probe", and the third, "field irrigation schedule", approaches use field specific crop water use (Buchheim, 1976).

The irrigation guide gives irrigation intervals for major crops in an area. The guide is updated weekly with climatic data from a central location of the area. Information on crop water use is given for different soils and planting dates. The stage of growth for the crop is that typical of the area. The irrigation guide is a supplement to other scheduling approaches. It is necessary that the data on the climate, soils, and crops represent the general area conditions.

The neutron probe approach measures the soil water content of the field. A computer or graph may be used to present the measurement data and project ahead to the irrigation date. At least two observations are necessary between irrigations.

With a field irrigation schedule, the farmer is provided with the current soil water condition in each field. The computer results are sent to the farmer once or twice a week. The approach requires the most field data to model correctly the actual field conditions.

Water Budget Model

The model used in the WPRS irrigation scheduling computer program has been developed from the USDA model. Some major differences between the models are in calculation of the reference crop ET, basal crop coefficients, and allowable depletion.

The alfalfa reference crop ET (ET_{ra}) is for healthy alfalfa with 25 to 30 cm of top growth. Calculation of this ET_{ra} is done specifically with the Jensen-Haise ET estimation method as follows:

$$ET_{ra} = ET_{JH} = C_t\ (T_a - T_x)\ R_s$$

The values C_t and T_x must be carefully selected for the area. Estimation of these two parameters can also be done from long-term air temperature data.

Basal crop coefficients are not related to time but rather to an increment of energy input which influences crop development. An accumulated value of ET_{JH} is used rather than a time scale. This requires that cumulative ET_{JH} values are specified at effective full cover and at termination of the season.

Allowable depletion is set by the program user for each field. An alternative estimate is available from the following equation:

$$W_{ad} = (0.33 + \frac{J - J_p}{60})\ c_{cs}$$

$$W_{ad,min} = 0.33\ c_{cs}$$

$$W_{ad,max} = c_{cs}$$

where W_{ad} is the allowable depletion (mm), J is the current julian date, J_p is the planting julian date, and c_{cs} is a factor dependent on crop and soil type. The maximum limit for W_{ad}($W_{ad,max}$) occurs at 40 days after planting. The factor c_{cs} is determined as follows:

$$c_{cs} = c_c\ W_{max}$$

where c_c is a crop factor which is the product of the maximum rootzone and the critical percent soil water depletion (mm), and W_{max} is the maximum available water content per unit depth of soil (mm/mm). Table 3.1 gives the c_c values for various crops. In Table 3.2 approximate values of W_{max} are presented. This data was taken from Buchheim et al. (1980). No guides are given as to selection of W_{max} if a range is given. Table 3.2 is a general guide and the recommendation is made that W_{max} should be determined for the various soils in the project area.

Table 3.1. Crop factors for use in estimating allowable soil water depletion for use with the WPRS irrigation scheduling program (Buchheim et al., 1980).

crop	crop factor (mm)
corn	450
sugar beets	450
small grains	450 to 640
pasture	370
beans	400
potatoes	240
alfalfa	730

Table 3.2. Approximate maximum available soil water values for various soil textural classes (Buchheim et al., 1980).

textural class	maximum available soil water (mm/mm)
coarse sand and gravel	0.02 to 0.06
sands	0.04 to 0.09
loamy sands	0.06 to 0.12
sandy loams	0.11 to 0.15
fine sandy loams	0.14 to 0.18
loams and silt loams	0.17 to 0.23
clay loams and silty clay loams	0.14 to 0.21
silty clays and clays	0.13 to 0.18

Reference Fields

The irrigation scheduling computer program requires comparison of calculated values to actual data in the field. The WPRS has introduced a concept known as a reference field. These selected fields should be above average in crop and field conditions for the area, but still representative of major crops (Buchheim et al., 1980).

The reference fields allow a concentrated data collection effort on some fields. This is a practical solution to the need for verification of the water budget model and current seasonal information. Refinement of a theoretical forecast to represent local conditions is necessary for providing a quality and reliable irrigation scheduling service.

Soil water depletion data collected from reference fields determine the allowable soil water depletion and extraction pattern. Water use rate and crop growth stage observation enable adjustments to growth stage estimates, crop coefficients, or computed ET.

Neutron Probe Measurements

With the introduction of a lightweight neutron probe in 1975, graphical procedures were developed for irrigation scheduling. The soil water content plotted as a function of time enables projection to a predetermined allowable water content to schedule the next irrigation date. The irrigation amount is also known (Buchheim and Ploss, 1977).

Ploss (1976) illustrated in a series of four cases how the neutron probe irrigation scheduling is done. In this series of examples, the probe measurements are used together with computed ET. It is assumed that this estimated ET is from the WPRS computer program.

The first case is when only one probe measurement has been done since the previous irrigation. A "full" value is the soil water content after an irrigation and after excess water has drained (Buchheim and Ploss, 1977). Field capacity values may be used as a first estimate. The allowable depletion is estimated by any of the following three methods:

1) from crop and soil knowledge
2) from a "set" value, which is the allowable soil water depletion from the top 30 cm
3) from a conservative (low) value that is corrected with further neutron measurements.

The second method will be discussed in more detail later. The first method assumes local experience and the third method is when more information is needed. The depth of measurement with the neutron probe should include the major portion of the maximum rootzone.

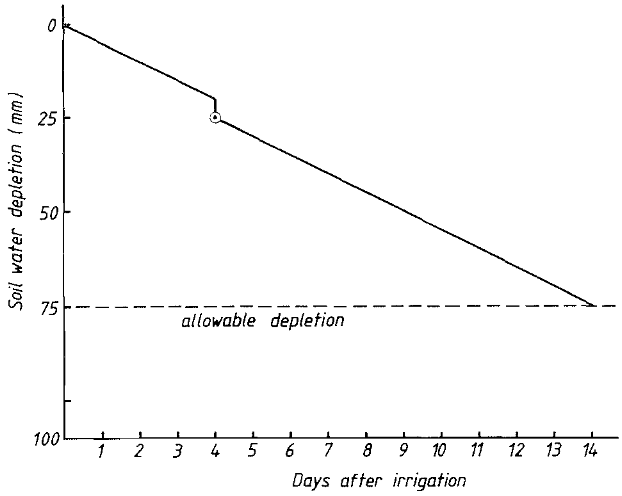


Fig. 3.1. Neutron probe irrigation scheduling, first case when only one measurement has been taken. The ET rate is 5 mm/day and the circled point is a probe measurement.

Figure 3.1 shows an example of the daily soil water depletion for the first case. The field capacity water content is used to convert the neutron measurement on the fourth day after irrigation to soil water depletion. The computed ET rate is 5 mm/day and determines the slope of the lines. An adjustment is necessary to the soil water depletion on the fourth day to fit the field measurement. The allowable depletion is a conservative estimate of 75 mm. The irrigation interval is 14 days.

The second case is after two probe measurements have been taken. The full value can be determined by projection back to the previous irrigation as shown for each of the measurement layers in Figure 3.2. The full value was first assumed to be 50 mm for each layer, but later projections show full values of 45.0, 45.0 and 52.5 mm for each of the three layers. The soil water depletion at the first measurement changes from 25 mm to 17.5 mm. The depletion at the second measurement is 35 mm.

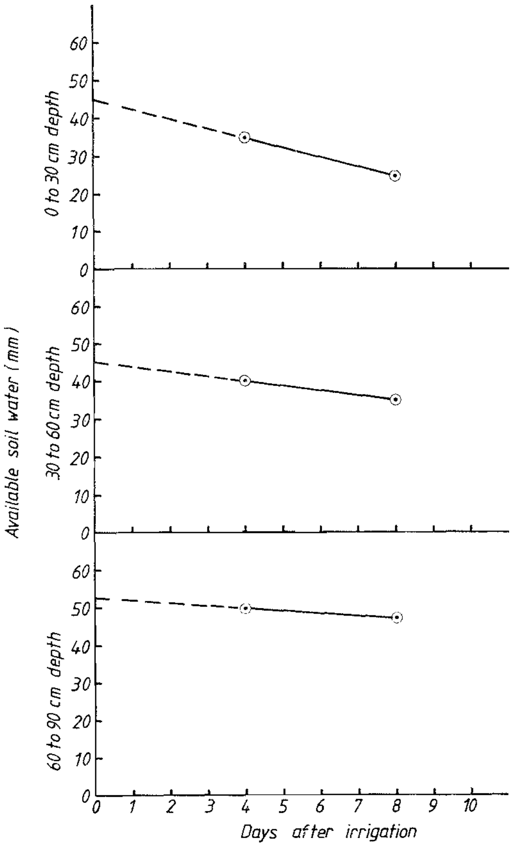


Fig. 3.2. Neutron probe measurements for the second case when two measurements have been taken. The circled points indicate probe measurements.

The allowable depletion can now be adjusted. A root decimal is defined as the ratio of the soil water depletion rate in the top 30 cm to that of the entire measurement depth. The root decimal can only vary between 0.3 to 1.0 and only decreases with time to represent an increasing rootzone. From Figure 3.2, 0.57(10/(10 + 5 + 2.5)) is the value of the root decimal at the first measurement.

A set value is defined as the maximum soil water depletion from the top 30 cm without causing plant stress. Ploss (1976) estimates the set value as 80 percent of the maximum available water in the top 30 cm. For the current example a set value of 45 mm is used. The allowable depletion is calculated as follows:

$$W_{ad} = SET/RD$$

where SET is the set value as previously defined and RD is the root decimal. The allowable depletion is then 80 mm (45/0.57).

The estimated ET can be adjusted with the measured data. The water use between the first and last (in this case last refers to the second measurement) is 4.38 mm/day. The adjustment factor ADJ for ET is then determined as follows:

$$ADJ = ET_{meas}/ET_{calc}$$

$$0.85 \leq ADJ \leq 1.15$$

The adjustment factor in this case has a value of 0.88, using a calculated ET of 5 mm/day. This is within the limits set for ADJ. The ET to use for projection to the next irrigation date is 4.38 mm/day. The irrigation interval is now 18 days as shown in Figure 3.3.

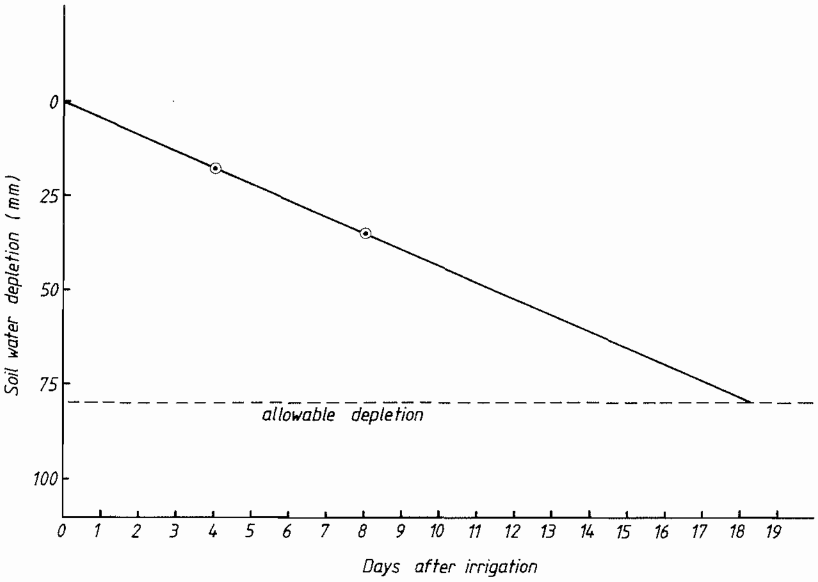


Fig. 3.3. Neutron probe irrigation scheduling, second case when two measurements have been taken. The circled points are probe measurements.

The third case shows how additional probe measurements are used. The first and last measurements are used together. The full values will not be changed but can be by using the first two measurements after an irrigation. Figure 3.4 gives the probe measurements for each 30 cm soil layer. The soil water depletion at the last measurement is 55.0 mm for the profile.

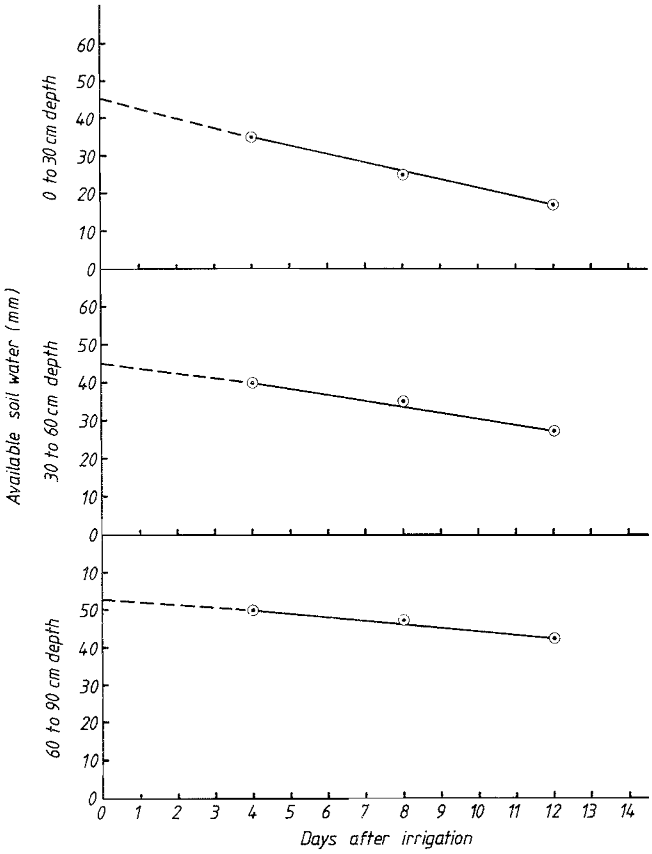


Fig. 3.4. Neutron probe measurements for the third case when three measurements have been taken. The circled points are probe measurements.

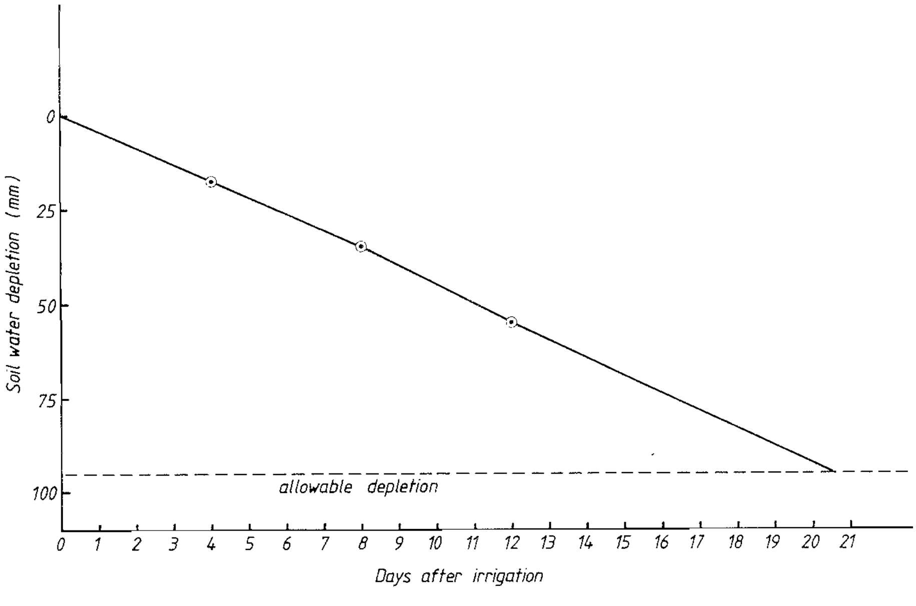


Fig. 3.5. Neutron probe irrigation scheduling, third case when three measurements have been taken. The circled points are probe measurements.

The root decimal is 0.47 (17.5/(17.5 + 12.5 + 7.5)) which is less than for the second case and indicates an expanding water extraction pattern. Note that the soil water depletion rate for each soil layer is determined from the difference between the first and last measurements. Using the same set value of 45 mm as for the second case, the allowable depletion is 95 mm. The ET determined from the second case is 4.38 mm/day. The field measured ET between the first and last measurement is 4.69 mm/day. The new value for ADJ is the product of the previous ADJ (0.88) and the ratio of measured to calculated ET which is 1.07. ADJ has the value of 0.94 which is then used with the computed ET (5.0 mm/day) to get the ET for projection to the next irrigation. The irrigation interval is now 20 days as shown in Figure 3.5.

The fourth case shows how an irrigation date is used to correct the set value. The actual irrigation date is on day 19 after the previous irrigation. Figure 3.6 shows the new set value from the top 30 cm data. Projection of the ET rate to day 19 gives a new set value of 42.5 cm. With the root decimal value of 0.47, the allowable depletion is 90 mm. The interval for the next irrigation period is determined with the previous ADJ value and the calculated ET. If the estimated ET is 5.0 mm/day, then the next irrigation interval is 19 days.

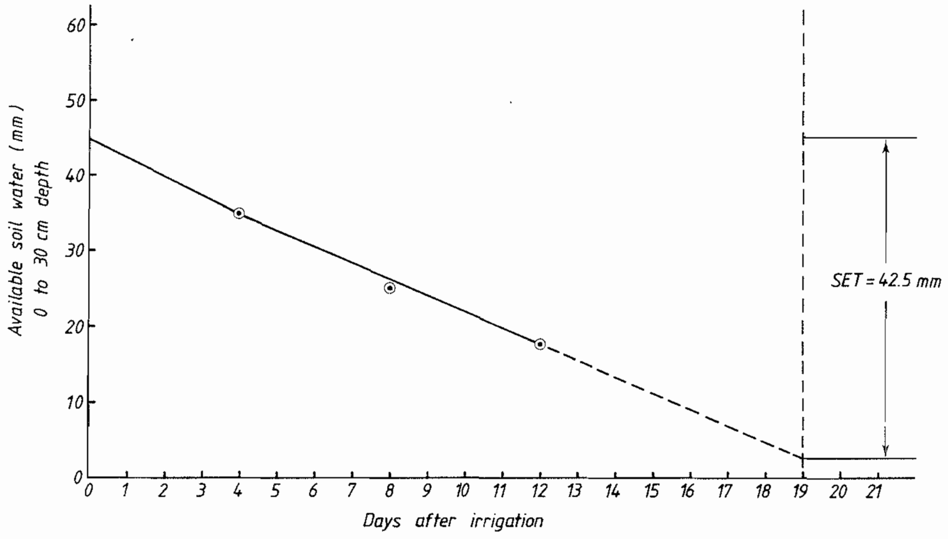


Fig. 3.6. Neutron probe measurements for the fourth case when an irrigation has occurred. The circled points are probe measurements.

The procedure appears complicated but WPRS uses computers to do the calculations. The references cited do not consider precipitation events. Also the value of using set and root decimal values is not explained. The advantage of using an ET adjustment factor, ADJ, is that estimated ET may vary with the weather conditions but still will be corrected to field conditions. The ET estimation procedure would eventually be corrected in the form of refined or new crop coefficient curves (Buchheim and Ploss, 1977). Allowable depletion values for specific field and crop combinations also become available as field data is accumulated (Ploss, 1976).

The development of allowable depletion values depends on the definition of a correct irrigation. Gear et al. (1977) present three methods for determination of the correct depletion level for an irrigation. First by the use of tensiometers that have known field desorption relations between the suction head reading and water content. The soil water potential at irrigation is then determined from the literature, such as those given by Haise and Hagan (1967, p. 580-581). This estimated allowable depletion can be adjusted by use of the tensiometer and neutron probe combination in a representative field location. A second method is to observe the crop water stress in the field. The allowable depletion should be adjusted to avoid visible crop stress. A third method follows the farmers judgement of the allowable depletion.

Distribution System Scheduling

The IMS program besides scheduling field irrigations extends scheduling to farm turnouts. This allows planned deliveries which improve district water management. Forecasts of peak demands, efficient water transfer within the system, reduced operating spills, reliable and correct water deliveries are improvements possible for a district (Ploss et al., 1979).

Two levels of system scheduling procedures are used. If only part of the distribution system is scheduled on a field by field basis, then the remaining fields kan be handled on an irrigation guide basis. Actual delivery water orders are also used. Field irrigation schedules may require adjustment so that the capacity of the delivery system is not exceeded. Water measurement both on farm and at the farm turnout complete the management of irrigation water.

Buchheim et al. (1980) present a computer program TIMS which performs distribution system scheduling. The program consists of fourteen BASIC language subprograms to allow use with a microcomputer, with 16000 of memory storage.

Development of the IMS Program for the El Dorado Irrigation District

Bethell et al. (1980) provide an example of the development of an IMS program for one irrigation district in California. Regardless of the irrigation scheduling technique an understanding of how to provide the service to the farmers is needed. By looking at the El Dorado irrigation district (EID) from 1976 to the present, the realities of an irrigation scheduling service become clearer.

1976

A drought condition began in the winter of 1976 and EID asked for voluntary water conservation. In cooperation with the WPRS an IMS program was started in the district. WPRS provided soil water measurement equipment and technical knowledge. EID provided program management and transportation. Both WPRS and EID shared labor costs. The financial help provided by WPRS was expected to decrease gradually over a three year period. Then it was hoped the farmers would recognize the benefits of irrigation scheduling and individually pay for the service.

Three hundred neutron probe sites were installed for pear and apple orchards, and pastures. The program started late so determination of field capacity values was not possible. Twenty-five tensiometers were installed to provide allowable depletion data but time did not allow their use. The neutron probe sites were read 25 to 30 times during the season requiring 2.5 people. One person worked with program management and record keeping.

The irrigation schedules were delivered to farmers as graphs. This was not successful because of poor verbal communication. Most farmers continued with their own scheduling methods.

1977

The drought continued and water rationing was required. Research was begun to determine the water requirements for foothill orchards. Calibration of the neutron probes was accomplished for all major soils. The IMS program was staffed by three new and inexperienced people. They received little training other than how to use the neutron probe. Farmers responded better to irrigation notes giving the next irrigation date. Due to the limited water allocation farmers showed more interest in IMS.

1978

The drought ended and the final season began for WPRS support of the scheduling program. The WPRS computer program was used to provide printouts for the farmers.

Fewer probe readings were required with the computer program, but still needed to refine and check the accuracy of program results. Thirty percent of the probe sites had accurate allowable depletion points determined. The research studies on pear and apple orchard water use were also completed. The farmers responded well to the weekly computer schedules. More time was still needed to refine the IMS program so that farmers would be willing to pay for it.

1979

Additional farms were added to the IMS program. Poor probe monitoring sites were moved to more representative locations. All stations had accurate field capacity points determined after a large rainfall early in the season. Tensiometers at 45 cm depths were used to determine refill points, specified as readings of 60 centibars. With both field capacity and refill values, the allowable depletion could then be determined for the probe site.

All farms were computer scheduled. On the same day as the soil water measurements were taken, a computer printout was mailed to the farmer. Newsletters and meetings helped to explain the computer printout. Frequent field contacts gave the farmers more knowledge about IMS and added confidence in the irrigation recommendations. Reliability in the sending of the irrigation schedules is important for the farmers confidence of IMS.

Proper irrigation system performance is also needed for good water management. Measurements of irrigation system efficiencies and application rates were started.

1980

The main objective of this irrigation season was to refine the computer estimates of crop water requirements. Site specific crop coefficient curves helped to reduce probe measurements which decreased the IMS labor requirements by half. Additional farms and crops were added to the IMS program. Crop water requirements for other foothill crops: plums, cherries, Christmas trees, wine grapes, and pasture were also studied.

Irrigation system analysis work was continued. Computer recommendations were being used by farmers with interest and confidence. Personnel with the IMS program were the same and farmers trusted their irrigation knowledge. Farmers also provided irrigation and tillage dates, so less field checking was required.

1981

The report by Bethell et al. (1980) was completed before the start of the 1981 season. The main question is still the motivation of the farmers to take full financial responsibility of the IMS program. Irrigation system analysis is not completed but it is thought that the El Dorado IMS program is among the best in existance. The goal is to have the farmers pay for an irrigation consultant to operate the IMS program. The California Irrigation Management Information Service, the Soil Conservation Service, and the University of California Cooperative Extension should all be able to assist the El Dorado irrigation district.

Summary and Conclusions

The El Dorado irrigation district provided a test and demonstration area for the WPRS irrigation management service. The development of the irrigation scheduling techniques were specific for the area. The neutron probe measurements provided a scheduling service from the start and continued to provide monitoring of field conditions as the IMS changed over to computer scheduling. Research was necessary to determine crop water requirements which refined the computer program for the area. Most of the refinements came from soil water measurements taken for scheduling purposes.

The farmers gradually gained confidence in the irrigation recommendations. Irrigation system analysis and subsequent improvements are necessary for full use of irrigation scheduling. Despite the IMS program success after five years, the farmers still appear reluctant to pay for the IMS program. The benefits of irrigation scheduling are difficult to show. Bethell et al. (1980) express the hope that farmers will continue with irrigation scheduling.

Nebraska Computer Network and Irrigation Scheduling

Computer Network: AGNET

The University of Nebraska began in 1975 a computer network to allow use of developed computer programs. WPRS provided financial support to add an irrigation scheduling program. The computer network began slowly with only a few computer terminals. Within a few years terminals were added in neighboring states. At the present the network is spreading to other states and is known internationally. The concepts of a computer network can also be applied to irrigation scheduling by computer.

At the University of Nebraska in 1975, the computer was used in classroom and workshop activities. Thompson et al. (1978) stated that their programming efforts soon led to interest by other instructors. This led to a committee being formed to examine possible uses of the computer in extension.

Dependability and ease of use were keywords that helped to establish the operating goals of AGNET (AGricultural computer NETwork). Lightweight portable computer terminals make access to the network possible wherever a telephone exists. Ease of use means that the computer programs are accessed by typing only one word and that questions and instructions are provided to help the user. The possible users of AGNET are as follows:

1) university teaching, research, and extension
2) county agents to answer farmers' questions
3) district and state extension agents to refine their recommendations
4) extension for training workshops
5) field day demonstration
6) network users for communication between themselves
7) university to send out soil test results

By 1978, constructive comments were being returned to program authors. This led to refinements in existing models and to development of new programs. The most important use of AGNET appears to be in extension advice to the farmer. With the computer the extension agent could answer farmers' questions with current prices and situations.

Besides the cooperation between the university and extension other benefits result from AGNET. Former university students are able to keep up with current agricultural technology. Dissemination of current information is possible. Adult and continuing education is assisted. The development of interdisciplinary models promotes cooperation between departments in research. For example, the irrigation scheduling program is largely an engineering model, but agronomic and economic inputs are also required.

The technique for computer model development that works well for AGNET is given in steps as follows:

1) preliminary model outline
2) one person should develop model and make it operational as a computer program for testing
3) the model must be written with knowledge that expansion and modification will occur later

4) constructive criticism from other departments on the model with improvement suggestions.

Nebraska Irrigation Scheduling

Water management in Nebraska is needed for the following reasons (Watts, 1976):

1) High energy costs require better water management where high pumping lifts exist.
2) Legal restrictions are limiting the amount of total water pumpage in areas with declining water tables.
3) Where cost of water is low, excessive nitrogen loss occurs plus increasing disease and insect problems.

The university of Nebraska conducted research on nitrogen leaching. This revealed that 13 to 17 kg per hectare of nitrogen were leached for each 2.5 cm of irrigation water passing through the rootzone. This implies a direct benefit to the farmer by better managing irrigation water.

Scheduling by estimates of crop needs and with periodic soil water checks in the field have the following problems in Nebraska:

1) Little space is available for rainfall in the soil.
2) Rainfall will run off on heavier soils and leach through light soils, with some combination on medium textured soils.
3) Space should be made available at the end of the crop season for storage of winter and early spring rains.

Table 3.3. Depletion scheduling example on corn in Nebraska (Watts, 1976).

Date	Allowable soil water depletion (mm)
June 19	0
July 10	13
July 24	33
August 7	33
August 21	64
September 30	114

One solution to this problem of rainfall storage is to provide additional storage capability in the soil by a "depletion scheduling" approach. Table 3.3 shows how the allowable soil water depletion increases through the season for corn. Irrigations in June and July supplemented rainfall and provided an almost full profile through tasseling. At tasseling with the rootzone at a maximum, the depletion was gradually increased during the grain filling period. The depletion reached maximum at maturity. Watts (1976) states that this method cannot be used on soils with less than 32 mm of holding capacity, and also on soils with low intake rates and subsequent runoff problems.

Watts (1976) also presents three levels of irrigation scheduling techniques. The first level involves soil water measuring. Soil probes and the feel method are difficult to use on sandy soils. Resistance blocks are used on medium to heavy textured soils. Tensiometers are used on light soils but cost and maintenance problems occur. The neutron probe is for use by commercial scheduling companies or large-scale farmers. The second level is water use information plus monitoring. The time in the field may be reduced by fifty percent, if daily ET estimates are available. The Extension Service provides daily or twice weekly information to radio, newspaper, or telephone "hotline". The farmer then calculates actual irrigation amounts and checks field soil water every ten days. The third level is the commercial scheduling service. Computer calculations provide weekly instructions to farmers. Instructions are necessary in the schedule if precipitation occurs. The best irrigation recommendations are made by companies doing both monitoring and ET estimates. Cost of irrigation scheduling is repaid by reduced pumping and increased yield.

Irrigation Scheduling Survey

Surveys of irrigation management services are available for 1974 and 1977 (Jensen 1975 and 1978b). Results for commercial services are given in Table 3.4. Commercial services are independent, private enterprises that charge a fee. Agency services are government agencies, produce companies, or irrigation district organizations. Land area scheduled by agency service is given in Table 3.5. The largest agency is the WPRS which operated at 16 irrigation districts in 1974, 25 in 1977, and 21 in 1979. The Salt River Project in Arizona has been scheduling since 1965. Total scheduled land area is about two percent of the irrigated land in the western United States. An additional two percent are aided by the WPRS irrigation guide approach.

Some useful information concerning field monitoring is given by Jensen (1975) from the 1974 survey. The land area monitored by one technician is about 2350 hectares. Daily travel to monitor fields is 190 km and each field is visited 1.5 times per week. The responses given by each service company or agency were weighted by land area served.

Table 3.4. Characteristics of commercial irrigation scheduling services in the western USA (Jensen, 1975 and 1978b).

	1974	1977
Number of companies surveyed	10	11
Companies with less than five years of experience	5	3
Total area of summer crops scheduled (1000 ha)	102	214
Other services:		
irrigation system evaluation and design	6	6
plant nutrition	10	8
pest management	7	7
Scheduling techniques:		
soil water budget		
computer program	10	8
evaporation data (class A pan)	3	2
soil water measurements		
gravimetric sampling	5 (3)[a]	4 (4)
tensiometers	1 (4)	2 (2)
neutron probe	- (-)	2 (2)
auger and probe	- (8)	- (7)
crop observation		
plant symptons	- (1)	- (-)

[a] The parenthesis indicate monitoring measurements to support soil water budget estimates.

Some idea of fees charged was given by Jensen (1978b). The service cost ranges from 7 to 15 dollars per hectare. At an exchange rate of 5 Swedish crowns per dollar, the service costs range from 35 to 75 crowns per hectare.

Table 3.5. Land area of agency irrigation scheduling in the western USA (Jensen, 1975 and 1978b, and WPRS, 1979).

	1974	1977	1979
Total area of summer crops scheduled (1000 ha)	54	69	75

The most common reason given by the service groups for a farmer wanting to continue irrigatin scheduling are: 1) improved water management, 2) increased yield and/or quality, 3) lower production costs, and 4) good service. Reasons for discontinuing the service are: 1) belief in no direct benefit, fee too high, or not reducing operating costs, 2) poor service or communications, 3) does not fit operations, and 4) do not have time (Jensen, 1978b).

Major problems listed by commercial services were given by Jensen (1978b) as follows:

1) lack of farmers confidence in the first year
2) soil variability
3) difficult to arrange discussion with farmers.

With agency services the problems listed were as follows:

1) communications
2) lack of farmers confidence in the first year
3) unknown irrigation amounts
4) lack of trained personnel and/or temporary summer employees who lacked motivation.

CHAPTER 4

IRRIGATION SCHEDULING MODEL ADAPTED FOR SWEDISH CONDITIONS

Modifications to the 1971 version of the USDA irrigation scheduling computer program (Jensen et al., 1971) are necessary because of two reasons. The first is that research results since 1971 need to be added. The second is that the program needs to be adapted to Swedish climatic conditions. This chapter covers the water balance equation, reference crop ET, crop ET, added water, and allowable depletion. Added water refers to an irrigation or precipitation event. Equation development is explained where necessary.

Water Balance Equation

The soil water depletion in the effective rootzone can be determined for each day as follows:

$$W_J = W_{J-1} + (ET - P_e - I_n)_J$$

The drainage and capillary rise term (D) has been neglected. Suggestions were made by Jensen (1972) for inclusion of this term into the USDA scheduling model. The empirical nature of the recommended relations present difficulties in use. The estimation of ET is done by an empirical approach that provides the basic identity of the USDA scheduling model. The precipitation and irrigation terms are field measured inputs.

Implicit in the concept of depletion is the idea of maximum available soil water. The limits of this term must be defined. Jensen et al. (1971) state that the depletion is zero after a thorough irrigation. This fits the concept of field capacity. In Sweden the idea of a drainage equilibrium, as presented by Johansson (1974), is used as the upper limit. The lower limit is taken as the permanent wilting point. To allow laboratory determination of the maximum available soil water, the upper limit is defined as the sum of the water contents for each soil layer determined from the soil water potential taken as the height above the water table. The lower limit is defined at -15.0 bars. The soil water depletion which avoids crop water stress, the allowable depletion, is usually expressed as a percentage of the maximum available soil water. The predicted irrigation date is when the soil water depletion matches the allowable depletion. The irrigation amount is computed as follows:

$$I = \frac{W_{ad}}{E} 100$$

where I is the irrigation amount (mm), W_{ad} is the allowable depletion (mm), and E is the field irrigation efficiency (%).

Grass Reference Crop ET

The ET of a crop is determined by the use of a crop coefficient which adjusts a climatically determined, standard ET. The climatic standard in the irrigation scheduling program is that of a reference crop ET, which has replaced the concept of potential ET. A reference crop provides defined surface conditions which can be reproduced in different locations to check the performance of ET estimation methods. Calibration of the ET method to the reference crop ET is also possible. Also, the crop coefficient values developed at a research location can be transferred to other areas by use of a specified reference crop.

The USDA program uses an alfalfa reference crop. For Sweden, a grass reference crop is more suitable. The ET estimation methods in this work which have been chosen to represent daily grass reference crop ET (ET_{rg}) are:

1) a locally calibrated Penman method, 2) the FAO Penman method, and 3) the Johansson method or the Andersson evaporimeter. A grass reference crop as defined by Doorenbos and Pruitt (1977) is "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". The three different methods have been included to allow for selection of the best method under actual scheduling conditions.

Submodels

Some parameters are common to two or all three of the estimation methods. The submodels include: 1) saturation air vapor pressure, 2) air vapor pressure, and 3) the Penman weighting function.

The saturation air vapor pressure is a function of air temperature and a relation was developed from one given by Murray (1967). This formula is originally from Tetens (1930) as follows:

$$e'_a = \exp\left[(19.078955\ T_a + 429.41016)/(T_a + 237.3)\right]$$

where e'_a is the air saturation vapor pressure (mbar), and T_a is the air temperature (^{o}C). The term exp represents the exponential function. The relation was compared to other e'_a formulas and is one of the most accurate and simplest to use (Erpenbeck, 1981). It is assumed in using this formula that T_a is always greater than freezing.

The air vapor pressure is computed from the relative humidity with the following relation:

$$e_a = e'_a \cdot RH/100$$

where e_a is the air vapor pressure (mbar), and RH is the relative humidity (%).

The Penman weighting function is defined as:

$$W = \frac{\Delta}{\Delta + \gamma}$$

$$\gamma = 1615.25\ P_a/L$$

$$P_a = 1013 - 0.1152\ (h) + 5.44E\text{-}6\ (h)^2$$

$$L = 2.49037E6 - 2.1346E3\ (T_a)$$

$$\Delta = e'_a \left[4098.0259/(T_a + 237.3)^2 \right]$$

where W is the Penman weighting function, Δ is the slope of the saturation vapor pressure curve (mbar/°C), γ is the psychrometric constant (mbar/°C), P_a is the air pressure (mbar), L is the latent heat of vaporization (J/kg_w), and h is the altitude (m). The number 5.44E-6 represents $5.44 \cdot 10^{-6}$. The relation for P_a is from Doorenbos and Pruitt (1977). The equation for L is given by Jensen (1974).

Locally Calibrated Penman Method

The first ET method is the Penman (1948) method calibrated externally by linear regression. Calibration can also be done internal to the equation by deriving a wind function. The external calibration is simpler and is done as follows:

$$ET_{rg} = a_c + b_c \, ET_p$$

$$ET_p = W(R_n - G) + (1 - W) \, f_{u,p} \, (e'_a - e_a)$$

$$f_{u,p} = 0.2625 + 0.1409 \, u$$

where ET_{rg} is the grass reference crop ET (mm/day), a_c and b_c are linear regression calibration coefficients (a_c has units of mm/day), ET_p is the Penman method, estimated ET (mm/day), R_n is the net radiation (mm/day), G is the soil heat flux which is positive in sign when the soil is warming (mm/day), $f_{u,p}$ is the Penman (1948) wind term $(\frac{mm/day}{mbar})$, and u is the windspeed at 2 meters height (m/s).

The calibration coefficients, a_c and b_c, can be derived from measured ET_{rg} and calculated ET_p values. Kristensen (1979) at Copenhagen, Denmark measured weekly values of ET_{rg} with a weighing lysimeter from 1966 to 1978. The coefficient of determination (r^2) value is 0.938, for the regression between ET_{rg} and ET_p using long-term values. The relation is as follows:

$$ET_{rg} = -0.083 + 0.921 \, ET_p$$

Kristensen (1979) used measured values of net radiation and soil heat flux as inputs to the Penman method.

Net radiation is calculated as follows:

$$R_n = (1 - a_s) R_s - \epsilon_s (1 - \epsilon_a) \sigma T_a^4$$

where a_s is the crop albedo, R_s is the solar radiation (mm/day), ϵ_s is the surface emissivity, ϵ_a is the atmospheric emissivity, σ is the Stefan-Boltzmann constant $(\frac{mm/day}{^oK^4})$ and T_a is the air temperature (^{o}K). According to Jensen (1974) the albedo of a grass reference crop is 0.23 and the surface emissivity is 0.98.

The value of σ is 2.00239E-9 $\frac{mm/day}{^oC^4}$. The relation for net radiation, with T_a in units of ^{o}C, is now as follows:

$$R_n = 0.77 R_s - 0.98(1 - \epsilon_a) 2.00239E\text{-}9(T_a + 273.16)^4$$

The atmospheric emissivity is determined from:

$$\epsilon_a = \epsilon_{ao} (1.44 - 0.46 R_{s/so})$$

$$\epsilon_{ao} = 1.24 \left[e_a/(T_a + 273.16) \right]^{1/7}$$

where ϵ_{ao} is the clear sky emissivity, and $R_{s/so}$ is the ratio of solar to clear sky solar radiation. The relation for ϵ_{ao} is from Brutsaert (1975). The constants 1.44 and -0.46 were determined at Kimberly, Idaho by Erpenbeck (1981).

A relation is needed for clear sky solar radiation. Using historic solar radiation data, the R_{so} envelope curve can be expressed as a polynomial equation, as follows:

$$R_{so} = a_o + a_1(J) + a_2(J)^2 + a_3(J)^3 + a_4(J)^4$$

where R_{so} is the clear sky solar radiation (mm/day), a_o to a_4 are the regression coefficients, and J is the julian date, which is the days after Januari 1. The ratio $R_{s/so}$ is then found as follows:

$$R_{s/so} = R_s/R_{so}$$

A limit is placed in $R_{s/so}$ as follows:

$$\text{if } R_{s/so} > 1.0, \text{ then } R_{s/so} = 1.0$$

Soil heat flux is estimated as follows:

$$G = (T_a - T_p)\ c_s$$

$$T_p = (T_{a,J-1} + T_{a,J-2} + T_{a,J-3})/3$$

where G is the soil heat flux (mm/day), T_p is the mean air temperature for the previous three days (^oC), and c_s is an empirical, specific heat coefficient $(\frac{mm/day}{^oC})$. The equation for G was developed from the following relation:

$$G = k_t \frac{\Delta T}{\Delta z}$$

where k_t is the thermal conductivity, which has a value of 400 $\frac{cal}{cm\ ^oC\ day}$ or 6.8 $\frac{cm\ mm/day}{^oC}$. The variable Δz is the depth below the soil surface over which the temperature difference ΔT applies. The value of Δz is approximately 45 cm. The coefficient c_s is then 0.15 $\frac{mm/day}{^oC}$.

FAO Penman Method

Doorenbos and Pruitt (1977) presented modifications to the Penman equation which make use of secondary, meaning long-term, weather parameters. The method again represents a grass reference crop. The equation is as follows:

$$ET_{P-FAO} = c\left[W\ R_{n,FAO} + (1 - W)\ f_{u,FAO}(e'_a - e_a)\right]$$

$$f_{u,FAO} = 0.27 + 0.2333\ u$$

where c is an empirical coefficient determined from secondary weather data. FAO symbolizes variables determined in a particular way for this ET estimation method.

The net radiation is determined from:

$$R_{n,FAO} = 0.75\ R_s - 2.00239E\text{-}9\ (T_a + 273.16)^4\ \left[0.34 - 0.044\ (e_a)^{0.5}\right]$$

$$(-0.35 + 1.8\ R_s/R_a)$$

where R_a is the extra-terrestrial radiation (mm/day). The computation procedure for R_a is given in Appendix C. The air temperature is the average of the minimum and maximum air temperatures.

The coefficient c is presented in Table 4.1 from Doorenbos and Pruitt (1977) as a function of long-term values of solar radiation ($\overline{R}_s$), daytime windspeed ($\overline{u}_{day}$), maximum relative humidity ($\overline{RH}_{max}$), and day to night windspeed ratio ($\overline{r}$). These values are determined from 10-day or 30-day periods from the data records. Values of $\overline{u}_{day}$ can be computed from $\overline{u}$ and $\overline{r}$ as follows:

$$\overline{u}_{day} = \overline{u}\,\frac{2\,\overline{r}}{1 + \overline{r}}$$

Table 4.1. The coefficient c in the FAO Penman ET method as a function of long-term weather parameters (Doorenbos and Pruitt, 1977).

	$\overline{RH}_{max}$ = 30 %				$\overline{RH}_{max}$ = 60 %				$\overline{RH}_{max}$ = 90 %			
$\overline{R}_s$ mm/day	3	6	9	12	3	6	9	12	3	6	9	12
$\overline{u}_{day}$ m/sec	$\overline{r}$ = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.32
6	.68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.33
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.27
	$\overline{r}$ = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.28
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.22
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.18
	$\overline{r}$ = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.69	.76	.85	.92	.83	.91	.99	1.05	.89	.98	1.10	1.14
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
	$\overline{r}$ = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.64	.71	.82	.89	.78	.86	.94	.99	.85	.92	1.01	1.05
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

Johansson Method

A climatic standard that has been developed and used in Sweden is the Andersson evaporimeter as described by Andersson (1969). Estimation of evaporation from this device was developed by Johansson (1969). This relation was developed at Ultuna with evaporimeter and meteorological measurements in 1961 over a grass surface. The regression equation with an r^2 of 0,914 is as follows:

$$ET_{rg} = 0.7\ E_J$$

$$E_J = 0.14 + 0.22\ R_s + 0.092\ u(e_a' - e_a)$$

where E_J is the evaporation from Andersson evaporimeter as computed by the Johansson method (mm/day). The conversion factor of 0.7 is given by Johansson (1969).

Expected Reference Crop ET

The distribution of ET_{rg} during the growing season can be represented by a normal equation. Daily long-term mean values of ET_{rg} can then be used to determine the equation coefficients. The equation for expected ET_{rg} is as follows:

$$\overline{ET}_{rg} = \overline{ET}_{rg,max}\ \exp\left[-\left(\frac{J - t_{max}}{\Delta t}\right)^2\right]$$

where the overbar indicates a long-term value as also done earlier. The three equation coefficients: $\overline{ET}_{rg,\ max}$, t_{max}, and Δt are shown in Figure 4.1. The parameter Δt can have a different value before and after t_{max}.

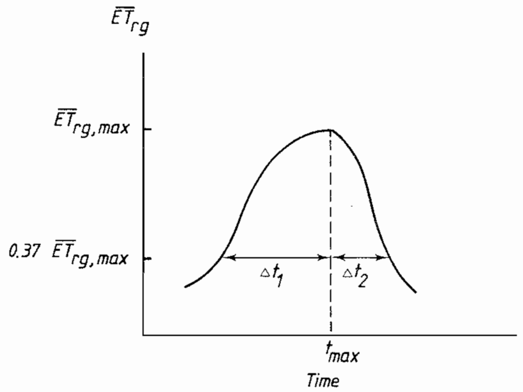


Fig. 4.1. Expected reference crop ET as represented by a normal distribution equation. Equation coefficients are shown.

Weather Data

The same weather data is required for each of the three ET_{rg} methods. Daily measurements of air temperature, relative humidity, windspeed, and solar radiation are needed. In Sweden, the daily sum of solar radiation is recorded and three measurement times daily: 0800, 1400, and 1900 are available for the remaining parameters.

Modén (1939) presented a formula to calculate the mean air temperature from the three readings for the day and the minimum temperature, as follows:

$$T_a = c_1 T_8 + c_2 T_{14} + c_3 T_{19} + c_4 T_{min}$$

where T_8 is the air temperature at 0800 (°C), T_{14} at 1400 (°C), T_{19} at 1900 (°C), and T_{min} is the minimum air temperature (°C). The coefficients c_1, c_2, c_3 and c_4 depend on the longitude and the month. This method is awkward to use because of the variation in the coefficients. A simpler approach is adapted, as follows:

$$T_a = (T_8 + T_{14} + T_{19})/3$$

The mean of the three readings are used. This approach is also used for the relatively humidity and windspeed data, as follows:

$$RH = (RH_8 + RH_{14} + RH_{19})/3$$

$$u = (u_8 + u_{14} + u_{19})/3$$

The mean air temperature for use in the FAO Penman method is the average of the minimum and maximum air temperature.

The windspeed must be converted to a standard height of 2.0 meters. The following relation assuming a logarithmic wind profile is used:

$$u = c_u u_z$$

$$c_u = \ln\left(\frac{2}{0.01}\right)/\ln\left(\frac{z}{0.01}\right)$$

where u is the windspeed at 2 meters (m/s), c_u is the windspeed height adjustment coefficient, and z is the actual measurement height (m). Solar radiation is converted from units of langleys/day to an equivalent mm/day of evaporation by using the factor 0.0171.

Crop ET

The grass reference crop ET is converted to actual crop ET by using a crop coefficient as follows:

$$ET = k_c \; ET_{rg}$$

where k_c is the "dimensionless ET crop coefficient" (Wright, 1981). The values for k_c depend on crop growth and soil water conditions and may be estimated from:

$$k_c = k_{cb} \; k_a + k_s$$

where k_{cb} is the generalized basal crop coefficient, k_a is the crop coefficient dependent on available soil water, and k_s is the crop coefficient which allows for increased evaporation from the soil surface after a rain or irrigation. Figure 4.2 gives an idealized picture of the seasonal variation in k_c, with both adequate and limited soil water. The symbol k_a in Figure 4.2 represents qualitatively the reduction of k_c during limited soil water conditions.

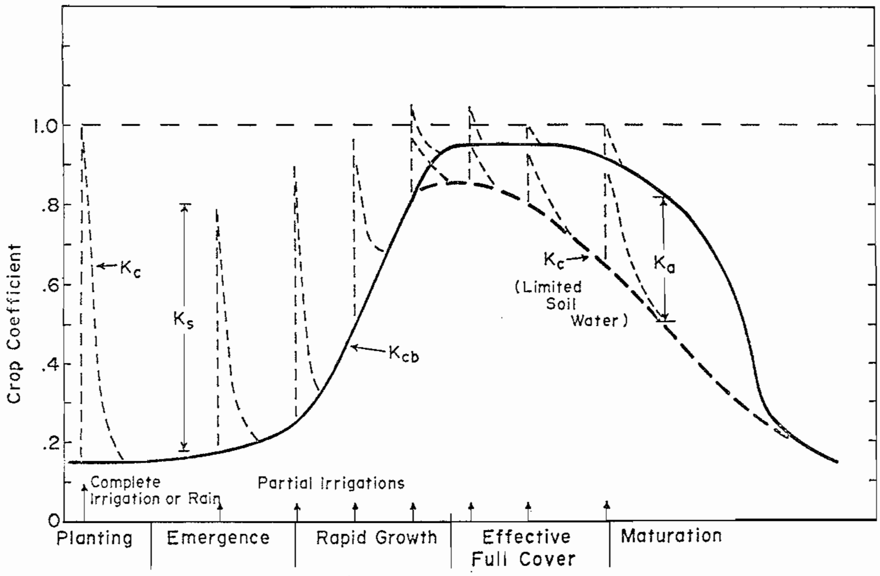


Fig. 4.2. Idealized seasonal variation in the crop coefficient under conditions of adequate and limited soil water (Wright, 1981).

Basal Crop Coefficients

The basal crop coefficient represents conditions when the soil surface is dry, but adequate soil water is available for crop growth. The k_{cb} "crop curve" can be determined from daily measurements of crop ET. The reference crop ET may be measured for the same time period or estimated by a calibrated estimation method. Figure 4.3 shows the drawing of a generalized k_{cb} curve from experimental data.

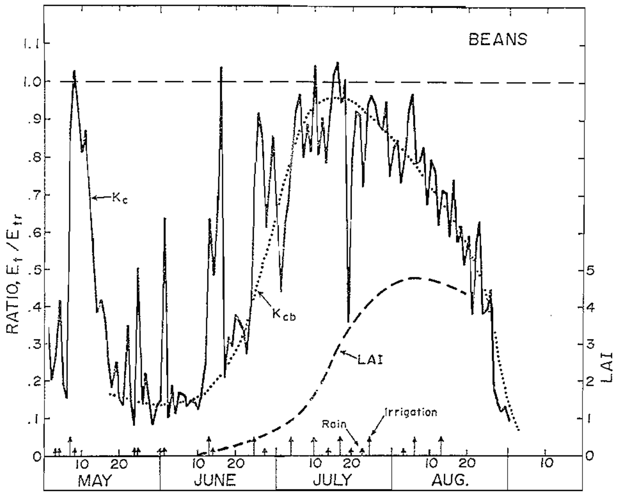


Fig. 4.3. A generalized basal crop coefficient curve as determined from lysimeter measured crop coefficient values for beans at Kimberly, Idaho (Wright, 1981).

Burman et al. (1980) presented k_{cb} values for various crops at two locations. The crop curves from Kimberly, Idaho were expressed with respect to an alfalfa reference crop, while those from Davis, California were given with respect to a grass reference crop. The Kimberly data is converted to a grass reference crop as the climatic standard by use of the approximate conversion factors given i Table 4.2 (Erpenbeck, 1981). The conversion factor is expressed in equation form as follows:

$$k_{a/g} = ET_{ra}/ET_{rg}$$

Table 4.2. Conversion factors from an alfalfa to a grass reference crop for Davis, California (Erpenbeck, 1981).

Month	$k_{a/g}$	Month	$k_{a/g}$
January	1.701	July	1.202
February	1.441	August	1.214
March	1.295	September	1.230
April	1.247	October	1.267
May	1.218	November	1.428
June	1.208	December	1.653

The basal crop coefficients are usually given as a function of a normalized time scale. This helps to account for variation in crop development between years or locations. The original USDA scheduling program used two time scales: 1) percent time from planting to effective full cover, and 2) days after effective full cover. The length of the planting to emergence period can vary considerably. So the crop curves have been converted to a percent time from emergence to effective full cover for the first half of the season. Percent time from effective full cover to harvest is not used because the harvest date is not necessarily related to crop maturity. A more growth related index would be desirable, but the adjustment of the predicted effective full cover date enables the model to match actual field crop development.

The effective full cover date occurred for most crops at Kimberly after the rows closed when the leaf area index was 3.5 to 4.0 (Wright, 1981). The date at which the k_{cb} first reaches a maximum can also be used as the effective full cover date. The number of days from emergence to effective full cover for various crops in a region can be used as a guide for first estimates of effective full cover dates. Again, the predicted effective full cover date should be adjusted if crop growth is faster or slower than normal.

Doorenbos and Pruitt (1977) presented values needed to construct crop coefficient curves for various crops. The growing season is divided into four stages as illustrated in Figure 4.4 and described as follows:

1) initial stage
    - crop cover is less than 10 percent
    - soil surface is mostly bare
2) crop development stage
    - crop cover is from 10 to 70 or 80 percent
    - ends at effective full cover
3) mid-season stage
    - from effective full cover to start of maturation
4) late stage
    - from start of maturation to full maturity or harvest

The mid-season and harvest-maturity k_{cb} values are given for various annual crops by Doorenbos and Pruitt (1977). These can be compared to research results from Kimberly, Idaho and Davis, California. Also, k_{cb} values from Prosser, Washington are available (Erpenbeck, 1981). Table 4.3 compares the mid-season k_{cb} values for annual crops. Table 4.4 shows the harvest-maturity k_{cb} values. The Doorenbos and Pruitt FAO k_{cb} values are given for Swedish and semi-arid conditions. Confidence in the FAO k_{cb} values is judged by comparison of the semi-arid figures to the western U.S. locations. Some idea of the climatic adjustment necessary to the k_{cb} curves for Swedish conditions is then possible. The FAO climatic adjustment depends on long-term minimum relative humidity ($\overline{RH}_{min}$) and windspeed ($\overline{u}$).

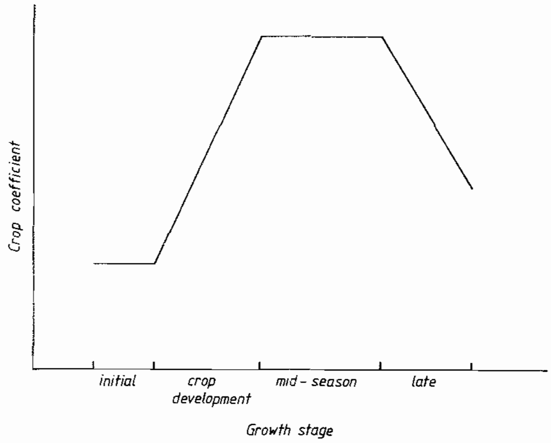


Fig. 4.4. FAO idealized crop coefficient curve (Doorenbos and Pruitt, 1977).

Table 4.3. Mid-season stage basal crop coefficients for annual crops, with respect to a grass reference crop. The FAO values are estimates.

Crop	FAO		Kimberly	Davis	Prosser
	Swedish[a]	semi-arid[b]			
beans (dry)	1.10	1.15	-	1.10	1.17
beans (snap)	0.98	1.00	1.14	-	-
corn (field)	1.10	1.15	1.14	1.17	1.03
peas	1.10	1.15	1.14	-	-
potatoes	1.10	1.15	0.96	-	1.17
small grains	1.10	1.15	1.22	-	1.21
sorghum		1.10	-	1.05	1.11
sugar beets	1.10	1.15	1.21	1.13	1.15
tomatoes		1.20	-	1.16	-

[a] $\overline{RH}_{min}$ = 50 to 55 percent and $\overline{u}$ = 2.3 to 3.8 m/s

[b] $\overline{RH}_{min}$ = 20 percent and $\overline{u}$ = 1.4 to 1.5 m/s

Table 4.4. Harvest or maturity basal crop coefficients for annual crops, with respect to a grass reference crop. The FAO values are estimates.

Crop	FAO		Kimberly	Davis
	Swedish[a]	semi-arid[b]		
beans (dry)	0.28	0.25	-	0.37
beans (snap)	0.88	0.90	0.31[c]	-
corn (field)	0.58	0.60	0.96[d]	0.53
peas	1.00	1.05	0.24[c]	-
potatoes	0.72	0.75	0.30 (0.86[e])	-
small grains	0.22	0.20	0.19	-
sorghum		0.55	-	0.73
sugar beets	0.95	1.00	1.00	1.01
tomatoes		0.65	-	0.61

[a] $\overline{RH}_{min}$ = 50 to 55 percent and $\bar{u}$ = 2.3 to 3.8 m/s

[b] $\overline{RH}_{min}$ = 20 percent and $\bar{u}$ = 1.4 to 1.5 m/s

[c] perhaps grown for seed

[d] perhaps cut for silage

[e] frost date value

A near majority of mid-season k_{cb} values from the three western U.S. locations are within ± 2 percent of the FAO semi-arid values. Another third are within ± 5 percent of the FAO values. The k_{cb} value for Kimberly snap beans exceeds the FAO value by 14 percent, due perhaps to difference in crop definition. The Kimberly snap beans k_{cb} does match the FAO dry beans k_{cb} value. Prosser field corn and Kimberly potatoes k_{cb} values are 10 and 16 percent low, respectfully. It is concluded that the published mid-season k_{cb} data generally agree with the semi-arid FAO k_{cb} values. For Swedish conditions, a 4 percent reduction in the mid-season k_{cb} value is suggested by FAO. The reason for this climatic adjustment is that k_{cb} is affected by wind. This is due to increased turbulence over a taller and rougher crop as compare to a smooth grass reference crop surface. This affect is more pronounced in dry than in humid climates. This is one reason why alfalfa has often been preferred as the reference crop in that its aerodynamic roughness is closer to most field crops.

It is more difficult to compare the harvest-maturity k_{cb} values as published for Kimberly and Davis with those from FAO. The condition of the crop when this final k_{cb} value was selected does not appear to be standardized. For sugar beets a 4 percent reduction in the k_{cb} value is suggested for Swedish climatic conditions.

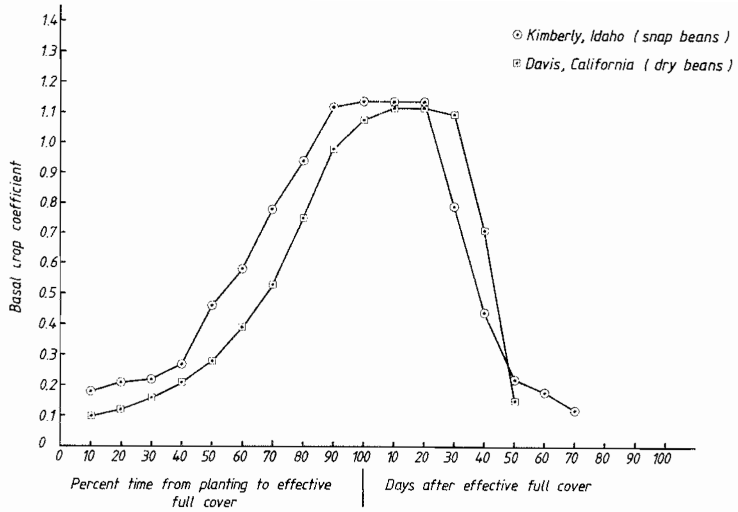


Fig. 4.5. Basal crop coefficient curves for beans with respect to a grass reference crop.

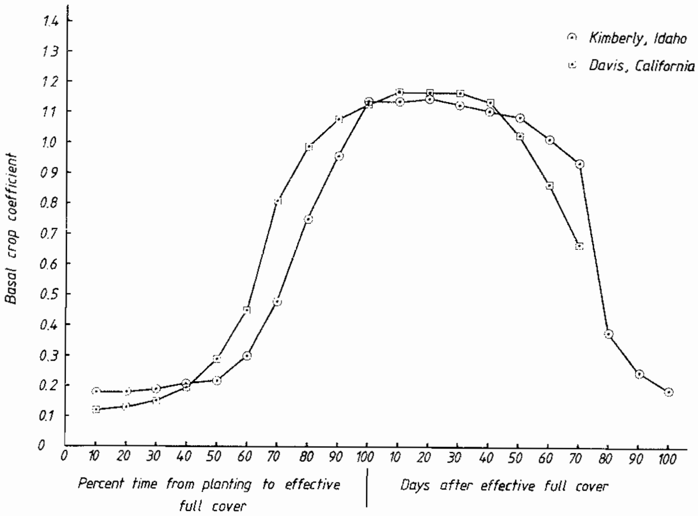


Fig. 4.6. Basal crop coefficient curves for field corn with respect to a grass reference crop.

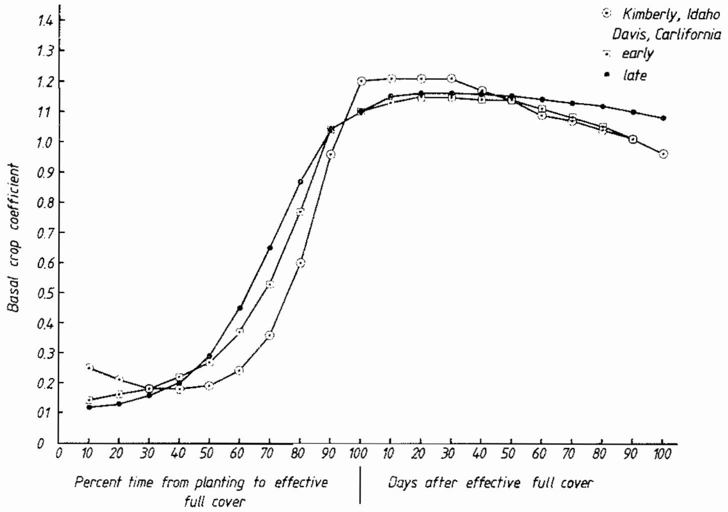


Fig. 4.7. Basal crop coefficent curves for sugar beets with respect to a grass reference crop.

There exists some variation in the seasonal k_{cb} curves for crops where ET measurements were done at both Kimberly and Davis. Figures 4.5 to 4.7 show the differences in crop curves for beans, field corn, and sugar beets. Snap beans at Kimberly and dry beans at Davis are actually different crops, so the deviation is justified. Field corn and sugar beets indicate the difficulties in using a time scale rather than a growth related scale.

Table 4.5. Before effective full cover, daily basal crop coefficients with a grass reference crop, derived by lysimeter measurements at Kimberly, Idaho.

Percent time emergency to effective full cover	Basal crop coefficients						
	small grains	snap beans	peas	potatoes	sugar beets	corn	winter[a] wheat
10	0.23	0.23	0.21	0.34	0.18	0.20	0.83
20	0.29	0.28	0.22	0.44	0.19	0.21	0.88
30	0.42	0.42	0.24	0.51	0.21	0.22	0.94
40	0.68	0.53	0.30	0.61	0.24	0.27	0.99
50	0.88	0.64	0.42	0.72	0.32	0.37	1.05
60	1.04	0.78	0.59	0.81	0.44	0.51	1.10
70	1.15	0.90	0.77	0.88	0.60	0.71	1.16
80	1.20	1.03	0.93	0.93	0.82	0.87	1.19
90	1.21	1.12	1.07	0.95	1.03	1.01	1.21
100	1.23	1.14	1.15	0.96	1.21	1.14	1.23

[a] Time scale for winter wheat is percent time from start of growth to effective full cover.

Table 4.6. After effective full cover, daily basal crop cofficients with a grass reference crop, derived by lysimeter measurements at Kimberly, Idaho.

Days after effective full cover	Basal crop coefficients						
	small grains	snap beans	peas	potatoes	sugar beets	corn	winter wheat
10	1.23	1.14	1.12	0.96	1.21	1.14	1.23
20	1.20	1.14	0.99	0.96	1.21	1.14	1.21
30	0.96	0.79	0.60	0.91	1.21	1.13	1.15
40	0.60	0.44	0.44	0.90	1.17	1.11	0.60
50	0.30	0.22	0.24	0.89	1.14	1.09	0.24
60	0.12	0.18	0.12	0.88	1.09	1.02	0.12
70	0.12	0.12	0.12	0.86	1.07	0.94	0.12
80				0.62	1.04	0.38	
90				0.31	1.01	0.25	
100				0.25	0.96	0.19	

Table 4.7. Before effective full cover, percentage from minimum to maximum basal crop coefficient values with a grass reference crop, derived by lysimeter measurements at Kimberly, Idaho. Minimum ($k_{cb,min}$) and maximum ($k_{bc,max}$) basal crop coefficient values are also given.

Percent time emergence to effective full cover	Percent from minimum to maximum basal crop coefficients						
	small grains	snap beans	peas	potatoes	sugar beets	corn	winter wheat[a]
10	4.8	5.2	3.1	20.5	0	2.1	0
20	10.5	10.4	4.1	33.3	1.0	3.1	12.5
30	22.9	25.0	6.2	42.3	2.9	4.2	27.5
40	47.6	36.5	12.4	55.1	5.8	9.4	40.0
50	66.7	47.9	24.7	69.2	13.8	19.8	55.0
60	81.9	62.5	42.3	80.8	25.2	34.4	67.5
70	92.4	75.0	60.8	89.7	40.8	55.2	82.5
80	97.1	88.5	77.3	96.2	62.1	71.9	90.0
90	98.1	97.9	91.8	98.7	82.5	86.5	95.0
100	100.0	100.0	100.0	100.0	100.0	100.0	100.0
$k_{cb,min}$	0.18	0.18	0.18	0.18	0.18	0.18	0.83
$k_{cb,max}$	1.23	1.14	1.15	0.96	1.21	1.14	1.23

[a] Time scale for winter wheat is percent time from start of growth to effective full cover.

Table 4.8. After effective full cover, percentage from minimum to maximum basal crop coefficient values with a grass reference crop, derived by lysimeter measurements at Kimberly, Idaho. Minimum ($k_{cb,min}$) and maximum ($k_{cb,max}$) basal crop coefficients are also given.

Days after effective full cover	Percent from minimum to maximum basal crop coefficients						
	small grains	snap beans	peas	potatoes	sugar beets	corn	winter wheat
10	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20	97.3	100.0	87.0	100.0	100.0	100.0	98.2
30	75.7	65.7	48.0	93.0	100.0	98.9	92.8
40	43.2	31.4	32.0	91.5	84.0	96.8	43.2
50	16.2	9.8	12.0	90.1	72.0	94.7	10.8
60	0	5.9	0	88.7	52.0	87.4	0
70	0	0	0	85.9	44.0	78.9	0
80				52.1	32.0	20.0	
90				8.5	20.0	6.3	
100				0	0	0	
$k_{cb,min}$	0.12	0.12	0.12	0.25	0.96	0.19	0.12
$k_{cb,max}$	1.23	1.14	1.15	0.96	1.21	1.14	1.23

In the irrigation scheduling computer program for annual crops, the Kimberly k_{cb} curves are used. The k_{cb} values from Burman et al. (1980) are adapted to a grass reference crop. The k_{cb} data for small grains, snap beans, peas, potatoes, sugar beets, corn, and winter wheat are shown in Tables 4.5 and 4.6. The suggested adjustments for Swedish climatic conditions are not made, but in Tables 4.7 and 4.8 the k_{cb} values are given as a persentage from minimum to maximum k_{cb} values. The k_{cb} curves are used in this way in the program. If it is necessary to reduce the mid-season k_{cb} values then a new maximum k_{cb} can be entered. In all the tables the scale percent time from emergence to effective full cover is used. Before emergence the minimum k_{cb} of 0.18 is used, which was derived from Kimberly and Davis initial growth stage data. The basal crop coefficient curves are presented graphically in Figures 4.8 to 4.14.

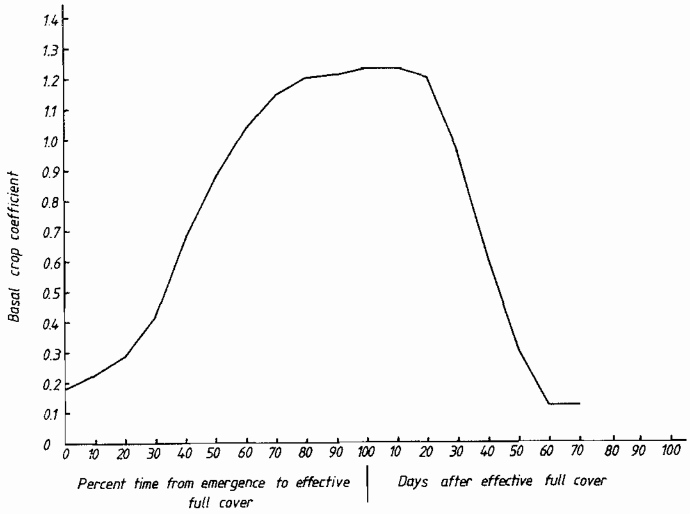


Fig. 4.8. Basal crop coefficient curve for small grains with respect to a grass reference crop, measured at Kimberly, Idaho.

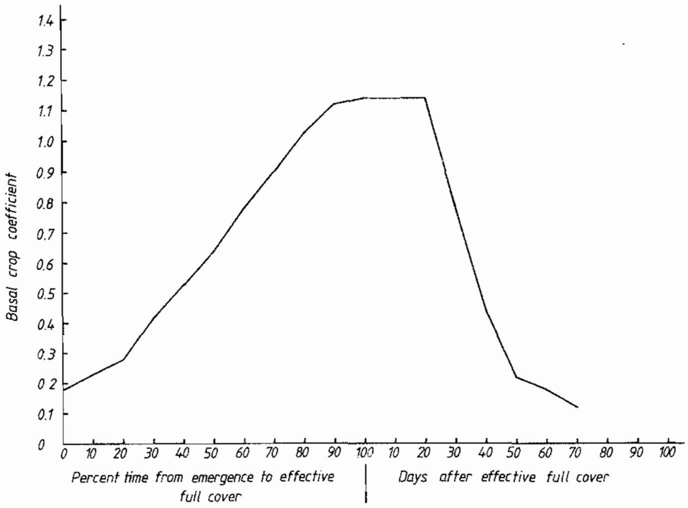


Fig. 4.9. Basal crop coefficient curve for snap beans with respect to a grass reference crop, measured at Kimberly, Idaho.

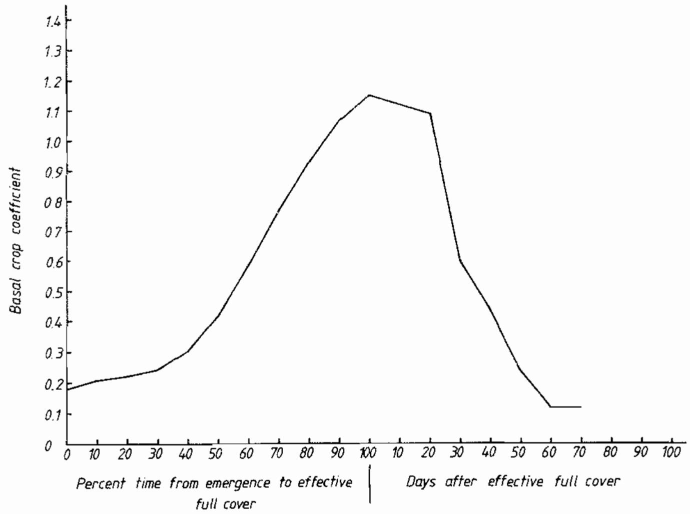


Fig. 4.10. Basal crop coefficient curve for peas with respect to a grass reference crop, measured at Kimberly, Idaho.

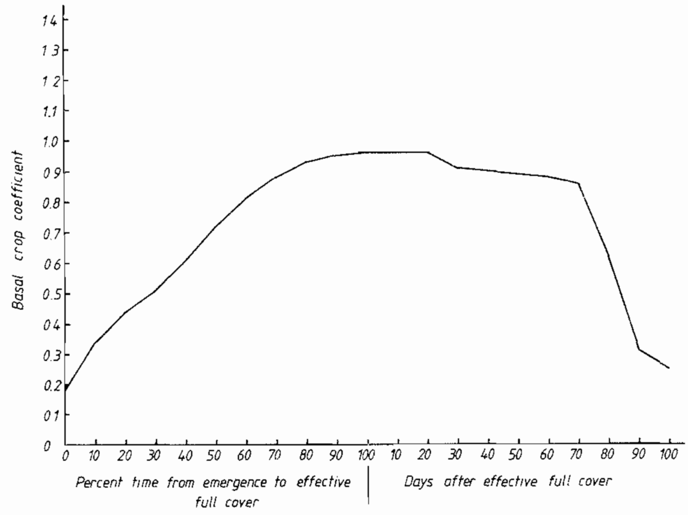


Fig. 4.11. Basal crop coefficient curve for potatoes with respect to a grass reference crop, measured at Kimberly, Idaho.

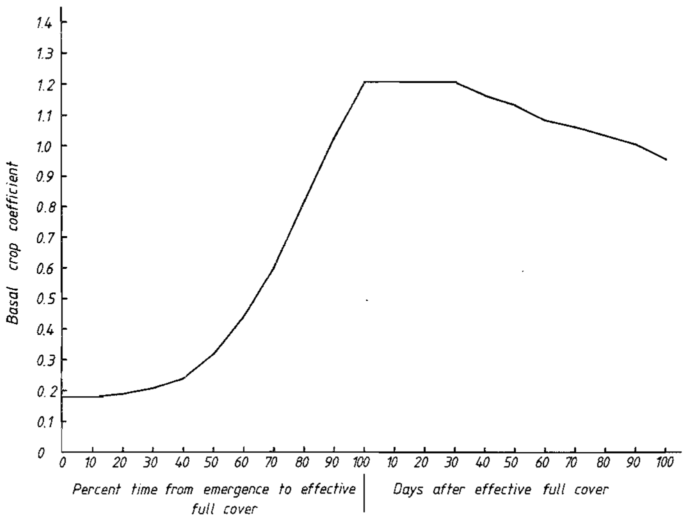


Fig. 4.12. Basal crop coefficient curve for sugar beets with respect to a grass reference crop, measured at Kimberly, Idaho.

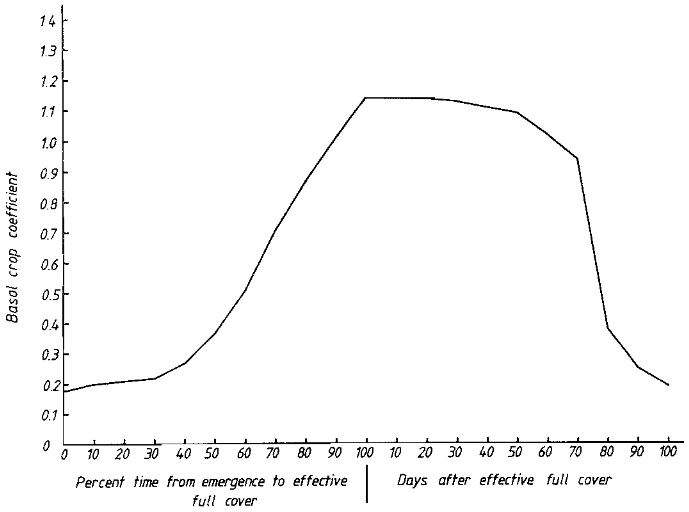


Fig. 4.13. Basal crop coefficient curve for corn with respect to a grass reference crop, measured at Kimberly, Idaho.

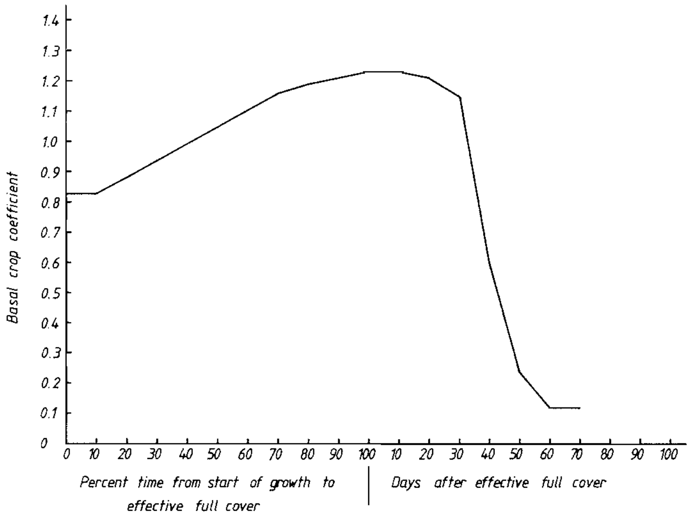


Fig. 4.14. Basal crop coefficient curve for winter wheat with respect to a grass reference crop, measured at Kimberly, Idaho.

For perennial crops, the model given by Doorenbos and Pruitt (1977) is used. Figure 4.15 illustrates the variation in k_{cb} as affected by cuttings. Four separate curves can be identified in the figure: 1) from start of growth to effective full cover, 2) from effective full cover to cutting, 3) from cutting to effective full cover, and 4) from effective full cover to killing frost. The k_{cb} values given by Wright (1981) for alfalfa are used to determine the actual shape of the curves. Table 4.9 gives the percentage from minimum to maximum k_{cb} values for the first and third curves and Table 4.10 for the fourth curve. The second curve is simply the value of the maximum k_{cb}. Table 4.11 gives the minimum and maximum k_{cb} values as indicated in Figure 4.15 for pasture, clover, grass, and alfalfa. The alfalfa values were taken from Wright (1981) and the remaining values from Doorenbos and Pruitt (1977) for Swedish general climatic conditions.

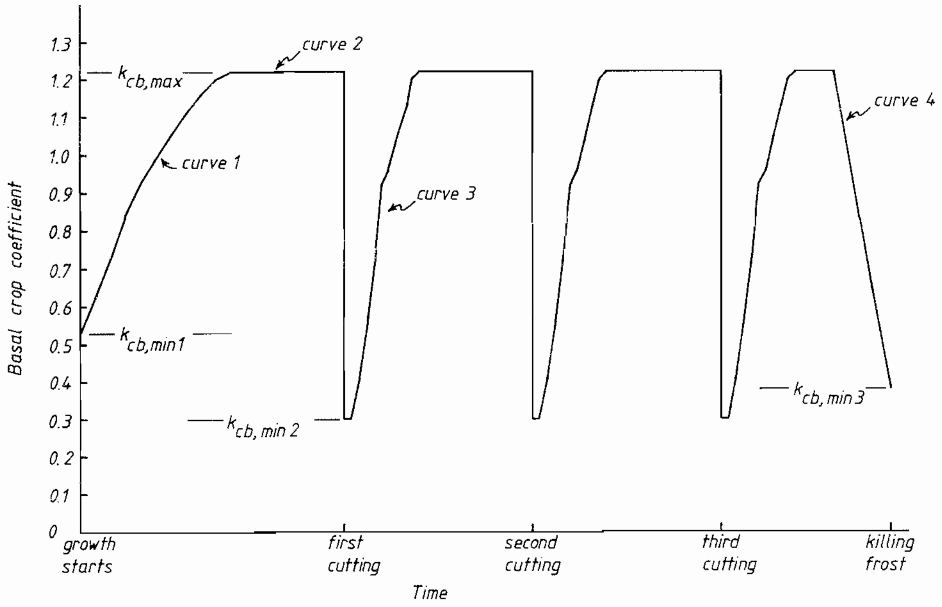


Fig. 4.15. Generalized alfalfa basal crop coefficient curve with respect to a grass reference crop. Curve numbers, and minimum and maximum k_{cb} values are also indicated.

Table 4.9. Before effective full cover, percentage from minimum to maximum basal crop coefficient values for perennial crops, with respect to a grass reference crop.

Percent time from start of growth or cutting to effective full cover	Percent from minimum to maximum basal crop coefficients	
	curve 1	curve 3
10	14.5	0
20	29.0	12.0
30	44.9	28.3
40	58.0	45.7
50	66.7	67.4
60	75.4	71.7
70	84.1	80.4
80	91.3	90.2
90	97.1	97.8
100	100.0	100.0

Table 4.10. After effective full cover, percentage from minimum to maximum crop coefficient values for perennial crops, with respect to a gras reference crop.

Days after effective full cover	Percent from minimum to maximum basal crop coefficients
	curve 4
10	100.0
20	100.0
30	31.0
40	0

Table 4.11. Minimum and maximum basal crop coefficients for perennial crops, with respect to a grass reference crop.

Crop	Basal crop coefficients[a]			
	$k_{cb,min1}$	$k_{cb,min2}$	$k_{cb,min3}$	$k_{cb,max}$
pasture (grazed grass, grass-legumes, or alfalfa	0.52	0.52	0.52	1.08
clover, grass-legumes (cut)	0.55	0.55	0.55	1.10
grass (cut)	0.58	0.58	0.58	1.08
alfalfa (cut)	0.53	0.30	0.38	1.22

[a] Refer to Figure 4.15 for the definitions of $k_{cb,min}$ and $k_{cb,max}$ values.

Crop Coefficient Related to Available Soil Water

The relation used in the USDA scheduling model is as follows:

$$k_a = \frac{\ln(W_a + 1)}{\ln(101)}$$

where W_a is the percentage of available soil water, which has a value of 100 when the soil water is at the upper limit. The change of k_a with soil water is shown in Figure 4.16.

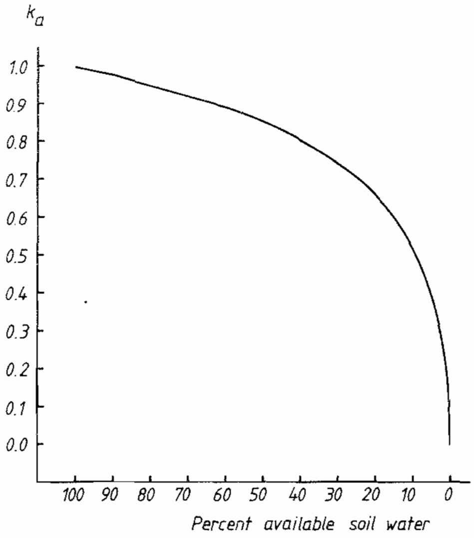


Fig. 4.16. The crop coefficent k_a as a function of percent available soil water.

Crop Coefficient Related to a Wet Surface

The increase in ET when the crop or soil surface is wet after an irrigation or rain is modelled as follows by Jensen et al. (1971):

$$\text{if } k_{cb}\, k_a < k_1$$

$$k_s = (k_1 - k_{cb}\, k_a) \exp(-\lambda t)$$

$$\text{if } k_{cb}\, k_a \geq k_1$$

$$k_s = 0$$

where k_1 and λ are empirical parameters, and t is days after the rain or irrigation. The parameter λ represents the combined effects of evaporative demand and soil characteristics. The coefficient k_1 was originally given the value of 0.9 with respect to an alfalfa reference crop. With a grass reference crop, k_1 has a value of 1.09. The relation for k_s when $k_{cb}\ k_a$ is less than 1.09 is simplified by replacing the term $\exp(-\lambda t)$ with a coefficient k_2, as follows:

$$k_s = (k_1 - k_{cb}\ k_a)\ k_2$$

The values for k_2 are given in Table 4.12.

Table 4.12. Values for the coefficient k_2 for each day following an irrigation or rain.

Days after irrigation or rain	k_2
0	1.0
1	0.8
2	0.5
3	0.3
≥ 4	0

Expected Crop ET

During future time the crop coefficient is computed by:

$$k_c = k_{cb}\ k_a$$

The k_s term is neglected and k_a is set at the value for the end of the present time. The ET is then calculated from the following:

$$ET = k_c\ \overline{ET}_{rg}$$

Added Water

The crop ET decreases the soil water content of the rootzone each day. A precipitation or irrigation adds to the water content, perhaps even exceeding the maximum amount that the soil can retain. The excess is lost to deep percolation below the rootzone. The amount of precipitation or irrigation needs to be measured for the field.

The measured values may need to be reduced due to losses from evaporation, runoff, or deep percolation. The USDA model does not make any internal adjustment of measured to effective precipitation. This is left to the users judgement. For conversion of measured to net irrigation amounts, an efficiency term for the irrigation system is used. The net irrigation is then computed as follows:

$$I_n = \frac{I}{E} 100$$

where E is the field irrigation efficiency (%) which is the ratio of the amount of water available for use by the crop to the amount applied. The applied depth depends on where the measurement is taken and is often specified at the field inlet as done by Doorenbos and Pruitt (1977).

Allowable Depletion

The allowable soil water depletion is where crop water stress begins and defines the date and amount of the next irrigation. The scheduling program provides two options for input of the allowable depletion. The first method is that an amount of soil water depletion is specified directly. This may be constant throughout the growing season or change in response to root development or critical growth stages of increased crop sensitivity to water stress. The ability to select the proper allowable depletion is gained after experience with the specific field.

The second method requires that a percent allowable depletion is specified. The allowable depletion is determined by the following:

$$W_{ad} = W_{pad} \cdot W_{max}$$

where W_{ad} is the allowable soil water depletion (mm), W_{pad} is the percent allowable soil water depletion, and W_{max} is the maximum available soil water content (mm). With soil layer values for W_{max} and a model for root development, W_{max} is then calculated. The maximum available soil water content is determined for each soil layer as follows:

$$W_{max,i} = (\theta_{de,i} - \theta_{wp,i}) \Delta z_i / 100$$

where θ_{de} is the drainage equilibrium soil water content (%), θ_{wp} is the permanent wilting point soil water content (%), Δz is the thickness of the soil layer (mm), and the subscript i refers to the soil layer number. Both θ_{de} and θ_{wp} are expressed in percent by volume. The maximum available soil water content for the rootzone is calculated by summing up the $W_{max,i}$ values. A fraction of the lowest soil layer may be needed to determine W_{max} for the exact depth of the rootzone.

The rootzone model for annual crops before effective full cover assumes that the roots develop from a minimum value at emergence to a maximum at effective full cover at a rate that is similar to the increase in the basal crop coefficient, as follows:

$$z_r = z_{r,min} + \frac{k_{cb} - k_{cb,e}}{k_{cb,fc} - k_{cb,e}} (z_{r,max} - z_{r,min})$$

where z_r is the rootzone depth (cm), $z_{r,min}$ is the minimum rootzone depth at planting, $z_{r,max}$ is the maximum rootzone depth at effective full cover, and the subscript e refers to emergence and fc refers to effective full cover. The minimum rootzone is assumed to be 15 cm and the maximum depends on the crop. For annual crops after effective full cover and for perennial crops, the rootzone depth is as follows:

$$z_r = z_{r,max}$$

If the soil has a limiting barrier to root development, then the rootzone depth is not allowed to exceed this limit.

CHAPTER 5

EXAMPLE OF THE IRRIGATION SCHEDULING COMPUTER PROGRAM

Four separate computer files have been written for the Ultuna RC-8000 computer system. The first file is the irrigation scheduling computational program called BEVATTNING and is written in FORTRAN language. The second file is the needed data file called DBEVATTNO with input values given in a free-format style. The number at the end indicates that the data file is updated as the season progresses. The third file is called JBEVATTN and consists of the job control statements needed to link the program with the data file and then run the program BEVATTNING. The fourth file, called LBEVATTN, is a listing of needed input data and variable definitions. This final file is only for record keeping. Listings of BEVATTNING and JBEVATTN are given in Appendix D.

This chapter gives an example of program operation and calculation for an irrigated potato field at Kungshamn (near Ultuna) in 1970. Input data, output results, and preparation for the next run are presented for a sample ten day period in June. The examples mentioned are given in Appendix E.

Required Data

The input data is broken into four subgroups: 1) program control data, 2) regional data, 3) climatic data, and 4) farm data. Example 1 gives the contents of the input data file, DBEVATTNO, for the period June 1 to June 10, 1970. Appendix B gives a listing of file LBEVATTN which summarizes the definitions of each variable in the input data file.

Program Control Data

The first line of DBEVATTNO is the program control data. This is the number of regions (1), the computational date (162), the computational year (1970), and the print control switch (0). Note that in freeformat style only a space is necessary between each variable. In LBEVATTN under the variable S1, four print options are given. This allows choice from a summary printing to a detailed day by day printout. Example 2 gives a sample of a daily printout (S1=3) and Example 3 gives a summary printout (S1=0).

Regional Data

The second line of DBEVATTNO in Example 1 is the start of a seventeen line group that makes up the regional data. The first line is the region name (ULTUNA) which is usually the same as the weather station used. The number of letters possible in alphanumeric names is given in Appendix B in the LBEVATTN file. Spaces are of no importance for alphanumeric entries. The next line consists of weather station information, mainly elevation (15), latitude (59.82), and windspeed measurement height (8.5). The units associated with each number are given in the LBEVATTN file. The region is defined by the area over which the weather data from one station can be used.

The next three lines are equation coefficients that are derived from past records of the weather station. The equations are to fit curves of expected grass reference crop ET, expected precipitation, and clear sky solar radiation. All of which are with respect to the time of the year. If past data is not available, then curves must be assumed until several years of weather data is collected. The derived relations for Ultuna are as follows:

expected grass reference crop ET

$$\overline{ET}_{rg} = 3.1 \exp\left(-\left(\frac{J - 166}{\Delta t}\right)^2\right)$$

if $J \leq 166$, then $\Delta t = 70$

if $J > 166$, then $\Delta t = 98$

expected precipitation

$$\overline{P} = 0.5687 - 3.9E\text{-}3\ (J) + 1.183E\text{-}4\ (J)^2 - 3.08E\text{-}7\ (J)^3$$

clear sky solar radiation

$$R_{so} = 0.7595 - 4.488E\text{-}2\ (J) + 2.1569E\text{-}3\ (J)^2 - 1.1738E\text{-}5\ (J)^3 + 1.6994E\text{-}8\ (J)^4$$

Where scientific notation is required as for the expected precipitation coefficient -3.9E-3, then it is entered in the data file as -3.9'-3 as required by the ALGOL language program for freeformating available on the RC-8000 system.

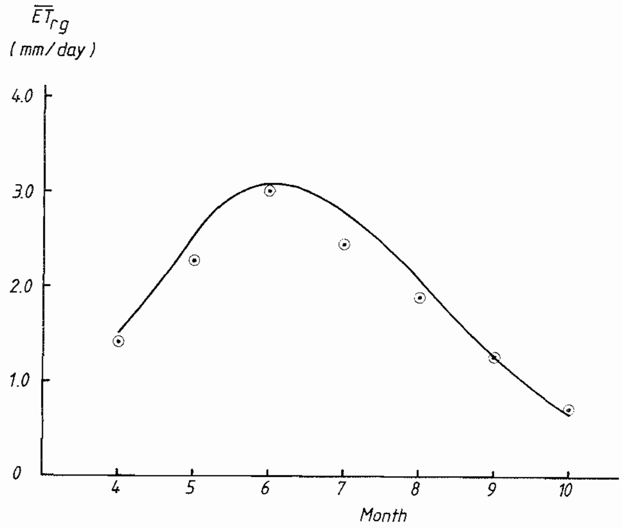


Fig. 5.1. Long-term grass reference crop ET ($\overline{ET}_{rg}$) for Uppsala as a function of time. The solid curve is from the normal equation and the circled points are historic 1961 to 1978 values.

The relation for $\overline{ET}_{rg}$ was developed, in a very approximate way, with data from Eriksson (1981). Long-term (1961-78) monthly Penman ET values were converted to $\overline{ET}_{rg}$. Figure 5.1 compares the data used to the derived normal equation. The regression for $\overline{P}$ was done with long-term (1885-1964) 15 day data from Håkansson et al. (1968). The r^2 value is 0.78 and visual comparison of the data with the regression curve is made in Figure 5.2. Clear sky solar radiation data in 1970 and 1971 were taken from "Meteorological Observations at Ultuna". An envelope curve is usually drawn after all the R_s data is plotted, but the availability of cloud cover data allowed selection of only R_{so} values. These are plotted along with a smooth curve fitted by hand through the points in Figure 5.3. The regression curve with an r^2 value of 0.997 was derived from the hand drawn curve. The regression analysis was done with the minitab statistical computing system available on the Ultuna FC-8000 computer. Polynomial regressions of various degrees were compared by their r^2 values.

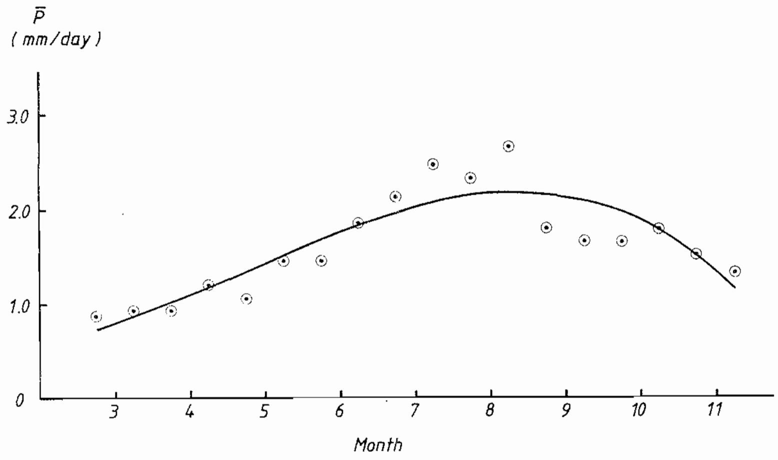


Fig. 5.2. Long-term precipitation ($\bar{P}$) for Uppsala as a function of time. The solid curve is from the polynomial regression equation and the circled points are historic 1885 to 1964 values.

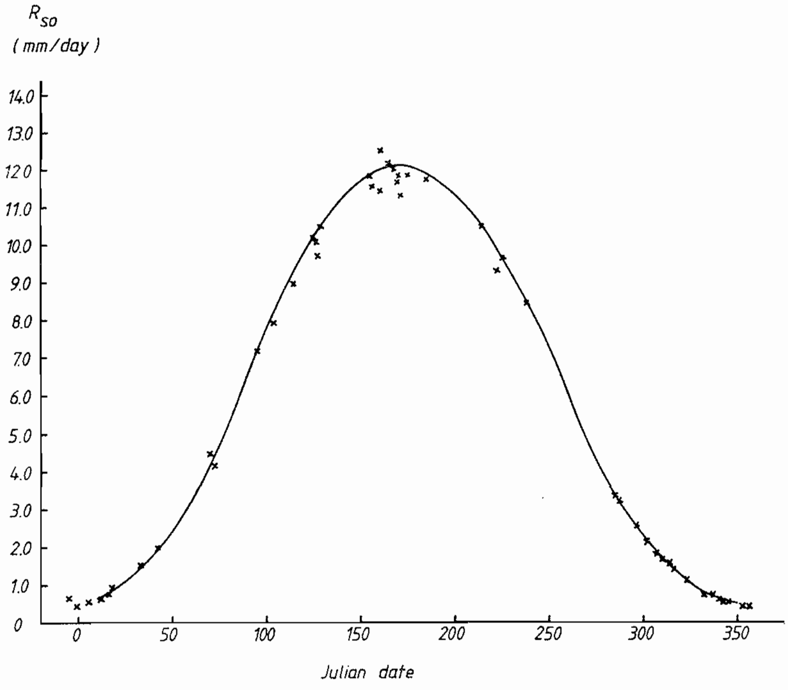


Fig. 5.3. Clear sky solar radiation (R_{so}) for Ultuna as a function of julian date. The solid curve is hand drawn through measured 1970 and 1971 values as indicated by crosses.

The next twelve lines contain long-term climatic data with one line for each month. Values are given at Ultuna for April to November. Long-term maximum relative humidity, windspeed, day to night wind ratio, and solar radiation have been obtained from Aniansson and Norén (1955). The maximum relative humidity was assumed to be at the 2100 reading. The day to night wind ratio is from the 1400 reading divided by the average of the 0800 and 2100 readings. These long-term values are used in the FAO Penman ET_{rg} method.

Climatic Data

This subgroup of input data is of a variable number of lines depending on the number of days of weather data for the program run. In Example 1, fourteen lines make up the climatic data with ten days of weather data. The first line in this group consists of only one value, the forecast grass reference crop ET for the next five days relative to the long-term or normal value. If conditions are expected to be cloudy where in a normal year sunny weather would occur, then the ET_{rg} value for the future five days can be reduced by the factor given. The next line gives a qualitative description of the future conditions. In Example 1 no change in the expected ET_{rg} equation value were made as indicated by the ratio of 1.0 and the qualitative description of "NORMAL CONDITIONS".

The following line gives the regional climatic condition. The starting date of the climatic data (152) is the first value. The three previous days, julian dates 149, 150, and 151, of air temperatures are given next (13.3, 15.0, and 13.9) for computation of soil heat flux in the Penman ET_{rg} method. Next, the starting date of the summations is given (121), then the seasonal summations of the Penman ET_{rg} method (111.42), FAO Penman ET_{rg} method (159.18), Johansson ET_{rg} method (84.46), and precipitation (4.5). These summations are up to day 151.

The following line contains the number of days of weather data (10) and the starting julian date (152). The starting julian date for the climatic data is required again so as to be a reminder to update the weather data with each run. The next ten lines in Example 1 contain the weather data for days 152 to 161. The first value is the julian date. This is followed by five air temperature readings at 0800, 1400, 1900, maximum, and minimum. Then three values of relative humidity and three of windspeed with readings for both at 0800, 1400, and 1900. Next is the solar radiation and the precipitation amount for the day. The weather data is from "Meteorological Observations at Ultuna".

Farm Data

In the two previous subgroups, regional data and climatic data, it is necessary to repeat the data lines if more than one region is being used. In this subgroup repetition occurs by farm-field combination. Example 1 shows only one farm-field combination, which is Kungshamn-K2. In Example 4 the data file listing of DBEVATTN4 (fourth sequential data file for the season) shows the complications of introducing another field on the Kungshamn farm, Kungshamn-K1, and two more farms each with one field, Lövsta-Lö and Ultuna-U12. The explanation that follows deals only with the simple case presented in Example 1. The farm-field data was taken from Johansson (1974).

The first line indicates the number of farms in the region (1). Each farm requires a variable number of data lines depending on the number of fields. Only one field is presented in Example 1 so eight lines are required for the farm. The first two lines are the farm name (KUNGSHAMN) and the number of fields (1). The next two lines contain the field name (K2) and crop name (POTATOES). The next four lines consist of basic field data, soil data, field irrigation data, and field condition.

The first item of basic field data is the crop number (4), which is defined under variable NCR in LBEVATTN and also in Table 5.1. The next four values are julian dates for planting (131), emergence (151), effective full cover (171), and harvest or final irrigation date (198). The next value is the starting julian date (132) for season summations of field rainfall, crop ET, and net irrigation amounts. This value probably matches the next julian date which is for the initial soil water depletion (132). This is followed by the initial soil water depletion for the maximum or limiting rootzone (7). The soil water depletion entry can be used later in the season to set the program depletion to a measured value. The next two values in the data line are the irrigation efficiency (80) and the minimum irrigation amount (15). Both of these would be determined from the irrigation method being used. The final three values consist of the minimum (15), maximum (60), and limiting (30) effective rootzone depths.

Table 5.1. List of crops that are part of the irrigation scheduling program.

Crop number	Crop
1	small grains
2	snap beans
3	peas
4	potatoes
5	sugar beats
6	corn
7	winter wheat
8	pasture (grazed grass, grass-legumes, or alfalfa)
9	clover or grass-legumes (cut)
10	grass (cut)
11	alfalfa (cut)

An extra data line is now required if the field has a perennial crop. This can be seen in the fields of pasture for farms Lövsta and Ultuna in Example 4. Space is provided for five cuttings. The julian date of the cutting and the following effective full cover is recorded for each cutting. For a perennial crop in the previous line, the emergence date becomes the start of growth and the harvest date becomes the end of growth. Tables 5.2 and 5.3 contain crop date information for annual and perennial crops, respectfully (Johansson, 1974).

Table 5.2. Crop date information from research at Ultuna for annual crops.

Crop	Days from ...		
	planting to emergence	emergence to effective full cover	effective full cover to harvest
small grains	10	20	87
potatoes	20	20	85

Table 5.3. Crop date information from research at Ultuna for perennial crops.

Crop	Days from ...			
	start of growth to effective full cover	effective full cover to cutting	cutting to effective full cover	effective full cover to end of growth
pasture	14	45	5	50
grass (cut)	14	20	5	25

The soil data allows five pairs of values for each soil layer. The values are depth to the lower boundary and maximum available soil water. For field K2 a drainage equilibrium of 0.7 meter was used to determine the maximum available soil water by Johansson (1974).

The field irrigation data includes the percent allowed soil water depletion (50), the allowed soil water depletion (0), the julian date of the previous irrigation (0), and the previous net irrigation amount (0). The option is available to use either a percent allowable depletion or an allowable depletion value. The one that is not used is given a zero value. The previous irrigation values also have zero values since an irrigation has not yet occurred. The last fifteen values of this data line are the rain and/or irrigation amount differences. The difference between the field and the region precipitation amounts are entered for each day. If irrigation amounts occur quite often, then entry of these values is also possible.

The field condition is the final data line for the field. Values are given for the soil water depletion (14.80) and the past three days of adjusted rain and/or irrigation amounts (0, 0, and 0.7). Season summations from the date indicated in the basic field data line (132) to day 151 are given for field values of rainfall (2.3), crop ET (13.60), and net irrigation amounts (0). The adjusted rain and/or irrigation amounts are used to compute the crop coefficient related to a wet surface. The rain and/or irrigation amount has been adjusted downward by the increase in ET due to this coefficient.

Program Calculations

The results of running the BEVATTNING program with the DBEVATTNO data file are given in Example 2 for a complete printout and in Example 3 for a summary printout. The listing JBEVATTN contains the commands for the RC-8000 computer system to run the program. The printout in Example 2 is discussed in five sections: 1) input data, 2) weather data, 3) grass reference crop ET, 4) field soil water depletion calculations, and 5) irrigation scheduling.

Input Data

At the beginning of Example 2, the first data input line is printed with an explanation for each variable. This is also done for the regional, climatic, and farm input data. Some arrays that are read internal to the program are also printed out, since these are input data as well. Where the array name is used, the definition may be found in LBEVATTN.

Weather Data

The computation date (11 JUN 1970) is the day when the program is run. The weather data for this day is not yet available. The weather data is printed in the original form and after being converted to the format usable in calculation of ET_{rg}. The mean values of air temperature, relative humidity, windspeed, and solar radiation are also printed for the update period from day 152 to 161.

Grass Reference Crop ET

Printouts are done for submodel and each of the three ET_{rg} method calculations. A summary printout is also made of the ET_{rg} results. In the submodel printout the air vapor pressure (e_a) and the saturation vapor pressure (e_a') are given. Also, the deficit air vapor pressure which is the difference between e_a' and e_a. The Penman weighting function (W) is also given and its needed values of the psychrometric constant (γ), the slope of the saturation vapor pressure curve (Δ), and the latent heat of vaporization (L). The calibrated Penman printout includes soil heat flux (G), net radiation (R_n), and the wind function ($f_{u,P}$). The soil heat flux when negative indicates heat flow from the soil. Components of R_n include the clear sky solar radiation (R_{so}), the ratio of solar to clear sky solar radiation ($R_{s/so}$), clear sky atmospheric emissivity (ϵ_{ao}), and atmospheric emissivity (ϵ_a). Both the original 1948 Penman equation and the calibrated Penman ET values are printed. The FAO Penman method printout includes net radiation and the wind function term. Net radiation is estimated by using extra-terrestrial radiation (R_a). Components of R_a are the declination of the sun (δ), the sunset hour angle (h_s), daytime hours at zero declination (h_{do}), and the radius vector of the earth (r_{ve}). The adjustment factor (c) and the final FAO Penman ET_{rg} value are also printed. For the Johansson method, solar radiation, windspeed, air vapor pressure deficit and the ET_{rg} value are printed. The summary printout contains the three ET_{rg} values plus precipitation. Daily, period. and season values are given. The forecast or expected ET_{rg} for the next five days is also printed.

Field Soil Water Depletion Calculations

The daily soil water depletion and calculated values are printed to enable a check of program operation. The components of the water balance equation: initial depletion, crop ET, precipitation, and irrigation are given for each day. The variables used to compute crop ET are the time scale, the percent from minimum to maximum basal crop coefficient, the rootzone depth (z_r), the maximum available soil water (W_{max}), the percent available soil water (W_a), and the grass reference crop ET (ET_{rg}). The time scale is percent time from emergence to effective full cover or days after effective full cover. Four crop coefficients are printed which are the basal crop coefficient (k_{cb}), the crop coefficient related to available soil water (k_a), the crop coefficient related to a wet surface (k_s), and the composite crop coefficient (k_c). The initial (W_{i-1}) and final (W_i) soil water depletion values are listed for each day. The allowable soil water depletion (W_{ad}) is also printed.

In Example 2 for field K2, the depletion exceeds the allowed amount on day 160. Note the changing values of allowable depletion for days 152 to 156 which reflects the increasing rootzone. Another aspect of the field soil water depletion calculations is illustrated in Example 5. The same field is used but ET_{rg} is computed by the Johansson method. The soil water depletion does not exceed the allowable depletion during the update period from day 152 to 161. So the irrigation date is still sometime in the future. Forecasting is done with no precipitation and with expected precipitation ($\overline{P}$) during the future. In Example 5, the daily depletions are printed for each of these two predictions. The output stops when the allowable depletion has been exceeded or at the harvest or final irrigation date. Some columns are missing to indicate that the variables are not being used. The expected precipitation is added each day and, as shown in the example, this sets the predicted irrigation date back five days as compared to the no rain condition.

Irrigation Scheduling

This section of the printout provides the essential information for irrigation scheduling. The farm name and computation date is given for record keeping. The fields for the farm are then listed. In Example 2 only field K2 is shown. The crop name is given with current and allowed values of the soil water depletion. The forecast crop ET and k_c values are printed to allow adjustment of the schedule if rain or irrigation should occur before irrigation begins. The predicted irrigation dates without and with rain in the future are given. The irrigation amount for the predicted irrigation date without rain is printed. Expected precipitation and expected ET_{rg} information are also given.

Preparation for the Next Computer Run

The conclusion of the printout includes required input data from the present computer run, which assists in preparations for the next irrigation schedule update. The regional climatic data replaces line number 210 in Example 1. The field condition replaces line number 410. The lines are printed to allow direct replacement in creating the next runs data file.

Referring again to Example 1, changes need to be made in several other lines for the next run. Line 10 requires a new computation julian date. The regional quantitative and qualitative forecasts in line 190 and 200, respectively, may need updating. The weather data from line 220 to 320 must also be changed. The field irrigation data for each field requires new information on irrigation and precipitation events. The difference between the field and region precipitation amounts will need to be entered carefully to place the values on the correct days. This field irrigation data in Example 1 for field K2 is on line 400.

If soil water measurements are made in the field, then the program soil water depletion can be set to the measured value in the basic field data, as shown in line 380. If the crop development in the field is noted to be different than the programs value, then the date of effective full cover can also be adjusted in line 380.

Example of Program Calculations

Measured soil water depletion data from research fields near Ultuna are presented by Johansson (1974). Two fields in 1970 are used as examples of the irrigation scheduling computer program calculations.

Two potatoe fields at Kungshamn had irrigations scheduled by the farmer. The first field K1 has a very low maximum available soil water content of 25 mm in a 40 cm rootzone. The second field K2 has a greater W_{max} value of 51 mm in a 30 cm rootzone, but has a shallow water table of 67 cm throughout the season. Both fields have rootzones that are limited due to soil profile conditions. The time from planting to harvest is only about 70 days as the potatoes were harvested early. The daily program calculated values of

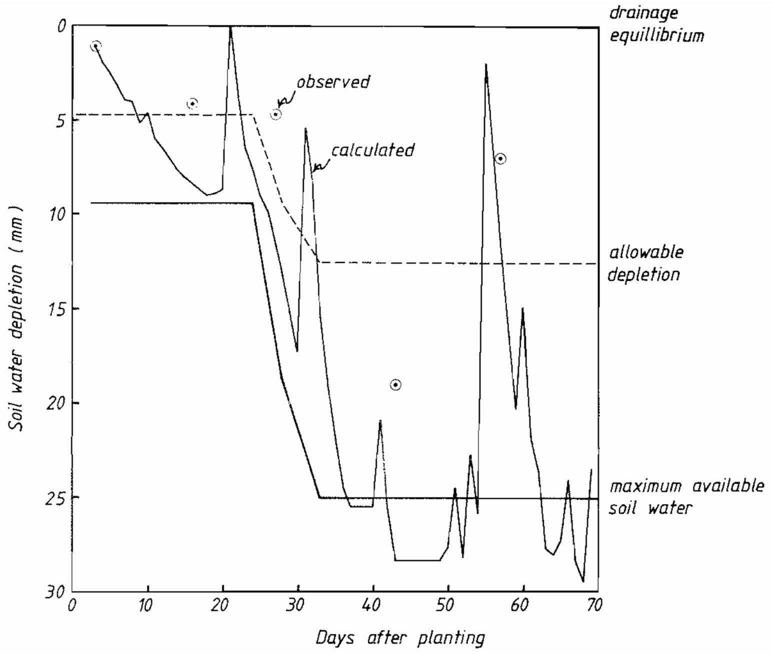


Fig. 5.4. Daily calculated (calibrated Penman ET_{rg}) and observed soil water depletion values for field Kungshamn-K1 with potatoes in 1970. Allowable depletion and maximum available soil water are also shown.

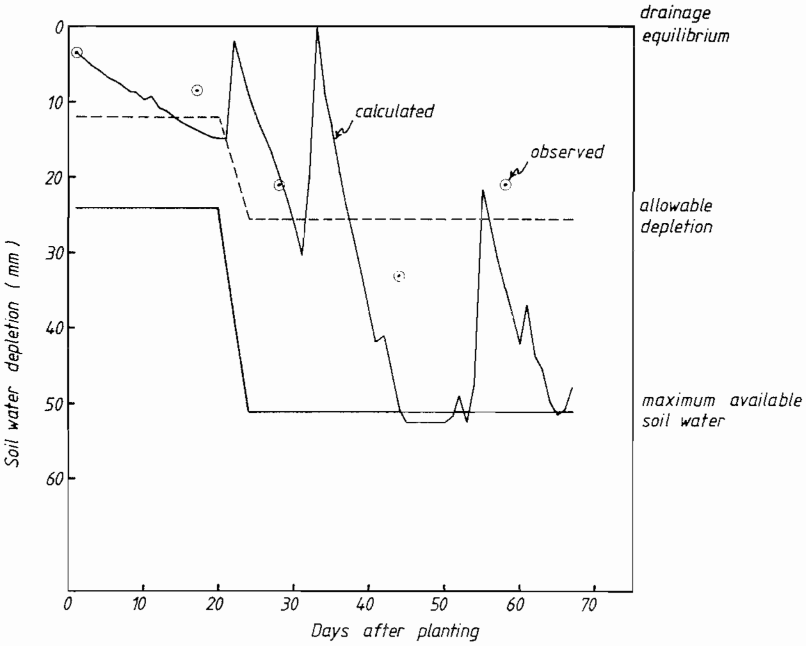


Fig. 5.5. Daily calculated (calibrated Penman ET_{rg}) and observed soil water depletion values for field Kungshamn-K2 with potatoes in 1970. Allowable depletion and maximum available soil water are also shown.

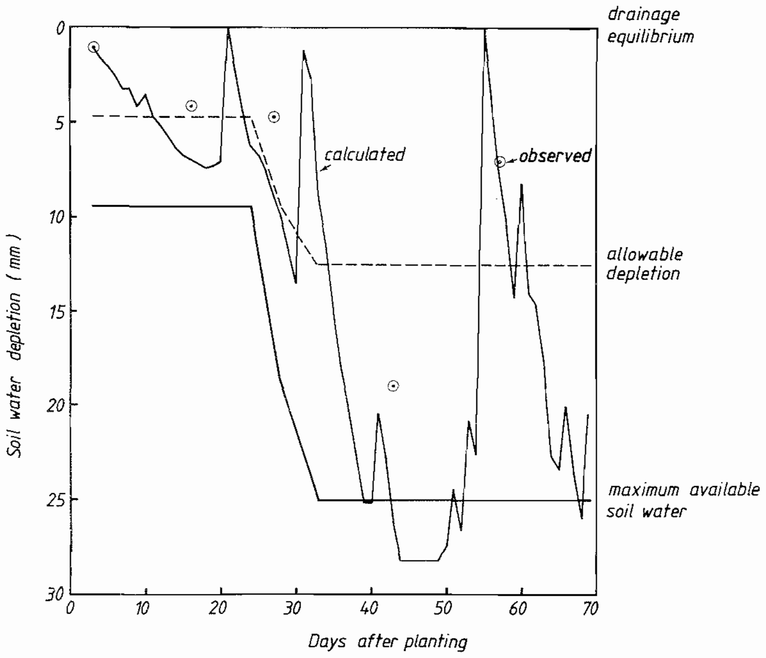


Fig. 5.6. Daily calculated (Johansson ET_{rg}) and observed soil water depletion values for field Kungshamn-K1 with potatoes in 1970. Allowable depletion and maximum available soil water are also shown.

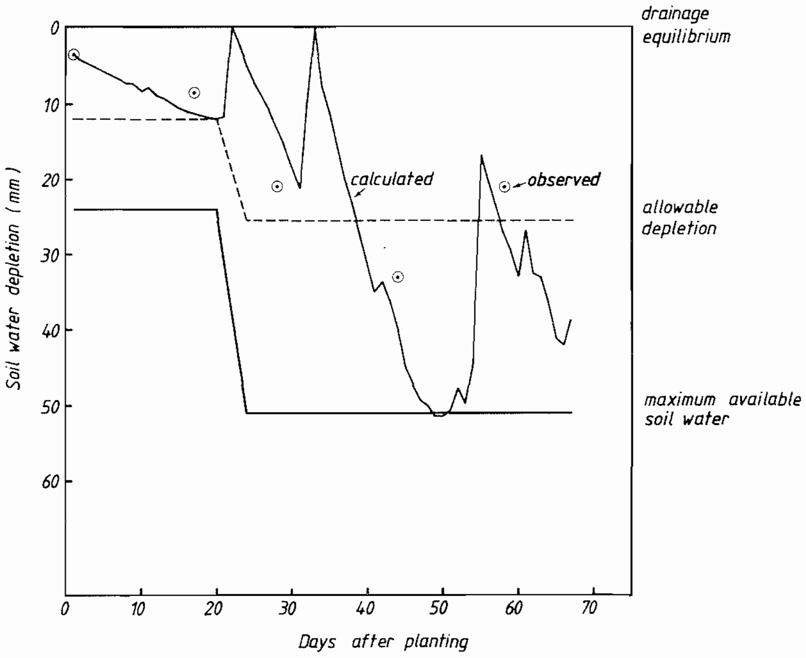


Fig. 5.7. Daily calculated (Johansson ET_{rg}) and observed soil water depletion values for field Kungshamn-K2 with potatoes in 1970. Allowable depletion and maximum available soil water are also shown.

Table 5.4. Comparison of calculated and observed soil water depletions for field Kungshamn-K1 with potatoes in 1970.

Date			Soil water depletion (mm)			Depletion change (mm)		
Calendar	Julian	Days after planting	Calculated		Observed 0 to 40 cm rootzone	Calculated		Observed 0 to 40 cm rootzone
			Calibrated Penman ET_{rg}	Johansson ET_{rg}		Calibrated Penman ET_{rg}	Johansson ET_{rg}	
May 15	135	3	1.1[a]	1.1[a]	1.1			
May 28	148	16	8.4	6.9	4.1	7.3	5.8	3.0
June 8	159	27	11.5	8.8	4.7	3.1	1.9	0.6
June 24	175	43	28.3	26.2	19.0	16.8	17.4	14.3
July 8	189	57	11.5	7.4	7.0	-16.8	-18.8	-12.0

[a] initialized values

Table 5.5. Comparison of calculated and observed soil water depletions for field Kungshman-K2 with potatoes in 1970.

Date			Soil water depletion (mm)			Depletion change (mm)		
Calendar	Julian	Days after planting	Calculated		Observed 0 to 30 cm rootzone	Calculated		Observed 0 to 30 cm rootzone
			Calibrated Penman ET_{rg}	Johansson ET_{rg}		Calibrated Penman ET_{rg}	Johansson ET_{rg}	
May 12	132	1	3.5[a]	3.5[a]	3.5			
May 28	148	17	13.7	11.2	8.5	10.2	7.7	5.0
June 8	159	28	19.7	13.3	21.0	6.0	2.1	12.5
June 24	175	44	50.7	40.1	33.0	31.0	12.0	12.0
July 8	189	58	34.8	27.0	21.0	-15.9	-12.0	-12.0

[a] initialized values

soil water depletion are presented in Figures 5.4 and 5.5 for fields K1 and K2, respectively. The observed depletions are also plotted. The calibrated Penman ET_{rg} value is used in these calculations. Figures 5.6 and 5.7 show the calculated depletions when the Johansson ET_{rg} values are used. Comparison of the calculated and observed depletions is done in Tables 5.4 and 5.5 for fields K1 and K2, respectively. The depletion change between measurement dates is also given.

Examination of Figures 5.4 through 5.7 shows areas where the program calculations deviate from the measured values. Early in the season before emergence, the soil evaporation is overpredicted regardless of the ET_{rg} method chosen. In Figure 5.4 for field K1, the July 8 measurement (57 days after planting) compares well to the calculated value. Similarly in Figure 5.5 for field K2, the June 8 measurement (28 days after planting) also compares well. Similar statements can be made concerning Figures 5.6 and 5.7, but with the limited number of soil water depletion observations no conclusions on program performance can be made. Also special conditions of the two fields is that K1 has a low water holding capacity and K2 has a shallow water table complicates any comparison between the program results and the measured data.

In Figures 5.4 to 5.7, the allowable depletion and maximum available soil water levels are also illustrated. Note the rapid rootzone development. The crops in both fields appear to be water stressed for a major portion of the season as the calculated and observed depletions fall below the allowable depletion.

CHAPTER 6

RECOMMENDATIONS TOWARD DEVELOPMENT OF AN IRRIGATION SCHEDULING SERVICE IN SWEDEN

The irrigation scheduling computer program presented in this paper is the first step in providing direct assistance with irrigation management for farmers in Sweden. This also applies for use of the model for simulation or forecasting in irrigated research trials. In this chapter the possible future development of the computer program is discussed. Recommendations are given toward modification of program operation and of the scheduling model. The eventual goal may be the realization of an irrigation scheduling service in Sweden. Practices in the western United States, as presented in earlier chapters, illustrate how a scheduling service gains experience in an area with using the computer program and with farmers needs. Recommendations are given on how a scheduling service might function in Sweden.

Irrigation Scheduling Computer Program

The present computer program could be made easier to operate, both in input of data and output of results. The present data input uses a freeformat subroutine particular to the Ultuna RC-8000 computer system. This is an improvement over the original program which used formated input developed for punched cards. An interactive data entry mode on a remote terminal could further improve the creation and updating of data files. If interactive, the computer program could stop and ask a question when data is required. This allows non-technical persons to operate the program.

The input data is presently placed in one data file. This could be replaced by separate data files for regional, climatic, and farm data. Interactive programs for entry of new data into the correct file could be written. Programs to display the data for checking would also be necessary. These separate data files would enable scheduling of one farm or field. In actual scheduling conditions operating on a real time basis, the needed data and field checks may not be available on a definite time interval to allow the running of all scheduled fields at one time. The computer program has only been tested with past historic data. For real time situations the program needs to be both convenient and flexible in operation.

The irrigation scheduling printout must match the farmers needs. Some explanation of the output will be necessary, but perhaps the wording or presentation could be made clearer. The English wording must be converted to Swedish. The farmers may require calculation of operating hours for the fields irrigation system. If precipitation occurs before the predicted irrigation date, the farmer needs to change the schedule. The delay in the irrigation date in response to various precipitation amounts could be printed. The field may need to be separated into irrigation sets to accomplish accurate scheduling under variable rainfall conditions.

The present version of the scheduling program may need to be changed considerably to meet the demands of the scheduling service and the farmers. The model may also need changes to better represent actual field conditions. The basic calculation approach of crop ET, with the use of a reference crop ET estimated from weather data and an empirical crop coefficient, has functioned well for irrigation scheduling in the western United States. Verification of the model is necessary with measured soil water depletion data for irrigated fields in Sweden. Modifications may then be required to the empirical relations used in computation of ET_{rg} and ET.

In Chapter 4, grass reference crop ET is computed with three different methods. Because of the lack of measured ET_{rg} data in Sweden, some flexibility in choise of ET_{rg} is given to the program user. The calibrated Penman method can be modified with local data. The Johansson method may prove to be the best temporary method for Sweden. The FAO Penman method may be valuable if the program is used outside of Sweden.

The basal crop coefficient curves may need to be adjusted for Swedish climatic conditions and suggestions have been given in Chapter 4. Information on crop stages is essential for first year operation of the program. A growth related rather than a time related scale for determination of k_{cb} could be developed. Refinement of the k_{cb} curves can be made by the scheduling service from the monitoring soil water measurements, but this may lead to the k_{cb} curves becoming correction factors for errors elsewhere in the model. The WPRS concept of reference fields where data collection is concentrated on selected fields may provide better quality data. Daily values of crop ET from a weighing lysimeter is the best way to derive the k_{cb} curves.

The exclusion of drainage and capillary rise from the water balance equation may be one source of error. Deep percolation below the rootzone is assumed negligible when the soil water content is at the upper limit of the maximum available soil water content. The upper limit in the presence of a water table is the drainage equilibrium. In the absence of a water table, the upper limit is often taken as the field capacity. Miller and Aarstad (1971) found that the time after an irrigation to sample for the field capacity is affected by ET rates, soil properties, and initial penetration depth of the irrigation water. So the time after an irrigation or precipitation event where the soil water depletion starts at zero is not easily specified. Stegman et al. (1980) suggested that the drainage amount should be calculated for each day until negligible, meaning less than or equal to 0.1 mm/day. Relations to compute drainage are available, such is given by Jensen (1972), but must be calibrated for each soil profile. Jensen (1972) also presented an equation for computation of the upward flow from a water table. Similarly, parameters in this relation must also be derived for each soil profile.

In the original scheduling program, the allowable depletion was an input value and determined by experience with each field. Field calibration enabled the allowable depletion to act as a calibration factor for the entire model. It is difficult to specify the allowable depletion without some previous experience, because of the need to consider the crop, rootzone development, and soil type. The use of percent allowable depletion, as presented in Chapter 4, simplifies determination of the allowable depletion. Still the uncertainties in the upper and lower limits of the maximum available soil water need to be considered.

The reduction in crop ET as soil water content decreases is represented by a logarithmic function. The relation for k_a is given in Figure 4.16. Often k_a is represented by a two stage relation. From zero to a critical soil water depletion, k_a has a value of 1.0. After the critical depletion, k_a decreases linearly to a value of zero at the lower limit. The selection of the critical depletion defines this relation for k_a. Since reduction of ET limits crop yield, the critical depletion is the same as the allowable depletion. Slabbers (1980) presented a relation to determine the critical depletion which is dependent on soil and plant characteristics, and the ET rate. This type of model for k_a and the allowable depletion is a possible improvement for the scheduling program.

Irrigation Scheduling Service

Jensen (1975) made the important conclusion that improved irrigation water management depends on a service approach to the farmer. Past experience with providing the farmer with technical knowledge or measurement devices have largerly proved ineffective. The USDA irrigation scheduling program was developed and has proved successful for this reason.

In Chapter 4, two large-scale irrigation scheduling efforts were reviewed. The WPRS provides scheduling services to irrigation districts and the Nebraska AGNET system to extension personnel or farmers directly. The WPRS uses the incentive of financial support to demonstrate the operation and perhaps benefits of better irrigation water management. The AGNET system provides a convenient and easy to use service that is handled by extension agents with good contact to farmers. Either approach appears possible for Sweden.

The WPRS approach has the advantage of being better able to adapt to new situations. As stated earlier the computer program presented in this report is a tool that requires experience and perhaps modification for proper use. In reviewing the development of a scheduling service by WPRS for the El Dorado irrigation district (EID), the service changed with time. This was in response to increases technical knowledge of the area and better understanding of the farmers needs. Confidence of the farmers appears to be essential and this is achieved with good communication between the service and farmer.

The scheduling techniques for EID progressed from soil water measurements with the neutron probe to calculations by the WPRS scheduling program. The neutron probe continues to be used to refine and check the accuracy of program results. Technical knowledge concerning the field capacity, allowable depletion, and crop water requirements for scheduled fields increased with time. The method of communication with the farmer changed from graphical to irrigation dates to computer printouts. Confidence by the farmers in using the irrigation recommendations improved. Education, reliability of service, and experience of the service personnel add to farmer confidence. The EID scheduling service was started during the severe drought years of 1976 and 1977 in California. In 1981, the future of the service was not certain because of doubts about farmer willingness to take financial responsibility for the service.

The Nebraska AGNET approach is an alternative to the direct WPRS service. The main benefit of a computer network is in education of the user. The irrigation scheduling program could be one of many available programs. The scheduling program could be similar to the one presented in this report or be of a simpler nature requiring soil water measurements as input data. The user would learn and hopefully gain motivation towards rational irrigation scheduling.

Regardless of whether the WPRS or AGNET approach are used in Sweden, the intensity of irrigation scheduling must also be decided. Watts (1976) presented three scheduling levels:

1) soil water measurement
2) water use information plus soil water monitoring
3) scheduling service using computer calculations plus soil water monitoring.

The WPRS provides an irrigation guide service that gives average irrigation dates for an area, but field measurements are not made. Perhaps in Sweden all three scheduling levels must by tested to find the approach that gives the best results. Results which show the farmers follow improved water management practices.

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APPENDIX A

List of Symbols

Symbol	Description
ADJ	adjustment factor for ET
a	linear regression coefficient, y-axis intercept
a_c	linear regression coefficient for the calibrated Penman ET_{rg} method (mm/day)
a_d	desired accuracy (%)
a_s	crop albedo
a_o to a_4	coefficients for the polynomial regression equation for R_{so}
b	linear regression coefficient, slope of line
b_c	linear regression coefficient for the calibrated Penman ET_{rg} method
C_t	Jensen-Haise ET estimation method coefficient
c	FAO Penman ET method adjustment factor
c_c, c_s	factors used in the WPRS calculation of W_{ad}
c_s	empirical, specific heat coefficient (mm/day)/°C
c_u	windspeed height adjustment coefficient
c_1 to c_4	coefficients for the Modén air temperature equation
D	drainage loss from the rootzone or capillary rise from a water table (mm/day)
E	field irrigation efficiency (%)
E_J	evaporation by an Andersson evaporimeter as estimated by the Johansson method (mm/day)
ET	evapotranspiration (mm/day)
ET_{JH}	Jensen-Haise method ET (mm/day)
ET_P	Penman method ET (mm/day)
ET_{P-FAO}	FAO Penman method ET (mm/day)
ET_{ra}	alfalfa reference crop ET (mm/day)
ET_{rg}	grass reference crop ET (mm/day)
$\overline{ET}_{rg,max}$	coefficient for expected ET_{rg} equation
e_a	air vapor pressure (mbar)
e'_a	saturation air vapor pressure (mbar)
f_u	Penman wind term (mm/day)/mbar
G	soil heat flux (mm/day)
h	altitude (m)
h_{do}	daytime hours at zero declination (hr)
h_s	sunset hour angle (deg)
I	irrigation amount (mm)

I_n	net irrigation amount (mm)
J	julian date, which is the days after January 1
k_a	crop coefficient related to available soil water
$k_{a/g}$	conversion factor from an alfalfa to a grass reference crop
k_c	crop coefficient
k_{cb}	basal crop coefficient
k_s	crop coefficient related to a wet surface
k_t	thermal conductivity (cm mm/day)/^{o}C
k_1, k_2	coefficients in the k_s equation
L	latent heat of vaporization (J/kg_w)
N_s	slow neutron count rate in a standard absorber
N_w	slow neutron count rate in the soil
n	number of soil water measurement sites
P_a	air pressure (mbar)
P_e	effective precipitation (mm)
q	water flow (cm/hr)
RD	root decimal, which is the ratio of the soil water depletion rate in the top 30 cm to that of the entire measurement depth
RH	relative humidity (%)
R_a	extra-terrestrial radiation (mm/day)
R_s	solar radiation (mm/day)
R_n	net radiation (mm/day)
R_{so}	clear sky solar radiation (mm/day)
$R_{s/so}$	ratio of solar to clear sky solar radiation
r	resistance to flow (hr)
$\bar{r}$	long-term day to night windspeed ratio
r^2	coefficient of determination
r_{ve}	radius vector of the earth
SET	allowable soil water depletion from the top 30 cm of soil (mm)
T_a	air temperature (^{o}C)
T_p	mean air temperature for the previous three days (^{o}C)
T_x	Jensen-Haise ET estimation method coefficient
t	days after rain or irrigation
t_{max}	coefficient for expected ET_{rg} equation
u	windspeed (m/s)
$\bar{u}_{day}$	long-term daytime windspeed (m/s)
W	Penman weighting function
W_a	percentage of available soil water,
W_{ad}	allowable soil water depletion (mm)

W_d	weight of the soil sample after drying (g)
W_J	soil water depletion on day J (mm)
W_{max}	maximum available soil water content (mm or mm/mm)
W_{pad}	percent allowable soil water depletion
W_w	weight of the soil sample at wet or field condition (g)
z	windspeed measurement height (m)
z_r	rootzone depth (cm)

Subscripts

calc	calculated
de	drainage equilibrium
e	emergence
FAO	Food and Agriculture Organization of the United Nations and referring to Doorenbos and Pruitt (1977)
fc	effective full cover
i	soil layer
max	maximum
meas	measured
min	minimum
min1 to min2	$k_{cb,min}$ values for the three points indicated in Figure 4.15
p	planting
wp	permanent wilting point
8	reading at 0800
14	reading at 1400
19	reading at 1900

Superscripts

$'$	saturation vapor pressure
—	long-term value

Miscellaneous

δ	declination of the sun (deg)
Δ	slope of the saturation vapor pressure curve (mbar/^{o}C)
ΔT	temperature difference for the soil heat flux equation (^{o}C)
Δt	coefficient for the expected ET_{rg} equation (days)
Δz	soil layer thickness (mm)
Φ	latitude (^{o}N)
γ	psychrometric constant (mbar/^{o}C)
ϵ_a	atmospheric emissivity

ϵ_{ao}	clear sky emissivity
ϵ_s	surface emissivity
ρ_b	dry bulk density of the soil (g_s/cm^3)
ρ_w	density of water (g_w/cm^3)
σ	Stefan-Boltzmann constant (mm/day)/^oC or standard deviation of the soil water measurements (%)
Ψ	water potential (cm or bar)
θ	soil water content (cm^3/cm^3 or %)
λ	coefficient in the k_s equation

APPENDIX B

Computer Program Variable Definitions, LBEVATTN Listing

```
 10 C     USERS GUIDE FOR PROGRAM BEVATTNING
 20 C
 30 C     PROGRAM BEVATTNING IS AN IRRIGATION SCHEDULING PROGRAM ADAPTED
 40 C     TO SWEDISH CONDITIONS.  THE ORIGINAL PROGRAM, IRRIGATE, WAS
 50 C     WRITTEN BY JENSEN, WRIGHT, AND PRATT OF THE AGRICULTURAL RESEARCH
 60 C     SERVICE.  IT WAS UPDATED AND REVISED WITH HEERMANN IN APRIL 1971
 70 C     FOR A TIME SHARING SYSTEM.  THE PROGRAM WAS ADAPTED TO AN IBM 370
 80 C     SYSTEM AND CARD INPUT BY D. H. FOURTIER, 1975, AT THE UNIVERSITY
 90 C     OF IDAHO.
100 C
110 C     THE PROGRAM IS DESCRIBED (BASIS AND USE OF) IN THE FOLLOWING
120 C     SELECTED REFERENCES:
130 C
140 C     JENSEN, M E, D C N ROBB, AND C E FRANZOY, "SCHEDULING IRRIGATIONS
150 C     USING CLIMATE-CROP-SOIL DATA," ASCE J IRR & DRAIN DIV, VOL 96,
160 C     NO IR1, PAPER 7131, MARCH 1970, PP 25-38.
170 C
180 C     JENSEN, M E, J L WRIGHT, AND B J PRATT, "ESTIMATING SOIL MOISTURE
190 C     DEPLETION FROM CLIMATE , CROP AND SOIL DATA," TRANS ASAE, VOL 14,
200 C     NO 5, 1971, PP 954-959.
210 C
220 C     JENSEN, M E, "PROGRAMING IRRIGATION FOR GREATER EFFICIENCY,"
230 C     OPTIMIZING THE SOIL PHYSICAL ENVIRONMENT TOWARD GREATER CROP
240 C     YIELDS, D HILLEL, ED, ACADEMIC PRESS, INC, NEW YORK, 1972,
250 C     PP 133-161.
260 C
270 C     WRIGHT, J L AND M E JENSEN, "PEAK WATER REQUIREMENTS OF CROPS IN
280 C     SOUTHERN IDAHO," ASCE, J IRR & DRAIN DIV, VOL 98, NO IR2, PAPER
290 C     8940, JUNE 1972, PP 193-201.
300 C
310 C     HEERMAN, D F, H H SHULL, AND R H MICKELSON, "CENTER PIVOT DESIGN
320 C     CAPACITIES IN EASTERN COLORADO," ASCE, J IRR & DRAIN DIV, VOL 100,
330 C     NO IR2, PAPER 10588, JUNE 1974, PP 127-141.
340 C
350 C     **********
360 C     BASIC PROGRAM LIMITS: 4 REGIONS, 15 NEW DAYS OF CLIMATIC DATA,
370 C     100 FIELDS (15 MAX PER FARM), AND 8 CROP TYPES.
380 C     **********
390 C
400 C     1.  PROGRAM CONTROL DATA (1 LINE)
410 C      1.A   NUMBER OF REGIONS AND COMPUTATION DATE
420 C               1...NREG-- NUMBER OF REGIONS
430 C               2...NDATE(1)--COMPUTATION JULIAN DATE
440 C                             DEFAULTS TO:  JSC(I)+N(I)
450 C               3...NDATE(2)--COMPUTATION YEAR
460 C               4...S1--PRINT CONTROL SWITCH
470 C
480 C     2.  REGIONAL DATA (ONE SET OF 17 LINES FOR EACH REGION)
490 C      2.A  REGION NAME
500 C            COL 1-20...REGION(I,K)--REGION NAME (DESCRIPTIVE)
510 C      2.B  WEATHER STATION INFORMATION
520 C               1...ELEV(I)--WEATHER STATION ELEVATION (M)
530 C               2...LAT(I)-- WEATHER STATION LATITUDE (DEGREES NORTH)
540 C               3...Z(I)--WINDSPEED MEASUREMENT HEIGHT (M)
550 C      2.C  EXPECTED GRASS REFERENCE CROP ET EQUATION COEFFICIENTS
560 C               1...ETRGM(I)--LONG-TERM MAXIMUM GRASS REFERENCE
570 C                             CROP ET (MM/DAY)
580 C               2...JM(I)--JULIAN DATE OF LONG-TERM MAXIMUM
590 C                          MAXIMUM GRASS REFERENCE CROP ET
600 C               3...DT1(I)--CONSTANT BEFORE JM(I)
610 C               4...DT2(I)--CONSTANT AFTER JM(I)
620 C      2.D  EXPECTED PRECIPITATION EQUATION COEFFICIENTS
630 C             1 TO 6...B(I,K)--POLYNOMIAL REGRESSION COEFFICIENTS
640 C      2.E  CLEAR SKY SOLAR RADIATION EQUATION COEFFICIENTS
650 C             1 TO 5...B1(I.K)--POLYNOMIAL REGRESSION COEFFICIENTS
660 C      2.F  LONG-TERM CLIMATIC DATA (1 LINE FOR EACH MONTH)
670 C               1...RHMAXL(I,L)--LONG-TERM MAXIMUM RELATIVE
680 C                                HUMIDITY (%)
690 C               2...UL(I,L)--LONG-TERM WINDSPEED (M/S)
700 C               3...RL(I.L)--LONG-TERM DAY TO NIGHT WIND RATIO
710 C               4...RSL(I.L)--LONG-TERM SOLAR RADIATION (MM/DAY)
720 C
730 C     3.  CLIMATIC DATA (ONE SET OF 4+NDAY LINES FOR EACH REGION)
740 C      3.A  REGIONAL QUANTITATIVE FORECAST DATA
750 C               1...FCT(I)--FORECAST GRASS REFERENCE CROP ET
760 C                           FOR NEXT 5 DAYS RELATIVE TO THE
770 C                           LONG-TERM VALUE
780 C      3.B  REGIONAL QUALITATIVE FORECAST DATA
790 C            COL 1-60...FORC(I,K)--WEATHER FORECAST (DESCRIPTIVE)
800 C      3.C  REGIONAL CLIMATIC CONDITION
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 810 C                     1...JSCP--STARTING JULIAN DATE OF CLIMATIC DATA
 820 C                               AS INDICATED BY PREVIOUS PROGRAM RUN
 830 C                     2...SHFT(I,1)--AIR TEMPERATURE, 3 DAYS BEFORE
 840 C                                    (DEGREES C)
 850 C                     3...SHFT(I,2)--AIR TEMPERATURE, 2 DAYS BEFORE
 860 C                                    (DEGREES C)
 870 C                     4...SHFT(I,3)--AIR TEMPERATURE, 1 DAY BEFORE
 880 C                                    (DEGREES C)
 890 C                     5...JRSUM--STARTING JULIAN DATE FOR SUMMATION OF
 900 C                                REGIONAL DATA
 910 C                                DEFAULTS TO:  JSC(I)
 920 C                     6...SUMPC(I)--SEASON SUMMATION OF GRASS REFERENCE
 930 C                                   CROP ET AS CALCULATED BY THE CALIBRATED
 940 C                                   PENMAN METHOD (MM)
 950 C                     7...SUMPF(I)--SEASON SUMMATION OF GRASS REFERENCE
 960 C                                   CROP ET AS CALCULATED BY THE FAO PENMAN
 970 C                                   METHOD (MM)
 980 C                     8...SUMJ(I)--SEASON SUMMATION OF GRASS REFERENCE
 990 C                                  CROP ET AS CALCULATED BY THE JOHANSSON
1000 C                                  METHOD (MM)
1010 C                     9...SUMR(I)--SEASON SUMMATION OF REGIONAL
1020 C                                  PRECIPITATION (MM)
1030 D      3.D  REGIONAL PROGRAM CONTROL DATA
1040 C                     1...N(I)--NUMBER OF DAYS OF NEW CLIMATIC DATA
1050 C                     2...JSC(I)--STARTING JULIAN DATE ASSOCIATED
1060 C                                 WITH CLIMATIC DATA
1070 C      3.E  DAILY CLIMATIC DATA (ONE LINE FOR EACH DAY)
1080 C                     1...JDATE(I,J)--JULIAN DATE
1090 C                     2...T08--AIR TEMPERATURE AT 0800 (DEGREES C)
1100 C                     3...T14--AIR TEMPERATURE AT 1400 (DEGREES C)
1110 C                     4...T19--AIR TEMPERATURE AT 1900 (DEGREES C)
1120 C                     5...TMAX--MAXIMUM AIR TEMPERATURE (DEGREES C)
1130 C                     6...TMIN--MINIMUM AIR TEMPERATURE (DEGREES C)
1140 C                     7...RH08--RELATIVE HUMIDITY AT 0800 (%)
1150 C                     8...RH14--RELATIVE HUMIDITY AT 1400 (%)
1160 C                     9...RH19--RELATIVE HUMIDITY AT 1900 (%)
1170 C                    10...U08--WINDSPEED AT 0800 (M/S AT HEIGHT Z(I))
1180 C                    11...U14--WINDSPEED AT 1400 (M/S AT HEIGHT Z(I))
1190 C                    12...U19--WINDSPEED AT 1900 (M/S AT HEIGHT Z(I))
1200 C                    13...RS--SOLAR RADIATION (LANGLEYS/DAY)
1210 C                    14...PRCP(I,J)--REGIONAL RAINFALL AMOUNT (MM)
1220 C
1230 C      4.  FARM DATA (ONE SET OF 1+2(NFARMS)+6(NFLD) FOR EACH REGION)
1240 C       4.A  FARM PROGRAM CONTROL DATA
1250 C                     1...NFARMS--NUMBER OF FARMS
1260 C       4.B  FARM INFORMATION (ONE SET OF 2+6(NFLD) LINES FOR EACH FARM)
1270 C        4.B1  FARM NAME
1280 C              COL 1-20...FARM(K)--FARM NAME (DESCRIPTIVE)
1290 C        4.B2  FIELD PROGRAM CONTROL DATA
1300 C                     1...NFLD--NUMBER OF FIELDS
1310 C        4.B3  FIELD DATA (ONE SET OF 6 LINES FOR EACH FIELD)
1320 C                 NOTE:  PERENNIAL CROPS WILL REQUIRE ADDITIONAL LINE
1330 C          4.B3A  FIELD NAME (3A4)
1340 C              COL 1-12...FIELD(K)--FIELD NAME (DESCRIPTIVE)
1350 C          4.B3B  CROP NAME (3A4)
1360 C              COL 1-12...CROP(K)--CROP NAME (DESCRIPTIVE)
1370 C          4.B3C  BASIC FIELD DATA
1380 C                     1...NCR--CROP NUMBER
1390 C                     2...JDP--JULIAN DATE OF PLANTING
1400 C                     3...JDE--JULIAN DATE OF EMERGENCE
1410 C                              IF PERENNIAL OR WINTER CROP, JULIAN DATE
1420 C                              OF START OF GROWTH
1430 C                     4...JDEFC--JULIAN DATE OF EFFECTIVE FULL COVER
1440 C                     5...JDH--JULIAN DATE OF HARVEST OR FINAL IRRIGATION
1450 C                              IF PERENNIAL CROP, JULIAN DATE OF END
1460 C                              OF GROWTH
1470 C                     6...JFSUM--STARTING JULIAN DATE FOR SUMMATION
1480 C                                OF FIELD DATA
1490 C                     7...JIN--JULIAN DATE OF INITIAL SOIL WATER
1500 C                              DEPLETION
1510 C                     8...WIN--INITIAL SOIL WATER DEPLETION FOR THE
1520 C                              MAXIMUM OR LIMITING ROOTZONE (MM)
1530 C                     9...E--IRRIGATION EFFICIENCY (%)
1540 C                    10...XMIN--MINIMUM IRRIGATION AMOUNT (MM)
1550 C                    11...RZMIN--MINIMUM EFFECTIVE ROOTZONE DEPTH (CM)
1560 C                    12...RZMAX--MAXIMUM EFFECTIVE ROOTZONE DEPTH (CM)
1570 C                    13...RZLIM--LIMITING MAXIMUM EFFECTIVE ROOTZONE
1580 C                                DEPTH (CM)
1590 C          4.B3CC  EXTRA DATA FOR PERENNIAL CROPS
1600 C               1 TO 10...JDC(NC,K)--PERENNIAL CROP JULIAN DATES
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1610 C                               K=1  CUTTING JULIAN DATE
1620 C                               K=2  EFFECTIVE FULL COVER JULIAN DATE
1630 C         4.B3D  SOIL DATA
1640 C              1 TO 10...AW(NS,K)--MAXIMUM AVAILABLE SOIL WATER ARRAY
1650 C                              K=1  DEPTH TO THE LOWER BOUNDARY OF
1660 C                                   THE SOIL LAYER (CM)
1670 C                              K=2  MAXIMUM AVAILABLE SOIL WATER OF
1680 C                                   THE SOIL LAYER (MM)
1690 C         4.B3D  FIELD IRRIGATION DATA
1700 C                    1...DPAP--PERCENT ALLOWED SOIL WATER DEPLETION (%)
1710 C                              NOTE:  IF DPAP IS GIVEN, THEN THE ALLOWED
1720 C                                     SOIL WATER DEPLETION IS COMPUTED
1730 C                                     FROM THE MAXIMUM AVAILABLE SOIL
1740 C                                     WATER.
1750 C                    2...DPA--ALLOWED SOIL WATER DEPLETION (MM)
1760 C                             NOTE:  IF DPA IS GIVEN REMEMBER THAT THE
1770 C                                    MAXIMUM AVAILABLE SOIL WATER CHANGES
1780 C                                    DEPENDING ON THE EFFECTIVE ROOTZONE
1790 C                                    DEPTH.  THE ORIGINAL COMPUTER PROGRAM
1800 C                                    USED A GIVEN DPA, AS WELL AS, A GIVEN
1810 C                                    MAXIMUM AVAILABLE SOIL WATER.
1820 C                    3...JI--JULIAN DATE OF PREVIOUS IRRIGATION
1830 C                    4...XAMT--PREVIOUS NET IRRIGATION AMOUNT (MM)
1840 C              5 TO 19...R(K)--RAIN AND/OR IRRIGATION AMOUNT DIFFERENCE
1850 C                              WITHIN THE COMPUTATION PERIOD (MM)
1860 C                              NOTE:  THIS MAY BE AN IRRIGATION AMOUNT
1870 C                                     AND/OR THE DIFFERENCE BETWEEN THE
1880 C                                     FIELD AND REGION FOR PRECIPITATION
1890 C                                     AMOUNT.  NUMBER OF VALUES EQUALS
1900 C                                     THE NUMBER OF DAYS OF NEW CLIMATIC
1910 C                                     DATA AS GIVEN BY N(I).
1920 C         4.B3E  FIELD CONDITION
1930 C                    1...DPL--SOIL WATER DEPLETION (MM)
1940 C                2,3,4...R(K)--PAST THREE DAYS ADJUSTED RAIN AND/OR
1950 C                              IRRIGATION AMOUNTS (MM)
1960 C                    5...SUMRF--SEASON SUMMATION OF RAINFALL FOR EACH
1970 C                               FIELD (MM)
1980 C                    6...SUMET--SEASON SUMMATION OF CROP ET (MM)
1990 C                    7...SUMWT--SEASON SUMMATION OF NET IRRIGATION
2000 C                               AMOUNTS (MM)
2010 C
2020 C
2030 C     CALCULATION AND OUTPUT VARIABLES
2040 C
2050 C     AIR--IRRIGATION AMOUNT (MM)
2060 C     AKC--BASAL CROP COEFFICIENT ADJUSTED FOR AVAILABLE SOIL WATER
2070 C     AKC1--BASAL CROP COEFFICIENT
2080 C     AKC2--CROP COEFFICIENT RELATED TO AVAILABLE SOIL WATER
2090 C     AKC3--CROP COEFFICIENT RELATED TO A WET SURFACE
2100 C     AKC4--CROP COEFFICIENT
2110 C     AKC5--EXPECTED (FOR NEXT 5 DAYS) BASAL CROP COEFFICIENT
2120 C     AV--PERCENTAGE AVAILABLE SOIL WATER (%)
2130 C     AVM--MAXIMUM AVAILABLE SOIL WATER (MM)
2140 C     AVMSF--MAXIMUM AVAILABLE SOIL WATER AT START OF FUTURE (MM)
2150 C     AW(NS,K)--MAXIMUM AVAILABLE SOIL WATER ARRAY
2160 C           K=1  DEPTH OF THE LOWER BOUNDARY OF THE SOIL LAYER (CM)
2170 C           K=2  MAXIMUM AVAILABLE SOIL WATER OF THE SOIL LAYER (MM)
2180 C
2190 C     B(I,K)--EXPECTED RAINFALL POLYNOMIAL REGRESSION COEFFICIENTS
2200 C     B1(I,K)--CLEAR SKY SOLAR RADIATION EQUATION COEFFICIENTS
2210 C
2220 C     C(K,NCR)--BASAL CROP COEFFICIENT TABLE
2230 C               PERCENT FROM MINIMUM TO MAXIMUM BASAL CROP COEFFICIENT
2240 C           K=1 TO 10   FOR 10 TO 100 PERCENT OF TIME FROM ENERGENCE
2250 C                       TO EFFECTIVE FULL COVER
2260 C                       NOTE:  WINTER WHEAT (NCR=7) IS FROM START OF
2270 C                              GROWTH RATHER THAN EMERGENCE
2280 C           K=11 TO 20  FOR 10 TO 100 DAYS AFTER EFFECTIVE FULL COVER
2290 C               THE PERENNIAL CROPS (NCR=8 TO 11) ARE REPRESENTED BY
2300 C               THE FOLLOWING:
2310 C                  NCR=8  K=1 TO 10   FOR 10 TO 100 PERCENT OF TIME FROM
2320 C                                     START OF GROWTH TO EFFECTIVE FULL
2330 C                                     COVER
2340 C                         K=11 TO 20  FOR 10 TO 100 DAYS AFTER EFFECTIVE
2350 C                                     FULL COVER
2360 C                  NCR=9  K=1 TO 10   FOR 10 TO 100 PERCENT OF TIME FROM
2370 C                                     CUTTING TO EFFECTIVE FULL COVER
2380 C                         K=11 TO 20  FOR 10 TO 100 DAYS AFTER EFFECTIVE
2390 C                                     FULL COVER, BUT JUST BEFORE GROWTH
2400 C                                     STOPS
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2410 C      C1,C2,...,C8--FAO TABLE INTERPOLATION
2420 C      C9--FAO PENMAN METHOD ADJUSTMENT FACTOR
2430 C      CROP(J)--CROP NAME (DESCRIPTIVE)
2440 C      CT--TIME SCALE FOR BASAL CROP COEFFICIENT CALCULATION
2450 C          PERCENT TIME FROM EMERGENCE TO EFFECTIVE FULL COVER
2460 C      CU--WINDSPEED HEIGHT CONVERSION FACTOR TO A STANDARD 2 METER HEIGHT
2470 C
2480 C      D(K,NCR)--BASAL CROP COEFFICIENT VALUES
2490 C        K=1  MINIMUM AT EMERGENCE
2500 C             IF PERENNIAL OR WINTER CROP, MINIMUM AT START OF GROWTH
2510 C        K=2  MAXIMUM AT EFFECTIVE FULL COVER
2520 C        K=3  MINIMUM AFTER EFFECTIVE FULL COVER
2530 C             IF PERENNIAL CROP, MINIMUM AT CUTTING
2540 C        K=4  MINIMUM AT END OF GROWTH FOR PERENNIAL CROPS
2550 C      D0--DUMMY REAL VARIABLE
2560 C      D1,D2,...,D6--FAO TABLE INTERPOLATION
2570 C      DAY--JULIAN DATE
2580 C      DAY2--JULIAN DATE ASSOCIATED WITH PREDICTION OF NEXT IRRIGATION
2590 C            DATE, WITH EXPECTED PRECIPITATION
2600 C      DELTA--SLOPE OF THE SATURATION VAPOR PRESSURE CURVE (MBAR/DEG C)
2610 C      DLT--CONSTANT IN EXPECTED GRASS REFERENCE CROP ET EQUATION
2620 C      DPA--ALLOWED SOIL WATER DEPLETION (MM)
2630 C      DPAP--PERCENT ALLOWED SOIL WATER DEPLETION (%)
2640 C      DPASF--ALLOWED SOIL WATER DEPLETION AT THE START OF THE FUTURE
2650 C             PERIOD (MM)
2660 C      DPL--SOIL WATER DEPLETION (MM)
2670 C      DPLI--SOIL WATER DEPLETION FOR THE PREVIOUS DAY (MM)
2680 C      DPLSF--SOIL WATER DEPLETION AT START OF FUTURE (MM)
2690 C      DT1(I)--CONSTANT BEFORE DATE JM(I) (DAYS)
2700 C      DT2(I)--CONSTANT AFTER DATE JM(I) (DAYS)
2710 C
2720 C      E--IRRIGATION EFFICIENCY (%)
2730 C      EA0--CLEAR SKY EMISSIVITY
2740 C      ELEV(I)--WEATHER STATION ELEVATION (M)
2750 C      ET--EVAPOTRANSPIRATION (MM/DAY)
2760 C      ETA--EXPECTED (FUTURE) ET (MM/DAY)
2770 C      ETA5--EXPECTED ET NEXT 5 DAYS (MM/DAY)
2780 C      ETJ--GRASS REFERENCE CROP ET AS CALCULATED FROM THE JOHANSSON
2790 C           METHOD (MM/DAY)
2800 C      ETP--PENMAN ET METHOD (MM/DAY)
2810 C      ETPC--PENMAN ET METHOD CALIBRATED FOR A GRASS REFERENCE CROP AT
2820 C            COPENHAGEN, DENMARK (MM/DAY)
2830 C      ETPF--GRASS REFERENCE CROP ET AS CALCULATED FROM THE FAO PENMAN
2840 C            METHOD (MM/DAY)
2850 C      ETR--ET DUE TO WET SOIL CAUSED BY RAIN OR IRRIGATION (MM/DAY)
2860 C      ETRG--GRASS REFERENCE CROP ET (MM/DAY)
2870 C      ETRG5(I)--GRASS REFERENCE CROP ET EXPECTED FOR NEXT 5 DAYS
2880 C                (MM/DAY)
2890 C      ETRGM(I)--LONG-TERM MAXIMUM GRASS REFERENCE CROP ET (MM/DAY)
2900 C
2910 C      F1,F2,F3,F4--FAO TABLE INTERPOLATION
2920 C      FARM(K)--FARM NAME (DESCRIPTIVE)
2930 C      FCT(I)-- FORECAST GRASS REFERENCE CROP ET FOR THE NEXT 5 DAYS
2940 C               RELATIVE TO THE LONG-TERM VALUE
2950 C      FIELD(K)--FIELD NAME (DESCRIPTIVE)
2960 C      FLOAT--FUNCTION THAT CONVERTS A VALUE FROM INTEGER TO REAL
2970 C      FORC(I,J)--WEATHER FORECAST (DESCRIPTIVE)
2980 C      FU--PENMAN WIND FUNCTION (MM/DAY / MBAR)
2990 C
3000 C      G--SOIL HEAT FLUX (MM/DAY)
3010 C      G1--DECLINATION OF THE SUN (DEGREES)
3020 C      G2--SUNSET HOUR ANGLE (DEGREES)
3030 C      G3--DAYTIME HOURS AT ZERO DECLINATION (HRS)
3040 C      G4--RADIUS VECTOR OF THE EARTH
3050 C      GAMMA--PSYCHROMETRIC CONSTANT (MBAR/DEG C)
3060 C
3070 C      I--REGION COUNTER
3080 C      I0,I1--FAO TABLE INTERPOLATION
3090 C      IN--INPUT ZONE FOR THE FREEFORM SUBROUTINE
3100 C      IX--MONTH NUMBER FOR NEXT IRRIGATION WITH NO RAINFALL
3110 C      IY--DAY NUMBER FOR NEXT IRRIGATION WITH NO RAINFALL
3120 C
3130 C      J--DAY COUNTER
3140 C      J0,J1,...,J8--FAO TABLE INTERPOLATION
3150 C      JD--JULIAN DATE IN DATEE SUBROUTINE
3160 C      JDATE(I,J)--JULIAN DATE ASSOCIATED WITH THE CLIMATIC DATA
3170 C      JDAY--JULIAN DATE
3180 C      JDC(NC,K)--PERENNIAL CROP JULIAN DATES
3190 C             K=1  CUTTING JULIAN DATE
3200 C             K=2  EFFECTIVE FULL COVER JULIAN DATE
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3210 C      JDE--JULIAN DATE OF EMERGENCE
3220 C           IF PERENNIAL OR WINTER CROP, JULIAN DATE OF START OF GROWTH
3230 C      JDF--EXPECTED NEXT 5 DAYS FORECAST JULIAN DATE (JSC(I)+N(I)+2)
3240 C      JDH--JULIAN DATE OF HARVEST OR FINAL IRRIGATION
3250 C           IF PERENNIAL CROP, JULIAN DATE OF END OF GROWTH OR FINAL
3260 C           IRRIGATION
3270 C      JDP--JULIAN DATE OF PLANTING
3280 C      JDS--JULIAN DATE LIMIT IN DATEE SUBROUTINE
3290 C      JFSUM--STARTING JULIAN DATE FOR SUMMATION OF FIELD DATA
3300 C      JI--PREVIOUS IRRIGATION JULIAN DATE
3310 C      JIN--JULIAN DATE OF INITIAL SOIL WATER DEPLETION
3320 C      JM(I)--JULIAN DATE OF LONG-TERM MAXIMUM GRASS REFERENCE CROP ET
3330 C      JRSUM(I)--STARTING JULIAN DATE FOR SUMMATION OF REGIONAL DATA
3340 C      JSC(I)--STARTING JULIAN DATE OF CLIMATIC DATA
3350 C      JSCP--STARTING JULIAN DATE OF CLIMATIC DATA AS INDICATED
3360 C            BY PREVIOUS PROGRAM RUN
3370 C      JSF--STARTING JULIAN DATE ASSOCIATED WITH FUTURE TIME
3380 C      JX--MONTH NUMBER FOR NEXT IRRIGATION WITH EXPECTED RAINFALL
3390 C      JY--DAY NUMBER FOR NEXT IRRIGATION WITH EXPECTED RAINFALL
3400 C
3410 C      K--COUNTER
3420 C      KO--FAO TABLE INTERPOLATION
3430 C      KIND(K)--VARIABLE TYPE
3440 C               NUMERIC IF EQUAL TO 1
3450 C               ALPHABETIC IF EQUAL TO 5
3460 C
3470 C      L--MONTH OR PERIOD COUNTER
3480 C      LAT(I)--WEATHER STATION LATITUDE (DEGREES NORTH)
3490 C      LDATA(K)--ALPHANUMERIC ARRAY IN FREEFORM SUBROUTINE
3500 C      LH-- LATENT HEAT OF VAPORIZATION (J/KG)
3510 C
3520 C      M--FARM COUNTER
3530 C      MO--FAO TABLE INTERPOLATION
3540 C      M1--INPUT DEVICE NUMBER FOR WEATHER DATA
3550 C      M2--DEVICE TO SAVE INPUT DATA FOR NEXT RUN (PRINTER)
3560 C      M3--INPUT DEVICE NUMBER FOR REGIONAL AND FARM DATA
3570 C      M4--PRINTER DEVICE NUMBER
3580 C      MON(K)--MONTH NAME ARRAY
3590 C          K= 1 TO 12  MONTH NAME ABBREVIATED TO FOUR LETTERS
3600 C          K=13  THE WORD "NONE"
3610 C
3620 C      N(I)--NUMBER OF DAYS OF NEW CLIMATIC DATA
3630 C      NO--INTEGER DUMMY VARIABLE
3640 C      NA--NUMBER OF ALPHANUMERIC VALUES READ BY FREEFORM SUBROUTINE
3650 C      NC--CUTTING COUNTER
3660 C      NCR--CROP NUMBER:   1 - SMALL GRAINS
3670 C                          2 - SNAP BEANS
3680 C                          3 - PEAS
3690 C                          4 - POTATOES
3700 C                          5 - SUGAR BEETS
3710 C                          6 - CORN
3720 C                          7 - WINTER WHEAT
3730 C                          8 - PASTURE (GRAZED GRASS, GRASS-LEGUMES,
3740 C                              OR ALFALFA)
3750 C                          9 - CLOVER, GRASS-LEGUMES (CUT)
3760 C                         10 - GRASS (CUT)
3770 C                         11 - ALFALFA (CUT)
3780 C      NCROP--NUMBER OF CROPS
3790 C      NCUT--NUMBER OF CUTTINGS FOR A PERENNIAL CROP
3800 C      ND--DAY NUMBER FROM CONVERSION OF JULIAN DATE IN DATEE SUBROUTINE
3810 C      NDATE(K)--COMPUTATION DATE
3820 C            K=1  JULIAN DATE
3830 C            K=2  YEAR
3840 C      NDAY--NUMBER OF DAYS OF CLIMATIC DATA
3850 C      NF--FIELD COUNTER
3860 C      NFARMS--NUMBER OF FARMS IN A REGION
3870 C      NFLD--NUMBER OF FIELDS FOR A FARM
3880 C      NITEMS--NUMBER OF VARIABLES READ IN FREEFORM SUBROUTINE
3890 C      NM--MONTH NUMBER FROM CONVERSION OF JULIAN DATE IN DATEE SUBROUTINE
3900 C      NN--NUMBER OF NUMERIC VALUES READ BY FREEFORM SUBROUTINE
3910 C      NND(L)--STARTING JULIAN DATE FOR EACH MONTH
3920 C      NREG--NUMBER OF REGIONS
3930 C      NS--SOIL LAYER COUNTER
3940 C      NSL--NUMBER OF SOIL LAYERS
3950 C      NTF--TOTAL NUMBER OF FIELDS FOR SCHEDULING IN NEXT PROGRAM RUN
3960 C      NXD--JULIAN DATE OF NEXT IRRIGATION WITH NO FUTURE RAINFALL
3970 C      NXDP--JULIAN DATE OF NEXT IRRIGATION WITH EXPECTED RAINFALL
3980 C
3990 C      PA--AIR PRESSURE (MBAR)
4000 C      PCT--PERCENT FROM MINIMUM TO MAXIMUM BASAL CROP COEFFICIENT
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4010 C      PP--EXPECTED PRECIPITATION AT 50 PERCENT PROBABILITY FOR A TWO
4020 C          WEEK PERIOD (MM)
4030 C          NOTE:  THE PERIOD MAY BE LESS THAN TWO WEEKS IN THE SCHED
4040 C                 SUBROUTINE
4050 C      PRCP(I,J)--REGIONAL PRECIPITATION AMOUNT (MM)
4060 C                 NOTE:  THE SUM OF THE PERIOD REGIONAL PRECIPITATION
4070 C                        IS GIVEN IN J=NDAY+1
4080 C      PRCPF--FIELD PRECIPITATION AMOUNT (MM)
4090 C
4100 C      R(K)--RAIN AND/OR IRRIGATION AMOUNT DIFFERENCE (MM)
4110 C            ADJUSTED RAIN AND/OR IRRIGATION AMOUNT (MM)
4120 C            NOTE:  WHEN THE DATA IS READ IN,
4130 C                   THIS DOES NOT INCLUDE REGIONAL PRECIPITATION
4140 C                   GIVEN BY PRCP(I,J) AND ANY IRRIGATION AMOUNTS GIVEN
4150 C                   BY XAMT FOR THE IRRIGATION DATE JI.  THIS ARRAY'S
4160 C                   PURPOSE IS TO KEEP TRACK OF WATER AVAILABLE FOR
4170 C                   SURFACE EVAPORATION.
4180 C                   DURING THE PROGRAM COMPUTATION,
4190 C                   REGIONAL PRECIPITATION AND IRRIGATION AMOUNTS ARE
4200 C                   ADDED TO THE INPUT VALUES FOR EACH DAY.  WET
4210 C                   SURFACE EVAPORATION IS SUBTRACTED AS IT OCCURS.
4220 C                   THE ARRAY THEN CONTAINS ADJUSTED RAIN AND/OR
4230 C                   IRRIGATION AMOUNTS.
4240 C        K=1, 2, OR 3  PAST AMOUNTS  (DAYS FROM PREVIOUS RUN)
4250 C        K=4 TO 18  PRESENT AMOUNTS  (DAYS WITH CLIMATIC DATA)
4260 C      R1--RATIO OF ACTUAL TO CLEAR SKY SOLAR RADIATION
4270 C      RA--EXTRA-TERRESTRIAL RADIATION (MM/DAY)
4280 C      RDATA(K)--NUMERIC ARRAY IN FREEFORM SUBROUTINE
4290 C      REGION(I,K)--REGION NAME (DESCRIPTIVE)
4300 C      RH--RELATIVE HUMIDITY (%)
4310 C      RH08--RELATIVE HUMIDITY AT 0800 (%)
4320 C      RH14--RELATIVE HUMIDITY AT 1400 (%)
4330 C      RH19--RELATIVE HUMIDITY AT 1900 (%)
4340 C      RHMAXL(L)--LONG-TERM MAXIMUM RELATIVE HUMIDITY (%)
4350 C      RL(L)--LONG-TERM DAY TO NIGHT WINDSPEED RATIO
4360 C      RN--NET RADIATION (MM/DAY)
4370 C      RS--SOLAR RADIATION (MM/DAY)
4380 C      RSO--CLEAR SKY SOLAR RADIATION (MM/DAY)
4390 C      RSL(L)--LONG-TERM SOLAR RADIATION (MM/DAY)
4400 C      RX--UNADJUSTED VALUE FOR R(K) (MM)
4410 C      RZ--EFFECTIVE ROOTZONE DEPTH (CM)
4420 C      RZLIM--LIMITING MAXIMUM EFFECTIVE ROOTZONE DEPTH (CM)
4430 C      RZM--MAXIMUM EFFECTIVE ROOTZONE DEPTH WHETHER LIMITED BY
4440 C           THE CROP (RZMAX) OR THE SOIL (RZLIM) (CM)
4450 C      RZMAX--MAXIMUM EFFECTIVE ROOTZONE DEPTH (CM)
4460 C      RZMIN--MINIMUM EFFECTIVE ROOTZONE DEPTH (CM)
4470 C
4480 C      S1--PRINT CONTROL SWITCH
4490 C          S1=0.  NORMAL PRINT
4500 C          S1=1.  DATA STATEMENTS AND INPUT DATA
4510 C          S1=2.  INTERMEDIATE CALCULATIONS
4520 C          S1=3.  DAILY CALCULATIONS IN ETAVG SUBROUTINE
4530 C                 NOTE:  THIS PRINTING MAY BE OF EXCESSIVE LENGTH
4540 C      S2--ALLOWED SOIL WATER DEPLETION CALCULATION CONTROL SWITCH
4550 C          S2=0.  USE INPUT VALUE
4560 C          S2=1.  CALCULATE FOR EACH DAY USING THE PERCENT ALLOWED
4570 C                 SOIL WATER DEPLETION
4580 C      SHFT(I,K)--AIR TEMPERATURE (DEGREES C)
4590 C             K= 1 TO 3  THREE DAYS BEFORE START OF CLIMATIC DATA
4600 C             K= 4 TO 18  PRESENT COMPUTATION PERIOD
4610 C      SUMET--SEASON SUMMATION OF CROP ET (MM)
4620 C      SUMET2--PERIOD SUMMATION OF CROP ET (MM)
4630 C      SUMJ(I)--SEASON SUMMATION OF ETJ (MM)
4640 C      SUMP2--PERIOD SUMMATION OF PRECIPITATION FOR EACH FIELD (MM)
4650 C      SUMPC(I)--SEASON SUMMATION OF ETPC (MM)
4660 C      SUMPF(I)--SEASON SUMMATION OF ETPF (MM)
4670 C      SUMPP--SUMMATION OF PRECIPITATION FROM THE START OF THE FUTURE
4680 C             TO THE PREDICTED IRRIGATION DATE (MM)
4690 C      SUMR(I)--SEASON SUMMATION OF REGIONAL RAINFALL (MM)
4700 C      SUMRF--SEASON SUM OF RAINFALL FOR EACH FIELD (MM)
4710 C      SUMWT--SEASON SUMMATION OF NET IRRIGATION AMOUNTS (MM)
4720 C
4730 C      T--EXPECTED RAINFALL TIME PERIOD (DAYS)
4740 C      T08--AIR TEMPERATURE AT 0800 (DEGREES C)
4750 C      T14--AIR TEMPERATURE AT 1400 (DEGREES C)
4760 C      T19--AIR TEMPERATURE AT 1900 (DEGREES C)
4770 C      TA--AIR TEMPERATURE (DEGREES C)
4780 C      TM(J)--AIR TEMPERATURE CALCULATED FROM THE AVERAGE OF THE
4790 C             MAXIMUM AND MINIMUM AIR TEMPERATURES (DEGREES C)
4800 C      TMAX--MAXIMUM AIR TEMPERATURE (DEGREES C)
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4810 C      TMIN--MINIMUM AIR TEMPERATURE (DEGREES C)
4820 C
4830 C      U--WINDSPEED AT 2 METERS HEIGHT (M/S)
4840 C      U08--WINDSPEED AT Z(I) HEIGHT AT 0800 (M/S)
4850 C      U14--WINDSPEED AT Z(I) HEIGHT AT 1400 (M/S)
4860 C      U19--WINDSPEED AT Z(I) HEIGHT AT 1900 (M/S)
4870 C      UL(L)--LONG-TERM WINDSPEED AT 2 METERS HEIGHT (M/S)
4880 C
4890 C      VA(J)--AIR VAPOR PRESSURE (MBAR)
4900 C      VAL(K)--NUMERIC VALUES READ BY FREEFORM SUBROUTINE
4910 C      VALA(K)--ALPHANUMERIC VALUES READ BY FREEFORM SUBROUTINE
4920 C      VDEF(J)--AIR VAPOR PRESSURE DEFICIT (MBAR)
4930 C      VSAT--AIR SATURATION VAPOR PRESSURE (MBAR)
4940 C
4950 C      W(J)--PENMAN WEIGHTING FUNCTION
4960 C      W1--FAO TABLE INTERPOLATION
4970 C      WI(K,NF)--INPUT DATA FOR NEXT RUN
4980 C         K=1  SOIL WATER DEPLETION (MM)
4990 C         K=2  RAIN AND/OR IRRIGATION AMOUNT FOR THREE DAYS BEFORE (MM)
5000 C         K=3  RAIN AND/OR IRRIGATION AMOUNT FOR TWO DAYS BEFORE (MM)
5010 C         K=4  RAIN AND/OR IRRIGATION AMOUNT FOR PREVIOUS DAY (MM)
5020 C         K=5  SUMMATION OF RAINFALL OR IRRIGATION FOR EACH FIELD (MM)
5030 C         K=6  SUM OF CROP ET (MM)
5040 C         K=7  SUM OF NET IRRIGATION AMOUNTS (MM)
5050 C      WIN--INITIAL SOIL WATER DEPLETION FOR THE MAXIMUM OR LIMITING
5060 C           ROOTZONE (MM)
5070 C
5080 C      X(K,I,J)--VARIABLES SAVED FOR TRANSFER BETWEEN SUBROUTINES
5090 C                   OR LOOPS
5100 C        K=1  AIR TEMPERATURE (DEGREES C)
5110 C        K=2  RELATIVE HUMIDITY (%)
5120 C        K=3  WINDSPEED AT 2 METER HEIGHT (M/S)
5130 C        K=4  SOLAR RADIATION (MM/DAY)
5140 C        K=5  GRASS REFERENCE CROP ET AS CALCULATED FROM THE
5150 C                CALIBRATED PENMAN METHOD (MM/DAY)
5160 C        K=6  GRASS REFERENCE CROP ET AS CALCULATED FROM THE FAO
5170 C                PENMAN METHOD (MM/DAY)
5180 C        K=7  GRASS REFERENCE CROP ET AS CALCULATED FROM THE
5190 C                JOHANSSON METHOD (MM/DAY)
5200 C        NOTE:  THE SUMS OF THE PERIOD VALUES ARE GIVEN IN J=NDAY+1
5210 C      XO--ARGUEMENT IN THE TAN AND ACOS FUNCTIONS (RADIANS)
5220 C      X1--FAO TABLE INTERPOLATION
5230 C      XA(K)--ALPHANUMERIC VALUES READ BY FREEFORM SUBROUTINE
5240 C      XAMT--NET IRRIGATION AMOUNT (MM)
5250 C      XI--NET IRRIGATION AMOUNT FOR PREDICTED DATE WITHOUT
5260 C          PRECIPITATION (MM)
5270 C      XMIN--MINIMUM IRRIGATION AMOUNT (MM)
5280 C      XN(K)--NUMERIC VALUES READ BY FREEFORM SUBROUTINE
5290 C      XNMIN--MINIMUM NET IRRIGATION AMOUNT (MM)
5300 C
5310 C      Y1--FAO TABLE INTERPOLATION
5320 C
5330 C      Z(I)--WINDSPEED MEASUREMENT HEIGHT (M)
5340 C      Z1--FAO TABLE INTERPOLATION
5350 C
5360 C      END OF USERS GUIDE
```

APPENDIX C

Extra-terrestrial Radiation

The performance of these equations will need to be checked against tabulated values for the high latitudes of Sweden. From List (1951) the relation for extra-terrestrial radiation is as follows:

$$R_a = 1.26714\ (h_{do}/r_{ve}^2)\cdot 0.01745\ h_s\cdot \sin\ (0.01745\,\Phi)\cdot$$

$$\sin\ (0.01745\,\delta) + \cos\ (0.01745\,\Phi)\cdot$$

$$\cos\ (0.01745\,\delta)\cdot \sin\ (0.01745\ h_s)$$

where:
R_a is the extra-terrestrial radiation (mm/day)
h_{do} is the daytime hours at zero declination (hr)
r_{ve} is the radius vector of the earth
h_s is the sunrise or sunset hour angle (deg)
Φ is the latitude (^{o}N)
δ is the declination of the sun (deg)

The arguments for the sine and cosine functions are in radians, and a conversion factor of $\pi/180$ is used. The constant 1.26714 is developed from $2\ J_o/\pi$ where J_o is the solar constant with a value of 1.99042 mm/hr. The fraction h_{do}/π is a conversion from radians to hours. The 2 doubles the results of integration over the period from noon to sunset of the R_a equation presented by List (1951).

A polynomial regression of tabulated values from List (1951) of r_{ve} versus julian date gives the following relation with an r^2 of 0.9997:

$$r_{ve} = 0.98387 - 1.11403E{-4}\ (J) + 5.27747E{-6}\ (J)^2$$
$$- 2.68285E{-8}\ (J)^3 + 3.61634E{-11}\ (J)^4$$

The parameter h_{do} depends on latitude which is expressed as a second degree polynomial using tabulated data from List (1951). The r^2 value is 0.9909 for the regression equation:

$$h_{do} = 12.126 - 1.85191E{-3}\ (\Phi) + 7.61048E{-5}\ (\Phi)^2$$

The expression for h_s was also developed from List (1951) as follows:

$$h_s = 57.296\ \arccos\ (-\ \tan\ (0.01745\Phi)\ \tan\ (0.01745\Phi)$$

The declination of the sun is a function of time of year. Using tabulated data from List (1951), a fourth degree polynomial equation with r^2 of 0.9996 is as follows:

$$\delta = -22.7893 + 4.27921\text{E-}4\ (J) + 6.07616\text{E-}3\ (J)^2$$
$$- 3.50364\text{E-}5\ (J)^3 + 5.04922\text{E-}8\ (J)^4$$

APPENDIX D

JBEVATTN and BEVATTNING Computer Program Listings

```
C     BEVATTNING -- AN IRRIGATION SCHEDULING PROGRAM
C     MAJOR CHANGES HAVE BEEN MADE TO THE ORIGINAL PROGRAM (IRRIGATE)
C
C     DEVELOPED FOR THE RC 8000 AT SWEDISH UNIVERSITY OF AGRICULTURAL
C     SCIENCES BY JOE ERPENBECK (1981)
C     ORIGINAL FOR IBM 370 AT UNIVERSITY OF IDAHO BY D. FORTIER (1975) OF
C     1971 REVISION BY B. J. PRATT, M. E. JENSEN, AND D. F. HEERMANN.
C     PROGRAM FIRST WRITTEN WITH CONSIDERATION OF CONDITIONS FOR A
C     SEMI-ARID CLIMATE AND MORE SPECIFICALLY FOR SOUTHERN IDAHO, USA
C     CONDITIONS.  THE COMPUTER PROGRAM ORIGINALLY DATES FROM 1968.
C
      PROGRAM BEVATTNING
C     PROGRAM NUMBER 1
C
      COMMON /C12/ B1(4,5),ELEV(4),JDATE(4,15),LAT(4),RHMAXL(4,12),
     & RL(4,12),RSL(4,12),TM(15),UDAYL(4,12),UL(4,12),Z(4)
      COMMON /C13/ XN(40),XA(40)
      COMMON /C123/ FORC(4,15),MON(13),N(4),NDATE(2),PRCP(4,16),
     & REGION(4,5),X(7,4,16)
      COMMON /C127/ JRSUM(4),SHFT(4,18),SUMJ(4),SUMPC(4),SUMPF(4),
     & SUMR(4)
      COMMON /C134/ B(4,6)
      COMMON /C1236/ DT1(4),DT2(4),ETRGM(4),FCT(4),JM(4)
      COMMON /C1237/ JSC(4)
      LONG MON,XA
      REAL LAT
C
      DATA MON / 'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG',
     & 'SEP','OCT','NOV','DEC','---' /
C
C     DEFINE INPUT (5) AND OUTPUT (6) DEVICES
      M1=5
      M2=6
      M3=5
      M4=6
C
C     START PRINTING AT THE TOP OF A NEW PAGE
      WRITE(M4,1000)
 1000 FORMAT(1H1)
C
C
C     PROGRAM CONTROL DATA (1 LINE)
C          NOTE:  ONLY FOUR REGIONS ALLOWED WITH PRESENT DIMENSIONING
      CALL FREEFORM(NN,XN,NA,XA)
      NREG=XN(1)
      NDATE(1)=XN(2)
      NDATE(2)=XN(3)
      S1=XN(4)
      IF(S1.GE.1.) WRITE(M4,1010) NREG,NDATE(1),NDATE(2),S1
 1010 FORMAT (1H0,'PROGRAM CONTROL DATA'/1H ,5X,'NUMBER OF REGIONS:',
     & I4/1H ,5X,'COMPUTATION JULIAN DATE:',I5/1H ,5X,'YEAR:',
     & I6/1H ,5X,'PRINT SWITCH:',F5.0)
C
      CALL DATEE(NDATE(1),NM,ND,365)
      WRITE(M4,1020) ND,MON(NM),NDATE(2)
 1020 FORMAT(1H0,'COMPUTATION DATE:',I4,1X,A4,I5)
C
C     PRINT ARRAY MON
      IF(S1.GE.1.) WRITE(M4,1030) (MON(L),L=1,13)
 1030 FORMAT(1H0,'MON ARRAY:  ',7(3X,A4)/1H ,12X,6(3X,A4))
C
C     REGIONAL DATA (17 LINES FOR EACH REGION)
      DO 40 I=1,NREG
C          REGION NAME
      READ(M3,1040) (REGION(I,K),K=1,5)
 1040 FORMAT(5A4)
      IF(S1.GE.1.) WRITE(M4,1050) (REGION(I,K),K=1,5)
 1050 FORMAT(1H0,'REGIONAL DATA'/1H ,5X,'REGION:  ',5A4)
C
C          WEATHER STATION INFORMATION
      CALL FREEFORM(NN,XN,NA,XA)
      ELEV(I)=XN(1)
      LAT(I)=XN(2)
      Z(I)=XN(3)
      IF(S1.GE.1.) WRITE(M4.1060) ELEV(I),LAT(I),Z(I)
 1060 FORMAT(1H ,5X,'WEATHER STATION INFORMATION'/1H ,10X,'ELEVATION:',
     & F8.1/1H ,10X,'LATITUDE:',F10.2/1H ,10X,'WINDSPEED MEASUREMENT ',
     & 'HEIGHT:'.F7.1)
C
C          EXPECTED GRASS REFERENCE CROP ET EQUATION COEFFICIENTS
```

```
      CALL FREEFORM(NN,XN,NA,XA)
      ETRGM(I)=XN(1)
      JM(I)=XN(2)
      DT1(I)=XN(3)
      DT2(I)=XN(4)
      IF(S1.GE.1.) WRITE(M4,1070) ETRGM(I),JM(I),DT1(I),DT2(I)
 1070 FORMAT(1H ,5X,'EXPECTED GRASS REFERENCE CROP ET EQUATION ',
     & 'COEFFICIENTS'/1H ,10X,'ETRGM(I):',F7.2/1H ,10X,'JM(I):',
     & I7/1H ,10X,'DT1(I)',F6.1/1H ,10X,'DT2(I)',F6.1)
C
C           EXPECTED PRECIPITATION EQUATION COEFFICIENTS
      CALL FREEFORM(NN,XN,NA,XA)
      DO 10 K=1,6
      B(I,K)=XN(K)
   10 CONTINUE
      IF(S1.GE.1.) WRITE(M4,1080) (B(I,K),K=1,6)
 1080 FORMAT(1H ,5X,'EXPECTED PRECIPITATION EQUATION COEFFICIENTS'
     & /1H ,10X,'COEFFICIENTS:',3E15.6/1H ,23X,3E15.6)
C
C           CLEAR SKY SOLAR RADIATION EQUATION COEFFICIENTS
      CALL FREEFORM(NN,XN,NA,XA)
      DO 20 K=1,5
      B1(I,K)=XN(K)
   20 CONTINUE
      IF(S1.GE.1.) WRITE(M4,1090) (B1(I,K),K=1,5)
 1090 FORMAT(1H ,5X,'CLEAR SKY SOLAR RADIATION EQUATION COEFFICIENTS',
     & /1H ,10X,'COEFFICIENTS:',3E15.6/1H ,23X,2E15.6)
C
C           LONG-TERM CLIMATIC DATA (1 LINE FOR EACH MONTH)
      DO 30 L=1,12
C                READ DATA
      CALL FREEFORM(NN,XN,NA,XA)
      RHMAXL(I,L)=XN(1)
      UL(I,L)=XN(2)
      RL(I,L)=XN(3)
      RSL(I,L)=XN(4)
C                CALCULATE LONG-TERM DAYTIME WINDSPEED
      UDAYL(I,L)=UL(I,L)*2.0*RL(I,L)/(1.0+RL(I,L))
   30 CONTINUE
      IF(S1.GE.1.) WRITE(M4,1100) ((L,RHMAXL(I,L),UL(I,L),RL(I,L),
     & UDAYL(I,L),RSL(I,L)),L=1,12)
 1100 FORMAT(1H0,5X,'LONG-TERM CLIMATIC DATA'/1H ,10X,'MONTH   ',
     & 'MAX RH     U      UDAY/      UDAY      RS',/1H ,19X,'(%)',
     & '     (M/S)   UNIGHT   (M/S)    (MM/DAY)',12(/1H ,10X,I3,
     & F10.2,F9.2,F8.2,2F9.2)/1H ,10X,'UDAY IS A CALCULATED ',
     & 'VALUE')
C
   40 CONTINUE
C
C     CLIMATIC DATA (4+NDAY LINES FOR EACH REGION)
      DO 70 I=1,NREG
C           REGIONAL QUANTITATIVE FORECAST INFORMATION
      CALL FREEFORM(NN,XN,NA,XA)
      FCT(I)=XN(1)
      IF(S1.GE.1.) WRITE(M4,1110) FCT(I)
 1110 FORMAT(1H0,'CLIMATIC DATA'/1H ,5X,'REGIONAL QUANTITATIVE ',
     & 'FORECAST INFORMATION'/1H ,10X,'FORECAST GRASS REFERENCE CROP ',
     & 'RATIO:',F6.2)
C
C           REGIONAL QUALITATIVE FORECAST INFORMATION
      READ(M1,1120) (FORC(I,J),J=1,15)
 1120 FORMAT(15A4)
      IF(S1.GE.1.) WRITE(M4,1130) (FORC(I,J),J=1,15)
 1130 FORMAT(1H ,5X,'REGIONAL QUALITATIVE FORECAST INFORMATION'
     & /1H ,10X,'FORECAST:  ',15A4)
C
C           REGIONAL CLIMATIC CONDITION
      CALL FREEFORM(NN,XN,NA,XA)
      JSCP=XN(1)
      SHFT(I,1)=XN(2)
      SHFT(I,2)=XN(3)
      SHFT(I,3)=XN(4)
      JRSUM(I)=XN(5)
      SUMPC(I)=XN(6)
      SUMPF(I)=XN(7)
      SUMJ(I)=XN(8)
      SUMR(I)=XN(9)
      IF(S1.GE.1.) WRITE(M4,1140) JSCP,(SHFT(I,K),K=1,3),JRSUM(I),
     & SUMPC(I),SUMPF(I),SUMJ(I),SUMR(I)
 1140 FORMAT(1H ,5X,'REGIONAL CLIMATIC CONDITION'/1H ,10X,'STARTING',
```

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     & ' JULIAN DATE:',I5/1H ,10X,'AIR TEMPERATURE, THREE DAYS BEFORE',
     & ' START:',3F7.1/1H ,10X,'REGIONAL SUMMATION STARTING JULIAN',
     & ' DATE:',I5/1H ,10X,'SUM OF CALIBRATED PENMAN ET:',F8.2/1H ,
     & 10X,'SUM OF FAO PENMAN ET:',F8.2/1H ,10X,'SUM OF JOHANSSON',
     & ' ET:',F9.2/1H ,10X,'SUM OF PRECIPITATION:',F8.1)
C
C           REGIONAL PROGRAM CONTROL DATA
C                  NOTE:  ONLY 15 DAYS OF CLIMATIC DATA ALLOWED WITH
C                             PRESENT DIMENSIONING
      CALL FREEFORM(NN,XN,NA,XA)
      N(I)=XN(1)
      JSC(I)=XN(2)
      IF(S1.GE.1.) WRITE(M4,1150) N(I),JSC(I)
 1150 FORMAT(1H ,5X,'PROGRAM CONTROL DATA'/1H ,10X,'DAYS OF CLIMATIC',
     & ' DATA:',I4/1H ,10X,'STARTING JULIAN DATE:',I6)
      IF(JSC(I).NE.JSCP) GO TO 80
      IF(JRSUM(I).LE.0) JRSUM(I)=JSC(I)
      IF(NDATE(1).EQ.0) NDATE(1)=JSC(I)+N(I)
C
C           DAILY CLIMATIC DATA (1 LINE FOR EACH DAY)
      NDAY=N(I)
      X(1,I,NDAY+1)=0.
      X(2,I,NDAY+1)=0.
      X(3,I,NDAY+1)=0.
      X(4,I,NDAY+1)=0.
      DO 50 J=1,NDAY
C                  READ DATA
      CALL FREEFORM(NN,XN,NA,XA)
      JDATE(I,J)=XN(1)
      T08=XN(2)
      T14=XN(3)
      T19=XN(4)
      TMAX=XN(5)
      TMIN=XN(6)
      RH08=XN(7)
      RH14=XN(8)
      RH19=XN(9)
      U08=XN(10)
      U14=XN(11)
      U19=XN(12)
      RS=XN(13)
      PRCP(I,J)=XN(14)
C           PRINT CLIMATIC DATA
      IF(S1.GE.1. .AND. J.EQ.1) WRITE(M4,1160) Z(I)
 1160 FORMAT(1H0,5X,'DAILY CLIMATIC DATA'/1H ,10X,'JULIAN',11X,'AIR ',
     & 'TEMPERATURE',12X,' RELATIVE HUMIDITY',8X,'WINDSPEED',9X,'SOLAR',
     & 5X,'PRECIPITATION'/1H ,11X,'DATE',14X,'(DEGREES C)',21X,'(%)',
     & 12X,'(M/S AT',F6.1,' M)   RADIATION',7X,'(MM)'/1H ,95X,
     & '(LANGLEYS'/1H ,16X,'   0800   1400   1900    MAX    MIN',
     & 2('   0800   1400   1900'),5X,'/DAY)')
      IF(S1.GE.1.) WRITE(M4,1170) JDATE(I,J),T08,T14,T19,TMAX,TMIN,
     & RH08,RH14,RH19,U08,U14,U19,RS,PRCP(I,J)
 1170 FORMAT(1H ,10X,I4,2X,8F7.1,3F7.2,F9.1,F13.1)
C                  CALCULATIONS
C                       MEAN DAILY VALUES FOR CLIMATIC PARAMETERS
      X(1,I,J)=(T08+T14+T19)/3.
      X(2,I,J)=(RH08+RH14+RH19)/3.
      X(3,I,J)=(U08+U14+U19)/3.
      TM(J)=(TMAX+TMIN)/2.
C                       CONVERT WINDSPEED TO 2 METER HEIGHT
      IF(J.EQ.1) CU=ALOG(2/0.01)/ALOG(Z(I)/0.01)
      X(3,I,J)=X(3,I,J)*CU
C                       CONVERT SOLAR RADIATION UNITS TO MM/DAY
      X(4,I,J)=RS*0.0171
C                       PERIOD SUMS
      X(1,I,NDAY+1)=X(1,I,NDAY+1)+X(1,I,J)
      X(2,I,NDAY+1)=X(2,I,NDAY+1)+X(2,I,J)
      X(3,I,NDAY+1)=X(3,I,NDAY+1)+X(3,I,J)
      X(4,I,NDAY+1)=X(4,I.NDAY+1)+X(4,I,J)
C                       CHECK JULIAN DATE
      IF(JDATE(I,J).NE.(JSC(I)+J-1)) GO TO 90
   50 CONTINUE
C
C     PRINT WEATHER DATA
      WRITE(M4,1180) (REGION(I,K),K=1,5)
 1180 FORMAT(1H0,'WEATHER DATA'/1H ,5X,'REGION:   '.5A4)
      IF(S1.GE.2.) WRITE(M4.1190) Z(I),CU
 1190 FORMAT(1H ,5X,'WINDSPEED MEASUREMENT HEIGHT:',F8.1,'  METERS'
     & /1H ,15X,'CONVERSION FACTOR TO A 2 METER HEIGHT:',F8.3)
      WRITE(M4.1200)
```

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 1200 FORMAT(1H ,' DATE      JULIAN',7X,'AIR',7X,'RELATIVE   WINDSPEED',
     & 5X,'SOLAR'/1H ,11X,'DATE    TEMPERATURE   HUMIDITY      (M/S)',
     & '      RADIATION'/1H ,19X,'(DEGREES C)       (%)',7X,'AT 2 M)     ',
     & '(MM/DAY)')
      DO 60 J=1,NDAY
      CALL DATEE(JDATE(I,J),NM,ND,365)
      WRITE(M4,1210) ND,MON(NM),JDATE(I,J),(X(K,I,J),K=1,4)
 1210 FORMAT(1H ,I2,1X,A3,I8,F12.1,F13.1,F12.2,F11.2)
   60 CONTINUE
      DO=JDATE(I,NDAY)-(NDAY-1.)/2.
      WRITE(M4,1220) DO,X(1,I,NDAY+1)/NDAY,X(2,I,NDAY+1)/NDAY,
     & X(3,I,NDAY+1)/NDAY,X(4,I,NDAY+1)/NDAY
 1220 FORMAT(1HO,'MEAN',F12.1,F10.1,F13.1,F12.2,F11.2)
C
C     CLIMATIC DATA CALCULATIONS
      CALL EVAP(I,M4,S1,TMAX,TMIN)
   70 CONTINUE
C
C     FIELD CALCULATIONS AND SCHEDULING
      CALL FARMS(NREG,M3,M4,S1,NTF)
C
C     SAVE DATA FOR NEXT RUN
      CALL SAVE(NREG,NTF,M2,S1)
      GO TO 100
C
C     PRINT ERROR MESSAGES AND STOP PROGRAM
C            ERROR MESSAGE:  JSC
   80 WRITE(M4,1230) I,JSC(I),JSCP
 1230 FORMAT(1H ,'* ERROR JSC *',/,1H ,'FOR REGION:',I3,
     & ' THE STARTING JULIAN DATE OF THE CLIMATIC',
     & ' DATA:',I5,/1H ,'DOES NOT MATCH THE STARTING JULIAN DATE ',
     & 'OF THE CLIMATIC DATA FROM THE PREVIOUS PROGRAM',
     & ' RUN:',I5)
      GO TO 100
C            ERROR MESSAGE:  JDATE
   90 WRITE(M4,1240) I,JDATE(I,J),JSC(I)+J-1,J
 1240 FORMAT(1H ,'* ERROR JDATE *'/1H ,'FOR REGION:',I3,
     & ' THE JULIAN DATE GIVEN WITH THE CLIMATIC DATA:',I5,
     & ' DOES NOT MATCH THE JULIAN DATE:',I5/1H ,
     & 'AS COMPUTED FOR DAY NUMBER:',I4,' OF THE NEW CLIMATIC DATA')
C
  100 STOP
      END
C
C
C
      SUBROUTINE EVAP(I,M4,S1,TMAX,TMIN)
C     SUBROUTINE TO CALCULATE GRASS REFERENCE CROP ET
C     SUBROUTINE NUMBER 2
C
      DIMENSION VA(15),VDEF(15),W(15)
      COMMON /CEVAP/ CO(4,48)
      COMMON /C12/ B1(4,5),ELEV(4),JDATE(4,15),LAT(4),RHMAXL(4,12),
     & RL(4,12),RSL(4,12),TM(15),UDAYL(4,12),UL(4,12),Z(4)
      COMMON /C23/ ETRG5(4)
      COMMON /C123/ FORC(4,15),MON(13),N(4),NDATE(2),PRCP(4,16),
     & REGION(4,5),X(7,4,16)
      COMMON /C127/ JRSUM(4),SHFT(4,18),SUMJ(4),SUMPC(4),SUMPF(4),
     & SUMR(4)
      COMMON /C1236/ DT1(4),DT2(4),ETRGM(4),FCT(4),JM(4)
      COMMON /C1237/ JSC(4)
      LONG MON
      REAL LAT,LH
C
C     FAO PENMAN METHOD ADJUSTMENT FACTOR TABLE
      DATA CO / .86,.9,1.,1.,.64,.71,.82,.89,
     1 .43,.53,.68,.79,.27,.41,.59,.7,.96,.98,1.05,1.05,.78,.86,
     2 .94,.99,.62,.7,.84,.93,.5,.6,.75,.87,1.02,1.06,1.1,1.1,
     3 .85,.92,1.01,1.05,.72,.82,.95,1.,.62,.72,.87,.96,.86,.9,
     4 1.,1.,.69,.76,.85,.92,.53,.61,.74,.84,.37,.48,.65,.76,
     5 .96,.98,1.05,1.05,.83,.91,.99,1.05,.7,.8,.94,1.02,.59,
     6 .7,.84,.95,1.02,1.06,1.1,1.1,.89,.98,1.1,1.14,.79,.92,
     7 1.05,1.12,.71,.81,.96,1.06,.86,.9,1.,1.,.76,.81,.88,
     8 .94,.61,.68,.81,.88,.46,.56,.72,.82,.96,.98,1.05,1.05,
     9 .87,.96,1.06,1.12,.77,.88,1.02,1.1,.67,.79,.88,1.05,
     1 1.02,1.06,1.1,1.1,.94,1.04,1.18,1.28,.86,1.01,1.15,1.22,
     2 .78,.92,1.06,1.18,.86,.9,1.,1.,.79,.84,.92,.97,.68,.77,
     3 .87,.93,.55,.65,.78,.9,.96,.98,1.05,1.05,.92,1.,1.11,
     4 1.19,.85,.96,1.11,1.19,.76,.88,1.02,1.14,1.32,1.06,1.1,
     5 1.1,.99,1.1,1.27,1.32,.94,1.1,1.26,1.33,.88,1.01,1.16,
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```
     6 1.27 /
C
C      PRINT ARRAY CO
       IF(S1.GE.1.) WRITE(M4,1000) ((CO(K,NO),K=1,4),NO=1,48)
 1000 FORMAT(1H0,'PENMAN METHOD ADJUSTMENT FACTOR TABLE',
     & 24(/1H ,8F7.2))
C
C      SUBMODELS
       NDAY=N(I)
       DO 10 J=1,NDAY
C             CLIMATIC DATA
       TA=X(1,I,J)
       RH=X(2,I,J)
       U=X(3,I,J)
       RS=X(4,I,J)
C             PRECIPITATION SUMMATION
       SUMR(I)=SUMR(I)+PRCP(I,J)
C             SATURATION AIR VAPOR PRESSURE
       VSAT=EXP((19.078955*TA+429.41016)/(TA+237.3))
C             AIR VAPOR PRESSURE
       VA(J)=VSAT*RH/100.0
C             AIR VAPOR PRESSURE DEFICIT
       VDEF(J)=VSAT-VA(J)
C             AIR PRESSURE
       IF(J.EQ.1) PA=1013.-0.1152*ELEV(I)+5.44E-6*ELEV(I)**2
C             LATENT HEAT OF VAPORIZATION
       LH=2.49037E6-2.1346E3*TA
C             PSYCHROMETRIC CONSTANT
       GAMMA=1615.25*PA/LH
C             SLOPE OF SATURATION VAPOR PRESSURE VERSUS TEMPERATURE CURVE
       DELTA=VSAT*(4098.0259/(TA+237.3)**2)
C             PENMAN WEIGHTING FUNCTION
       W(J)=DELTA/(DELTA+GAMMA)
C             PRINT OUT
       IF(S1.LT.2.) GO TO 10
       IF(J.EQ.1) WRITE(M4,1010) ELEV(I),PA
 1010 FORMAT(1H0,'SUBMODELS'/1H ,5X,'ELEVATION:',F8.1,'  METERS',
     & /1H ,5X,'AIR PRESSURE:',F9.1,'  MBAR')
       IF(J.EQ.1) WRITE(M4,1020)
 1020 FORMAT(1H ,'JULIAN    VAPOR PRESSURE (MBAR)',8X,'LH',6X,
     & 'GAMMA   DELTA     WEIGHTING'/1H ,' DATE    SATUR-    AIR',
     & '    DEFICIT    (J/KG)    (MBAR/DEGREE C)     FUNCTION'/1H ,
     & 10X,'ATION',22X,'(1E6)')
       WRITE(M4,1030) JDATE(I,J),VSAT,VA(J),VDEF(J),LH/1.0E6,GAMMA,DELTA,
     & W(J)
 1030 FORMAT(1H ,I4,F10.2,2F9.2,F11:3,F9.3,F8.3,F12.3)
       IF(J.EQ.NDAY) WRITE(M4,1040)
 1040 FORMAT(1H ,'LH -- LATENT HEAT OF VAPORIZATION   (MULTIPLY ',
     & 'VALUE BY 1E6)'/1H ,'GAMMA -- PSYCHROMETRIC CONSTANT'
     & /1H ,'DELTA -- SLOPE OF THE SATURATION VAPOR PRESSURE CURVE')
   10 CONTINUE
C
C      CALCULATE GRASS REFERENCE CROP ET
C      ***** METHOD 1 IS WITH THE LOCALLY CALIBRATED PENMAN METHOD
       DO 40 J=1,NDAY
       JDAY=JDATE(I.J)
       DAY=JDAY
       X(5,I,J)=0.
       TA=X(1,I,J)
       U=X(3,I,J)
       RS=X(4,I,J)
       IF(TA.EQ.0. .OR. U.EQ.0. .OR. RS.EQ.0. .OR. VDEF(J).EQ.0.)GO TO 20
C             CALCULATE SOIL HEAT FLUX
       SHFT(I,J+3)=TA
       G=(SHFT(I,J+3)-(SHFT(I,J+2)+SHFT(I,J+1)+SHFT(I,J))/3.)*0.15
C             CLEAR SKY SOLAR RADIATION
       RSO=B1(I,1)+B1(I,2)*DAY+B1(I,3)*DAY**2+B1(I,4)*DAY**3
     & +B1(I,5)*DAY**4
C             RATIO OF ACTUAL TO CLEAR SKY SOLAR RADIATION
       R1=RS/RSO
       IF (R1.GT.1.0) R1=1.0
C             CLEAR SKY EMISSIVITY
       EA0=1.24*(VA(J)/(TA+273.16))**(1./7.)
C             ATMOSPHERIC EMISSIVITY
       EA=EA0*(1.44-0.46*R1)
C             NET RADIATION
       RN=0.77*RS-0.98*(1-EA)*2.00239E-9*(TA+273.16)**4
C             PENMAN (1948) WIND FUNCTION
       FU=0.2625+0.1409*U
C             PENMAN COMPUTED ET
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      ETP=W(J)*(RN-G)+(1-W(J))*FU*VDEF(J)
C          CALIBRATED PENMAN ET TO REPRESENT A GRASS REFERENCE CROP
C               NOTE:  CALIBRATION OF THE PENMAN METHOD IS FROM
C                      KRISTENSEN (1979) FOR COPENHAGEN, DENMARK
      ETPC=-0.083+0.921*ETP
C          SAVE VALUE
      X(5,I,J)=ETPC
C          SUMMATION
      SUMPC(I)=SUMPC(I)+ETPC
C          PRINT RESULTS
   20 IF(S1.LT.2.) GO TO 40
      IF(J.EQ.1) WRITE(M4,1050)
 1050 FORMAT(1H0,'CALIBRATED PENMAN METHOD'/1H ,'JULIAN     G      RSO',
     & '   RS/RSO  EMISSIVITY      RN     WIND     PENMAN ET'/1H ,' DATE',
     & '    (MM/    (MM/',25X,'(MM/    FUNC-    (MM/DAY)'/1H ,9X,'DAY)    ',
     & 'DAY)',9X,'CLEAR  ACTUAL  DAY)     TION'/1H ,58X,'1948  CALIB')
      IF(X(5,I,J).EQ.0.) GO TO 30
      WRITE(M4,1060) JDAY,G,RSO,R1,EA0,EA,RN,FU,ETP,ETPC
 1060 FORMAT(1H ,I4,2X,9F7.2)
      GO TO 40
   30 WRITE(M4,1070) JDAY,TA,U,RS,VDEF(J)
 1070 FORMAT(1H ,I4,'    MISSING WEATHER DATA    TA:',F7.1,'  U:',
     & F7.2,'  RS:',F7.2,'  VDEF:',F7.2)
   40 CONTINUE
      IF(S1.GE.2.) WRITE(M4,1080)
 1080 FORMAT(1H ,'G -- SOIL HEAT FLUX  (A NEGATIVE SIGN INDICATES ',
     & 'HEAT FLOW FROM THE SOIL)'/1H ,'RSO -- CLEAR SKY SOLAR ',
     & 'RADIATION'/1H ,'RS -- SOLAR RADIATION'/1H ,'RN -- NET ',
     & 'RADIATION'/1H ,'CALIB -- CALIBRATION BY KRISTIANSEN (1979) ',
     & 'RELATION FOR COPENHAGEN, DENMARK')
C
C     ***** METHOD 2 IS WITH THE FAO PENMAN METHOD
      G3=0.
      DO 80 J=1,NDAY
      JDAY=JDATE(I,J)
      DAY=JDAY
      X(6,I,J)=0.
      CALL DATEE(JDAY,L,ND,365)
      TA=TM(J)
      U=X(3,I,J)
      RS=X(4,I,J)
      IF(TA.EQ.0. .OR. U.EQ.0. .OR. RS.EQ.0. .OR. VDEF(J).EQ.0.)GO TO 60
C          INTERPOLATE IN THE C0 TABLE TO FIND C9
C              TABLE VALUES:
C                   RS IS 3, 6, 9, 12 (MM/DAY)
C                   UDAY IS 0, 3, 6, 9 (M/SEC)
C                   RHMAX IS 30, 60, 90 (%)
C                   UDAY/UNIGHT IS 1, 2, 3, 4
C          IF LONG-TERM WEATHER DATA IS MISSING
      C9=1.0
      IF(RSL(I,L).EQ.0.) GO TO 50
      IO=IFIX(RSL(I,L)/3.)
      JO=IFIX(UDAYL(I,L)/3.)+1
      KO=IFIX(RHMAXL(I,L)/30.)
      MO=IFIX(RL(I,L))
      IF(IO.GT.4) IO=4
      IF(JO.GT.4) JO=4
      IF(MO.GT.4) MO=4
      IF(IO.LE.0) IO=1
      IF(KO.LE.0) KO=1
      IF(MO.LE.0) MO=1
      I1=IO+1
      IF(I1.GT.4) I1=IO
      J1=(MO-1)*12+(KO-1)*4+JO
      J2=J1+4
      IF(J2.GT.48) J2=J1
      J3=J1+12
      IF(J3.GT.48) J3=J1
      J4=J3+4
      IF(J4.GT.48) J4=J3
      J5=J1+1
      IF(J5.GT.48) J5=J1
      J6=J2+1
      IF(J6.GT.48) J6=J2
      J7=J3+1
      IF(J7.GT.48) J7=J3
      J8=J4+1
      IF(J8.GT.48) J8=J4
      W1=FLOAT(IO)*3.
      X1=FLOAT(JO-1)*3.
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      Y1=FLOAT(K0)*30.
      Z1=FLOAT(M0)
      F1=0.
      F2=0.
      F3=0.
      F4=0.
C          NOTE:  NO EXTRAPOLATION ALLOWED
      IF(RL(I,L).GT.1. .AND. RL(I,L).LT.4.) F1=RL(I,L)-Z1
      IF(RHMAXL(I,L).GT.30. .AND. RHMAXL(I,L).LT.90.) F2=(RHMAXL(I,L)
     & -Y1)/30.
      IF(UDAYL(I,L).LT.9.) F3=(UDAYL(I,L)-X1)/3.
      IF(RSL(I,L).GT.3. .AND. RSL(I,L).LT.12.) F4=(RSL(I,L)-W1)/3.
C
      C1=C0(I0,J1)+F1*(C0(I0,J3)-C0(I0,J1))
      C2=C0(I0,J2)+F1*(C0(I0,J4)-C0(I0,J2))
      C3=C0(I0,J5)+F1*(C0(I0,J7)-C0(I0,J5))
      C4=C0(I0,J6)+F1*(C0(I0,J8)-C0(I0,J6))
      C5=C0(I1,J1)+F1*(C0(I1,J3)-C0(I1,J1))
      C6=C0(I1,J2)+F1*(C0(I1,J4)-C0(I1,J2))
      C7=C0(I1,J5)+F1*(C0(I1,J7)-C0(I1,J5))
      C8=C0(I1,J6)+F1*(C0(I1,J8)-C0(I1,J6))
      D1=C1+F2*(C2-C1)
      D2=C3+F2*(C4-C3)
      D3=C5+F2*(C6-C5)
      D4=C7+F2*(C8-C7)
      D5=D1+F3*(D2-D1)
      D6=D3+F3*(D4-D3)
      C9=D5+F4*(D6-D5)
C
C          EXTRA-TERRESTRIAL RADIATION
C               DECLINATION OF THE SUN
   50 G1=-22.7893+4.27921E-4*DAY+6.07616E-3*DAY**2
     & -3.50364E-5*DAY**3+5.04922E-8*DAY**4
C               HOUR ANGLE
      G2=57.296*ACOS(-TAN(0.01745*LAT(I))*TAN(0.01745*G1))
C               DAYTIME HOURS AT ZERO DECLINATION
      IF(J.EQ.1) G3=12.126-1.85191E-3*LAT(I)+7.61048E-5*LAT(I)**2
C               RADIUS VECTOR OF THE EARTH
      G4=0.98387-1.11403E-4*DAY+5.27747E-6*DAY**2
     & -2.68285E-8*DAY**3+3.61634E-11*DAY**4
C               EXTRA-TERRESTRIAL RADIATION
      RA=1.26714*G3/(G4**2)*(0.01745*G2*SIN(0.01745*LAT(I))
     & *SIN(0.01745*G1)+COS(0.01745*LAT(I))*COS(0.01745*G1)
     & *SIN(0.01745*G2))
C          NET RADIATION (FAO EQUATION)
      RN=0.75*RS-2.00239E-9*(TA+273.16)**4*(0.34-0.044*VA(J)**0.5)
     & *(-0.35+1.8*RS/RA)
C          PENMAN WIND FUNCTION (FAO EQUATION)
      FU=0.27+0.2333*U
C          FAO PENMAN METHOD ET FOR A GRASS REFERENCE CROP
      ETPF=C9*(W(J)*RN+(1-W(J))*FU*VDEF(J))
C          SAVE VALUE
      X(6,I,J)=ETPF
C          SUMMATION
      SUMPF(I)=SUMPF(I)+ETPF
C          PRINT RESULTS
   60 IF(S1.LT.2.) GO TO 80
      IF(J.EQ.1) WRITE(M4,1090) LAT(I)
 1090 FORMAT(1H0,'FAO PENMAN METHOD'/1H ,5X,'LATITUDE:',F8.2
     & /1H ,'JULIAN',7X,'AIR',7X,'C',6X,'G1',6X,'G2',6X,'G3',6X,
     & 'G4',6X,'RA',6X,'RN',5X,'WIND   FAO PENMAN'/1H ,' DATE',
     & 4X,'TEMPERATURE',41X,'(MM/   (MM/    FUNC-',6X,'ET'/1H ,
     & 9X,'(DEGREES C)',42X,'DAY)      DAY)    TION   (MM/DAY)')
      IF(X(6,I,J).EQ.0.) GO TO 70
      WRITE(M4,1100) JDAY,TA,C9,G1,G2,G3,G4,RA,RN,FU,ETPF
 1100 FORMAT(1H ,I4,F12.1,2X,4F8.2,F9.4,F7.2,2F8.2,F9.2)
      GO TO 80
   70 WRITE(M4,1110) JDAY,TA,U,RS,VDEF(J)
 1110 FORMAT(1H ,I3,'   MISSING WEATHER DATA   TA:',F7.1,'  U:',
     & F7.2,'  RS:',F7.2,'  VDEF:',F7.2)
   80 CONTINUE
      IF(S1.GE.2.) WRITE(M4,1120)
 1120 FORMAT(1H ,'C -- FAO PENMAN ADJUSTMENT FACTOR'/1H ,'G1 -- ',
     & 'DECLINATION OF THE SUN',/1H ,'G2 -- HOUR ANGLE'/1H ,'G3 -- ',
     & 'DAYTIME HOURS AT ZERO DECLINATION'/1H ,'G4 -- RADIUS VECTOR ',
     & 'OF THE EARTH'/1H ,'RA -- EXTRA-TERRESTRIAL RADIATION'/1H ,
     & 'RN -- NET RADIATION')
C
C     ***** METHOD 3 IS WITH THE JOHANSSON METHOD
      DO 110 J=1,NDAY
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5610       JDAY=JDATE(I,J)
5620       X(7,I,J)=0.
5630       U=X(3,I,J)
5640       RS=X(4,I,J)
5650       IF(TA.EQ.0. .OR. U.EQ.0. .OR. RS.EQ.0. .OR. VDEF(J).EQ.0.)GO TO 90
5660 C          JOHANSSON METHOD ET
5670       ETJ=0.14+0.22*RS+0.092*U*VDEF(J)
5680 C          JOHANSSON METHOD ET FOR A GRASS REFERENCE CROP
5690       ETJ= 0.7*ETJ
5700 C          SAVE VALUE
5710       X(7,I,J)=ETJ
5720 C          SUMMATION
5730       SUMJ(I)=SUMJ(I)+ETJ
5740 C          PRINT RESULTS
5750    90 IF(S1.LT.2.) GO TO 110
5760       IF(J.EQ.1) WRITE(M4,1130)
5770  1130 FORMAT(1H0,'JOHANSSON METHOD'/1H ,'JULIAN     SOLAR     WIND',
5780      & 'SPEED   AIR VAPOR   JOHANSSON'/1H ,' DATE    RADIATION      ',
5790      & '(M/S)     PRESSURE',7X,'ET'/1H ,9X,'(MM/DAY)',17X,'DEFICIT',
5800      & 4X,'(MM/DAY)'/1H ,34X,'(MBAR)')
5810       IF(X(7,I,J).EQ.0.) GO TO 100
5820       WRITE(M4,1140) JDAY,RS,U,VDEF(J),ETJ
5830  1140 FORMAT(1H ,I4,F11.2,F13.2,F12.2,F11.2)
5840       GO TO 110
5850   100 WRITE(M4,1150) JDAY,TA,U,RS,VDEF(J)
5860  1150 FORMAT(1H ,I3,'   MISSING WEATHER DATA   TA:',F7.1,'  U:',
5870      & F7.2,'  RS:',F7.2,'  VDEF:',F7.2)
5880   110 CONTINUE
5890 C
5900 C
5910 C     SET UP TEMPERATURES FOR SOIL HEAT FLUX CALCULATIONS FOR NEXT RUN
5920       DO 120 K=1,3
5930   120 SHFT(I,K)=SHFT(I,K+NDAY)
5940 C
5950 C     PRINT DAILY AND SUM AMOUNTS FOR ET AND PRECIPITATION
5960 C          PRINT COMPUTATION AND STARTING DATE
5970       CALL DATEE(JSC(I),NM,ND,365)
5980       WRITE(M4,1160) (REGION(I,K),K=1,5),ND,MON(NM),NDATE(2)
5990  1160 FORMAT(1H0/1H0,'GRASS REFERENCE CROP ET'/1H ,5X,'REGION:  ',
6000      & 5A4/1H ,5X,'STARTING DATE:',I4,1X,A4,I5)
6010       CALL DATEE(NDATE(1),NM,ND,365)
6020       WRITE(M4,1170) ND,MON(NM),NDATE(2)
6030  1170 FORMAT(1H ,5X,'COMPUTATION DATE:',I4,1X,A4,I5)
6040       CALL DATEE(JRSUM(I),NM,ND,365)
6050       WRITE(M4,1180) ND,MON(NM),NDATE(2)
6060  1180 FORMAT(1H ,5X,'SUMMATION STARTING DATE:',I4,1X,A4,I5)
6070       WRITE(M4,1190)
6080  1190 FORMAT(1H0,' DATE    JULIAN   GRASS REFERENCE CROP ET ',
6090      & '(MM/DAY)    PRECIPITATION'/1H ,10X,'DATE    CALIBRATED    ',
6100      & 'FAO',5X,'JOHANSSON',10X,'(MM)'/1H ,20X,'PENMAN    PENMAN')
6110       X(5,I,NDAY+1)=0.
6120       X(6,I,NDAY+1)=0.
6130       X(7,I,NDAY+1)=0.
6140       PRCP(I,NDAY+1)=0.
6150       DO 130 J=1,NDAY
6160 C          CALCULATE PERIOD SUMS
6170       X(5,I,NDAY+1)=X(5,I,NDAY+1)+X(5.I,J)
6180       X(6,I,NDAY+1)=X(6,I,NDAY+1)+X(6,I,J)
6190       X(7,I,NDAY+1)=X(7,I,NDAY+1)+X(7,I,J)
6200       PRCP(I,NDAY+1)=PRCP(I,NDAY+1)+PRCP(I,J)
6210       CALL DATEE(JDATE(I,J),NM,ND,365)
6220       WRITE(M4,1200) ND,MON(NM),JDATE(I,J),X(5,I.J),X(6,I,J),X(7,I.J),
6230      & PRCP(I,J)
6240  1200 FORMAT(1H ,I2,1X,A3,I7,2X,3F10.2,F17.1)
6250   130 CONTINUE
6260       DO=JDATE(I,NDAY)-(NDAY-1.)/2.
6270       WRITE(M4,1210) DO,X(5.I,NDAY+1)/NDAY,X(6,I,NDAY+1)/NDAY.
6280      & X(7,I,NDAY+1)/NDAY,PRCP(I,NDAY+1)/NDAY
6290  1210 FORMAT(1H0,'MEAN',F11.1,3F10.2,F18.2)
6300       WRITE(M4,1220) X(5,I,NDAY+1).X(6,I,NDAY+1),X(7,I,NDAY+1).
6310      & PRCP(I,NDAY+1)
6320  1220 FORMAT(1H ,'PERIOD SUM (MM)',3F10.2,F17.1)
6330       WRITE(M4,1230) SUMPC(I),SUMPF(I).SUMJ(I),SUMR(I)
6340  1230 FORMAT(1H ,'SEASON SUM (MM)'.3F10.2.F17.1)
6350 C
6360 C     EXPECTED GRASS REFERENCE CROP ET FOR NEXT 5 DAYS
6370       JDF=JSC(I)+NDAY+2
6380       DLT=DT1(I)
6390       IF(JDF.GT.JM(I)) DLT=DT2(I)
6400       ETRG5(I)=(ETRGM(I)/(EXP(((JDF-JM(I))/DLT)**2)))*FCT(I)
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C          PRINT EXPECTED ET FORECAST
      WRITE(M4,1240) FCT(I),ETRG5(I)
 1240 FORMAT(1H0,'FORECAST GRASS REFERENCE CROP ET FOR NEXT 5 DAYS'
     & /1H ,'  BASED ON',F7.2,'  OF LONG-TERM VALUE:',F8.2,'  MM/DAY')
C
      RETURN
      END
C
C
C
      SUBROUTINE FARMS(NREG,M3,M4,S1,NTF)
C     SUBROUTINE TO CALCULATE IRRIGATION DATES
C     SUBROUTINE NUMBER 3
C
      DIMENSION R(18)
      COMMON /CFARMS/ CROP(3),FARM(5),FIELD(3)
      COMMON /C13/ XA(40),XN(40)
      COMMON /C23/ ETRG5(4)
      COMMON /C37/ WI(7,100)
      COMMON /C38/ AW(5,2),RZMIN,RZMAX,RZLIM,NSL
      COMMON /C39/ C(20,9),JDC(5,2),NCUT
      COMMON /C123/ FORC(4,15),MON(13),N(4),NDATE(2),PRCP(4,16),
     & REGION(4,5),X(7,4,16)
      COMMON /C134/ B(4,6)
      COMMON /C389/ D(4,11),JDE,JDEFC,NCR
      COMMON /C1236/ DT1(4),DT2(4),ETRGM(4),FCT(4),JM(4)
      COMMON /C1237/ JSC(4)
      LONG MON,XA
C
C     BASAL CROP COEFFICIENT TABLE
C          CROPS ARE:
C               1     SMALL GRAINS
C               2     SNAP BEANS
C               3     PEAS
C               4     POTATOES
C               5     SUGAR BEETS
C               6     CORN
C               7     WINTER WHEAT
C               8     PASTURE (GRAZED GRASS, GRASS-LEGUMES, OR ALFALFA)
C               9     CLOVER, GRASS-LEGUMES (CUT)
C              10     GRASS (CUT)
C              11     ALFALFA (CUT)
C
      DATA C / 4.8,10.5,22.9,47.6,66.7,81.9,92.4,97.1,98.1,100.0,
     1 100.0,97.3,75.7,43.2,16.2,0.,0.,0.,0.,0.,
     2 5.2,10.4,25.0,36.5,47.9,62.5,75.0,88.5,97.9,100.0,
     3 100.0,100.0,65.7,31.4,9.8,5.9,0.,0.,0.,0.,
     4 3.1,4.1,6.2,12.4,24.7,42.3,60.8,77.3,91.8,100.,
     5 100.,87.,48.,32.,12.,0.,0.,0.,0.,0.,
     6 20.5,33.3,42.3,55.1,69.2,80.8,89.7,96.2,98.7,100.,
     7 100.,100.,93.,91.5,90.1,88.7,85.9,52.1,8.5,0.,
     8 0.,1.0,2.9,5.8,13.6,25.2,40.8,62.1,82.5,100.,
     9 100.,100.,100.,84.,72.,52.,44.,32.,20.,0.,
     1 2.1,3.1,4.2,9.4,19.8,34.4,55.2,71.9,86.5,100.,
     2 100.,100.,98.9,96.8,94.7,87.4,78.9,20.,6.3,0.,
     3 0.,12.5,27.5,40.,55.,67.5,82.5,90.,95.,100.,
     4 100.,98.2,92.8,43.2,10.8,0.,0.,0.,0.,0.,
     5 14.5,29.,44.9,58.,66.7,75.4,84.1,91.3,97.1,100.,
     6 100.,100.,100.,100.,100.,100.,100.,0.,0.,0.,
     7 0.,12.,28.3,45.7,67.4,71.7,80.4,90.2,97.8,100.,
     8 100.,100.,31.,0.,0.,0.,0.,0.,0.,0. /
      DATA D / 0.18,1.23,0.12,0.,
     1 0.18,1.14,0.12,0.,
     2 0.18,1.15,0.12,0.,
     3 0.18,0.96,0.25,0.,
     4 0.18,1.21,0.96,0.,
     5 0.18,1.14,0.19,0.,
     6 0.83,1.23,0.12,0.,
     7 0.52,1.08,0.52,0.52,
     8 0.55,1.10,0.55,0.55,
     9 0.58,1.08,0.58,0.58,
     1 0.53,1.22,0.30,0.38 /
C
C     SET NUMBER OF CROPS
      NCROP=11
      IF(S1.EQ.0.) GO TO 20
      WRITE(M4,1000)
 1000 FORMAT(1H0,'BASAL CROP COEFFICIENT ARRAY')
      DO 10 NCR=1,NCROP-2
      WRITE(M4,1010) (NCR,(C(K,NCR),K=1,20))
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 1010 FORMAT(1H ,'CROP:',I4,2(/1H ,5X,10F7.1))
   10 CONTINUE
      WRITE(M4,1020)
 1020 FORMAT(1H0,'MINIMUM AND MAXIMUM BASAL CROP COEFFICIENT ARRAY')
      WRITE(M4,1030) ((D(K,NCR),K=1,4),NCR=1,NCROP)
 1030 FORMAT(1H ,5X,4F7.2)
C
   20 NTF=0
C     START OF REGION LOOP
      DO 280 I=1,NREG
      JSF=JSC(I)+N(I)
C
C     FARM DATA ( 1+2(NFARMS)+6(NFLD) LINES FOR EACH REGION )
C           NUMBER OF FARMS
      CALL FREEFORM(NN,XN,NA,XA)
      NFARMS=XN(1)
      IF(S1.GE.1.) WRITE(M4,1040) NFARMS
 1040 FORMAT(1H0,'FARM DATA'/1H ,5X,'NUMBER OF FARMS:',I4)
C
C     START OF FARM LOOP
      DO 270 M=1,NFARMS
C
C           FARM INFORMATION ( 2+6(NFLD) LINES FOR EACH FARM )
C                 FARM NAME
      READ(M3,1050) (FARM(K),K=1,5)
 1050 FORMAT(5A4)
      IF(S1.GE.1.) WRITE(M4,1060) (FARM(K),K=1,5)
 1060 FORMAT(1H ,5X,'FARM INFORMATION'/1H ,10X,'FARM NAME:  ',5A4)
C                 NUMBER OF FIELDS
C                       NOTE:  ONLY 15 FIELDS FOR EACH FARM AND 100
C                              FIELDS FOR ALL REGIONS ARE ALLOWED WITH
C                              PRESENT DIMENSIONS
      CALL FREEFORM(NN,XN,NA,XA)
      NFLD=XN(1)
      IF(S1.GE.1.) WRITE(M4,1070) NFLD
 1070 FORMAT(1H ,10X,'NUMBER OF FIELDS:',I4)
      IF(NFLD.GT.15) GO TO 290
C
C     START OF FIELD LOOP
      DO 250 NF=1,NFLD
C
C                 FIELD DATA (6 LINES FOR EACH FIELD)
C                       FIELD NAME
      READ(M3,1080) (FIELD(K),K=1,3)
 1080 FORMAT(3A4)
      IF(S1.GE.1.) WRITE(M4,1090) (FIELD(K),K=1,3)
 1090 FORMAT(1H0,10X,'FIELD DATA'/1H ,15X,'FIELD NAME:  ',3A4)
C
C                       CROP NAME
      READ(M3,1100) (CROP(K),K=1,3)
 1100 FORMAT(3A4)
      IF(S1.GE.1.) WRITE(M4,1110) (CROP(K),K=1,3)
 1110 FORMAT(1H ,15X,'CROP NAME:  ',3A4)
C
C                       BASIC FIELD DATA
      CALL FREEFORM(NN,XN,NA,XA)
      NCR=XN(1)
      JDP=XN(2)
      JDE=XN(3)
      JDEFC=XN(4)
      JDH=XN(5)
      JFSUM=XN(6)
      JIN=XN(7)
      WIN=XN(8)
      E=XN(9)
      XMIN=XN(10)
      RZMIN=XN(11)
      RZMAX=XN(12)
      RZLIM=XN(13)
      IF(S1.GE.1.) WRITE(M4,1120) NCR,JDP,JDE,JDEFC,JDH,JFSUM,JIN,WIN,
     & E,XMIN,RZMIN,RZMAX,RZLIM
 1120 FORMAT(1H ,15X,'BASIC FIELD DATA'/1H ,20X,'CROP NUMBER:',I4,
     & /1H ,20X,'PLANTING JULIAN DATE:',I5
     & /1H ,20X,'EMERGENCE JULIAN DATE:',I5/1H ,20X,'EFFECTIVE ',
     & 'FULL COVER JULIAN DATE:',I5/1H ,20X,'HARVEST JULIAN DATE:',
     & I5/1H ,20X,'FIELD SUMMATION STARTING JULIAN DATE:',I5/1H ,
     & 20X,'JULIAN DATE OF INITIAL SOIL WATER DEPLETION:',I5
     & /1H ,20X,'INITIAL SOIL WATER DEPLETION:',F3.2/1H ,
     & 20X,'IRRIGATION EFFICIENCY:',F6.1/1H ,20X,'MINIMUM IRRIGATION ',
     & 'AMOUNT:',F6.1/1H ,20X,'MINIMUM EFFECTIVE ',
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     & 'ROOTZONE DEPTH:',F6.1/1H ,20X,'MAXIMUM EFFECTIVE ROOTZONE ';
     & 'DEPTH:',F6.1/1H ,20X,'LIMITING MAXIMUM EFFECTIVE ROOTZONE ',
     & 'DEPTH:',F6.1)
C
C                    EXTRA LINE FOR A PERENNIAL CROP
      NCUT=0
      IF(NCR.LT.8) GO TO 40
      CALL FREEFORM(NN,XN,NA,XA)
C                         SET NUMBER OF CUTTINGS
      NCUT=5
      DO 30 NC=1,NCUT
      JDC(NC,1)=XN(-1+2*NC)
      JDC(NC,2)=XN(2*NC)
   30 CONTINUE
      IF(S1.GE.1) WRITE(M4,1130) ((JDC(NC,1),JDC(NC,2)),NC=1,NCUT)
 1130 FORMAT(1H ,15X,'EXTRA DATA FOR PERENNIAL CROPS'/1H ,20X,
     & 'CUTTING JULIAN DATE    EFFECTIVE FULL COVER JULIAN DATE',
     & 5(/1H ,20X,I11,I27))
C
C                    SOIL DATA
C                         SET NUMBER OF SOIL LAYERS
   40 NSL=5
      CALL FREEFORM(NN,XN,NA,XA)
      DO 50 NS=1,NSL
      AW(NS,1)=XN(-1+2*NS)
      AW(NS,2)=XN(2*NS)
   50 CONTINUE
      IF(S1.GE.1.) WRITE(M4,1140) ((AW(NS,1),AW(NS,2)),NS=1,NSL)
 1140 FORMAT(/1H ,15X,'SOIL DATA'/1H ,20X,'DEPTH    MAXIMUM ',
     & 'AVAILABLE SOIL WATER',5(/1H ,20X,F5.1,F18.1))
C
C                    FIELD IRRIGATION DATA
      CALL FREEFORM(NN,XN,NA,XA)
      DPAP=XN(1)
      DPA=XN(2)
      JI=XN(3)
      XAMT=XN(4)
      NO=N(I)+4
      DO 70 K=5,19
      IF(K.GT.NO) GO TO 60
      R(K-1)=XN(K)
      GO TO 70
   60 R(K-1)=0.
   70 CONTINUE
      NO=N(I)+3
      IF(S1.GE.1.) WRITE(M4,1150) DPAP,DPA,JI,XAMT,((K-3,R(K)),K=4,NO)
 1150 FORMAT (1H ,15X,'FIELD IRRIGATION DATA'/1H ,20X,'PERCENT ',
     & 'DEPLETION ALLOWED:',F6.1/1H ,20X,'DEPLETION ALLOWED:',
     & F6.1/1H ,20X,'PREVIOUS IRRIGATION JULIAN DATE:',I5
     & /1H ,20X,'PREVIOUS IRRIGATION AMOUNT:',F6.1/1H ,
     & 20X,'PERIOD DAY    RAIN AND/OR IRRIGATION DIFFERENCE',
     & 15(/1H ,20X,I6,F25.1))
C
C                    FIELD CONDITION
      CALL FREEFORM(NN,XN,NA,XA)
      DPL=XN(1)
      R(1)=XN(2)
      R(2)=XN(3)
      R(3)=XN(4)
      SUMRF=XN(5)
      SUMET=XN(6)
      SUMWT=XN(7)
      IF(S1.GE.1.) WRITE(M4,1160) DPL,(R(K),K=1,3),SUMRF,SUMET,SUMWT
 1160 FORMAT(1H ,15X,'FIELD CONDITION'/1H ,20X,'SOIL WATER ',
     & 'DEPLETION:',F8.2/1H ,20X,'PAST THREE DAYS ADJUSTED PRECIPIT',
     & 'ATION AND/OR IRRIGATION AMOUNTS:'/1H ,25X,3F10.2/1H ,
     & 20X,'SUM OF PRECIPITATION:',F7.1/1H ,20X,'SUM OF CROP ET:',
     & F8.2/1H .20X,'SUM OF NET IRRIGATION AMOUNTS:'.F7.1)
C
C     SET SWITCH S2
C          IF THE ALLOWED SOIL WATER DEPLETION IS GIVEN AS AN INPUT
C          THEN THIS VALUE REMAINS CONSTANT AND SWITCH S2 HAS THE
C          VALUE OF 0.
      IF(DPA.NE.0.) S2=0.
C          IF THE ALLOWED SOIL WATER DEPLETION IS NOT GIVEN BUT THE
C          PERCENT ALLOWED SOIL WATER DEPLETION IS. THEN THE
C          ALLOWED SOIL WATER DEPLETION IS COMPUTED.  THE SWITCH
C          S2 HAS THE VALUE OF 1.
      IF(DPA.EQ.0.) S2=1.
C
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      NDAY=N(I)
      SUMETZ=0.
      SUMPZ=0.
      JDAY=JSC(I)
C     CHECK IF PAST HARVEST DATE
      IF(JSC(I).GT.JDH) GO TO 190
C     START OF DAY LOOP
      DO 180 J=1,NDAY
      JDAY=JSC(I)+J-1
C     CHECK IF DATE IS DURING THE CROP GROWTH SEASON
      IF(JDAY.LT.JDP .OR. JDAY.GT.JDH) GO TO 180
C     CHECK IF DATE IS BEFORE THE STARTING DATE
      IF(JDAY.LT.JIN) GO TO 180
C
C     GRASS REFERENCE CROP ET
      ETRG=0.
      ETRG=X(5,I,J)
      IF(ETRG.EQ.0.) ETRG=X(6,I,J)
      IF(ETRG.EQ.0.) ETRG=X(7,I,J)
C
C     CALCULATE CROP ET
C          BASAL CROP COEFFICIENT
      CALL KCB(JDAY,CT,PCT,AKC1)
C
C          CROP COEFFICIENT DEPENDING ON AVAILABLE SOIL WATER
C               MAXIMUM AVAILABLE SOIL WATER
      CALL MAXASW(JDAY,M4,RZ,AVM)
C               AVAILABLE SOIL WATER
      AV=(1.0-DPL/AVM)*100.0
      IF(AV.LT.0.) AV=0.
C               SOIL WATER CROP COEFFICIENT
      AKC2=ALOG(1.0+AV)/ALOG(101.0)
C          CROP COEFFICIENT EXCLUDING A WET SOIL SURFACE
      AKC=AKC1*AKC2
C
C          CROP ET ASSOCIATED WITH A WET SOIL SURFACE
      ETR=0.
      K=J+3
C               FARM PRECIPITATION
      PRCPF=PRCP(I,J)+R(K)
      R(K)=PRCPF
C               FARM ADDED WATER
      IF(JI.EQ.JDAY) R(K)=R(K)+XAMT
      RX=R(K)
      IF(AKC.GE.1.09) GO TO 140
      IF(JI.NE.JDAY) GO TO 80
C               IF IRRIGATION DAY
      ETR=(1.09-AKC)*ETRG
      IF(ETR.LT.0.) ETR=0.
      R(K)=R(K)-ETR
      GO TO 140
C               IF AFTER IRRIGATION OR RAIN
   80 IF(R(K-1).LE.0.) GO TO 110
      ETR=0.8*(1.09-AKC)*ETRG
      R(K-1)=R(K-1)-ETR
      IF(R(K-1).GE.0.) GO TO 130
      R(K-2)=R(K-2)+R(K-1)
      R(K-1)=0.
   90 IF(R(K-2).GE.0.) GO TO 130
      R(K-3)=R(K-3)+R(K-2)
      R(K-2)=0.
  100 IF(R(K-3).GE.0.) GO TO 130
      ETR=ETR+R(K-3)
      R(K-3)=0.
      GO TO 130
  110 IF(R(K-2).LE.0.) GO TO 120
      ETR=0.5*(1.09-AKC)*ETRG
      R(K-2)=R(K-2)-ETR
      GO TO 90
  120 IF(R(K-3).LE.0.) GO TO 130
      ETR=0.3*(1.09-AKC)*ETRG
      R(K-3)=R(K-3)-ETR
      GO TO 100
  130 IF(ETR.LT.0.) ETR=0.
C
C          CROP ET
  140 ET=AKC*ETRG+ETR
C
C     CALCULATE SOIL WATER DEPLETION
C          DETERMINE THE MAXIMUM EFFECTIVE ROOTZONE WHETHER LIMITED
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C          BY THE CROP (RZMAX) OR BY THE SOIL (RZLIM)
      IF(RZMAX.GT.RZLIM .AND. RZLIM.NE.0.) GO TO 150
      RZM=RZMAX
      GO TO 160
  150 RZM=RZLIM
C          INITIAL MEASUREMENT OF SOIL WATER DEPLETION
  160 IF(JDAY.EQ.JIN) DPL=WIN*RZ/RZM
C          INITIAL SOIL WATER DEPLETION
      DPLI=DPL
C          SOIL WATER BALANCE EQUATION
      DPL=DPL+ET-RX
      IF(DPL.LT.0.) DPL=0.
C
C     ALLOWED SOIL WATER DEPLETION
      IF(S2.EQ.1.) DPA=DPAP*AVM/100.
C
C     FIELD SUMMATIONS
      IF(JDAY.LT.JFSUM) GO TO 170
C          SEASONAL
      SUMET=SUMET+ET
      IF(JI.EQ.JDAY) SUMWT=SUMWT+XAMT
      SUMRF=SUMRF+PRCPF
C          PERIOD
  170 SUMET2=SUMET2+ET
      SUMP2=SUMP2+PRCPF
C
C     PRINT RESULTS
      IF(S1.LT.2.) GO TO 180
      AKC3=ETR/ETRG
      AKC4=ET/ETRG
      D0=0.
      IF(JI.EQ.JDAY) D0=XAMT
      IF(J.EQ.1 .OR. JDAY.EQ.JDP .OR. JDAY.EQ.JIN) WRITE(M4,1170)
     & (FIELD(N0),N0=1,3),(CROP(N0),N0=1,3),NCR
 1170 FORMAT(1H0,'FIELD SOIL WATER DEPLETION CALCULATIONS'
     & /1H ,5X,'FIELD:  ',3A4/1H ,5X,'CROP:  ',3A4/1H ,5X,'CROP NUMBER:'
     & ,I4/1H ,'JULIAN   TS   PCT   ROOT    AVM    INITIAL   AV   ETRG',
     & '   KC1   KC2   KC3   KC4     ET    IRRIG-   PRECIP-   WATER   ',
     & 'DPL   ALLOWED'/1H ,' DATE',15X,'ZONE   (MM)',6X,'DPL    (%)',
     & '   (MM)',27X,'(MM/    ATION   ITATION   ADDED   (MM)     DPL'
     & /1H ,20X,'(CM)',12X,'(MM)',42X,'DAY)    (MM)     (MM)     (MM)',
     & 12X,'(MM)')
      WRITE(M4,1180) JDAY,CT,PCT,RZ,AVM,DPLI,AV,ETRG,AKC1,AKC2,AKC3,
     & AKC4,ET,D0,PRCPF,D0+PRCPF,DPL,DPA
 1180 FORMAT (1H ,I4,F7.1,F6.1,F7.1,F8.2,F9.2,F7.1,F6.2,1X,4F6.2,F7.2,
     & F8.1,2F9.1,2F8.2)
      IF(J.EQ.NDAY) WRITE(M4,1190) SUMET2,XAMT,SUMP2,XAMT+SUMP2,SUMET,
     & SUMWT,SUMRF,SUMWT+SUMRF
 1190 FORMAT(1H ,'PERIOD SUM (MM)',64X,F7.2,F8.1,2F9.1
     & /1H ,'SEASON SUM (MM)',64X,F7.2,F8.1,2F9.1
     & /1H ,'TS -- TIME SCALE WHICH IS: PERCENT TIME FROM EMERGENCE ',
     & 'TO EFFECTIVE FULL COVER'/1H ,27X,'OR DAYS AFTER EFFECTIVE FULL',
     & ' COVER'/1H ,'PCT--PERCENT FROM MINIMUM TO MAXIMUM BASAL CROP ',
     & 'COEFFICIENT'
     & /1H ,'AVM -- MAXIMUM AVAILABLE SOIL WATER'/1H ,'DPL -- ',
     & 'SOIL WATER DEPLETION'/1H ,'AV -- PERCENT AVAILABLE SOIL',
     & ' WATER'/1H ,'ETRG -- GRASS REFERENCE CROP ET'/1H ,
     & 'KC1 -- BASAL CROP COEFFICIENT'/1H ,'KC2 -- CROP COEFFICIENT ',
     & 'RELATED TO AVAILABLE SOIL WATER'/1H ,'KC3 -- CROP COEFFICIENT ',
     & 'RELATED TO A WET SURFACE'/1H ,'KC4 -- CROP COEFFICIENT')
C
C     END OF DAY LOOP
  180 CONTINUE
C
C     CHECK IF DATE IS DURING THE CROP GROWTH SEASON
      IF(JDAY.LT.JDP .OR. JDAY.GT.JDH) GO TO 190
C     CHECK IF DATE IS BEFORE THE STARTING DATE
      IF(JDAY.LT.JIN) GO TO 190
C
C     PREDICT THE IRRIGATION DATE
C          FUTURE PERIOD STARTING DATE
      JSF=JDAY+1
C          MINIMUM NET IRRIGATION AMOUNT
      XNMIN=E*XMIN/100.0
      CALL SCHED(I,JSF,DPL,AVM,JDH,DPA,DPAP,XNMIN,M4,S1,S2,DPASF,NXD,
     & XI,NXDP)
C     CALCULATE THE IRRIGATION REQUIREMENT
      AIR=100.0*XI/E
C
C     CALCULATE EXPECTED ET FOR THE NEXT 5 DAYS
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C            BASAL CROP COEFFICIENT FOR NEXT 5 DAYS
      JDF=JSC(I)+N(I)+2
      CALL KCB(JDF,CT,PCT,AKC5)
C            EXPECTED ET FOR NEXT 5 DAYS
      ETA5=AKC5*ETRG5(I)
C
C     PRINT FIELD DATA
C            PAGE CONTROL
  190 IF(NF.EQ.1 .AND. S1.EQ.0.) WRITE(M4,1200)
 1200 FORMAT(1H1)
      CALL DATEE(NDATE(1).NM,ND,365)
      IF(NF.EQ.1 .OR. S1.GE.1.) WRITE(M4,1210) (FARM(K),K=1,5),
     & ND,MON(NM),NDATE(2)
 1210 FORMAT(1H0,'IRRIGATION SCHEDULING'/1H ,5X,'FARM:  ',5A4/1H ,5X,
     & 'COMPUTATION DATE:',I4,1X,A4,I6/1H0,'  FIELD',10X,'CROP',9X,'SO',
     & 'IL WATER DEPLETION',6X,'FORECAST',8X,'-- IRRIGATION DATES --',
     & '      IRRIGATION'/1H ,53X,'(NEXT 5 DAYS)',34X,'AMOUNT'/1H ,31X,
     & 'CURRENT    ALLOWED',21X,'PREVIOUS',6X,'-- NEXT --',7X,'(MM)'
     & /1H ,32X,'(MM)',7X,'(MM)',7X,'KC',6X,'ET'/1H ,59X,'(MM/DAY)',
     & 14X,'WITHOUT    WITH'/1H ,82X,'RAIN',6X,'RAIN')
      IF(JDAY.LT.JDP) GO TO 210
      IF(JDAY.GT.JDH) GO TO 220
      IF(JDAY.LT.JIN) GO TO 230
      CALL DATEE(NI,NM,ND,365)
      CALL DATEE(NXD,IX,IY,JDH)
      CALL DATEE(NXDP,JX,JY,JDH)
      IF(ABS(B(I,1)).LE.0.) GO TO 200
      WRITE(M4,1220) (FIELD(K),K=1,3),(CROP(K),K=1,3),DPL,DPASF,AKC5,
     & ETA5,ND,MON(NM),IY,MON(IX),JY,MON(JX),AIR
 1220 FORMAT(1H ,3A4,3X,3A4,F10.2,F11.2,F9.2,F8.2,2X,3(I6,1X,A4),F7.0)
      GO TO 240
  200 WRITE(M4,1230) (FIELD(K),K=1,3),(CROP(K),K=1,3),DPL,DPA,AKC5,
     & ETA5,ND,MON(NM),IY,MON(IX),AIR
 1230 FORMAT(1H ,3A4,3X,3A4,F10.2,F11.2,F9.2,F8.2,2X,2(I6,1X,A4),F7.0)
      GO TO 240
  210 CALL DATEE(JDP,NM,ND,365)
      WRITE(M4,1240) (FIELD(K),K=1,3),(CROP(K),K=1,3),ND,MON(NM)
 1240 FORMAT(1H ,3A4,3X,3A4,2X,'BEFORE THE PLANTING DATE:',I4,1X,A4)
      GO TO 240
  220 CALL DATEE(JDH,NM,ND,365)
      WRITE(M4,1250) (FIELD(K),K=1,3),(CROP(K),K=1,3),ND,MON(NM)
 1250 FORMAT(1H ,3A4,3X,3A4,2X,'PAST THE HARVEST OR FINAL IRRIGATION',
     & ' DATE:',I4,1X,A4)
      GO TO 240
  230 CALL DATEE(JIN,NM,ND,365)
      WRITE(M4,1260) (FIELD(K),K=1,3),(CROP(K),K=1,3),ND,MON(NM)
 1260 FORMAT(1H ,3A4,3X,3A4,2X,'BEFORE INITIAL SOIL WATER',
     & ' MEASUREMENT DATE:',I4,1X,A4)
C
C     CREATE DATA FILE FOR NEXT RUN
  240 NTF=NTF+1
      WI(1,NTF)=DPL
      WI(2,NTF)=R(NDAY+1)
      WI(3,NTF)=R(NDAY+2)
      WI(4,NTF)=R(NDAY+3)
      WI(5,NTF)=SUMRF
      WI(6,NTF)=SUMET
      WI(7,NTF)=SUMWT
C
C     END OF FIELD LOOP
  250 CONTINUE
C
C     EXPECTED PRECIPITATION
C            CALCULATION
      IF(ABS(B(I,1)).LE.0.) GO TO 260
      DAY=JSC(I)+7
      PP=14.*(B(I,1)+B(I,2)*DAY+B(I,3)*DAY**2+B(I,4)*DAY**3
     & +B(I,5)*DAY**4+B(I,6)*DAY**5)
      IF(PP.LT.0.) PP=0.
C            PRINT EXPECTED PRECIPITATION
      WRITE(M4,1270) PP
 1270 FORMAT(1H0,5X,'EXPECTED PRECIPITATION DURING THE NEXT TWO WEEKS:',
     & F7.0,'  MM')
C
C     PRINT FORECAST INFORMATION
  260 WRITE(M4.1280) (FORC(I,K),K=1,15).ETRG5(I).FCT(I)
 1280 FORMAT(1H0,5X,'FORECAST:  '.15A4/1H ,16X.
     & 'GRASS REFERENCE CROP ET FOR NEXT 5 DAYS:',F7.2,'  MM/DAY'
     & /1H ,18X,'BASED ON',F6.2,'  OF THE LONG-TERM VALUE'/1H0)
C
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C     END OF FARM LOOP
  270 CONTINUE
C
C     CHANGE STARTING JULIAN DATE FOR NEXT RUN
      JSC(I)=JSC(I)+N(I)
C
C     END OF REGION LOOP
  280 CONTINUE
C
      RETURN
C
C     PRINT ERROR MESSAGE AND STOP PROGRAM
C          ERROR MESSAGE: NFLD
  290 WRITE(M4,1290) I
 1290 FORMAT(1H0,'* ERROR NFLD *'/1H ,'FOR REGION',I4,
     & '  THE NUMBER OF FIELDS EXCEEDS MAXIMUM OF 15')
      STOP
C
      END
C
C
C
      SUBROUTINE SCHED(I,JSF,DPLSF,AVMSF,JDH,DPA,DPAP,XNMIN,M4,S1,S2,
     & DPASF,NXD,XI,NXDP)
C     SUBROUTINE TO DETERMINE THE NEXT IRRIGATION DATE
C     SUBROUTINE NUMBER 4
C          NOTE:  SOIL WATER DEPLETION AND MAXIMUM AVAILABLE SOIL WATER
C                 FROM THE LAST DAY OF THE PRESENT PERIOD ARE SAVED BY
C                 USING DPLSF AND AVMSF
C
      COMMON /C46/ CT,PCT,AV,ETRG,AKC1,AKC2,AKC
      COMMON /C134/ B(4,6)
C
C     NEXT IRRIGATION DATE WITHOUT PRECIPITATION
C          CHECK FIRST DAY
      DPASF=DPA
      IF(S2.EQ.1.) DPASF=DPAP*AVMSF/100.0
      IF(DPLSF.GE.DPASF .AND. DPLSF.GE.XNMIN) GO TO 20
      DPL=DPLSF
      DO 10 JDAY=JSF,JDH
C          MAXIMUM AVAILABLE SOIL WATER
      CALL MAXASW(JDAY,M4,RZ,AVM)
C          ALLOWED SOIL WATER DEPLETION
      IF(S2.EQ.1.) DPA=DPAP*AVM/100.0
C          COMPUTE ET
      CALL ETAVG(I,JDAY,DPLSF,AVMSF,ETA)
C          SOIL WATER DEPLETION
      DPLI=DPL
      DPL=DPL+ETA
C          PRINT RESULTS
      IF(JDAY.EQ.JSF .AND. S1.GE.3) WRITE(M4,1000) XNMIN
 1000 FORMAT(1H0,'PREDICTION OF NEXT IRRIGATION DATE'
     & /1H ,5X,'MINIMUM NET IRRIGATION AMOUNT:',F7.1
     & /1H ,'JULIAN   TS   PCT   ROOT    AVM    INITIAL   AV   ETRG',
     & '    KC1   KC2        KC4     ET',31X,'DPL   ALLOWED'
     & /1H ,' DATE',15X,'ZONE   (MM)      DPL    (%)   (MM)',
     & 27X,'(MM/',30X,'(MM)     DPL'/1H ,20X,'(CM)',12X,'(MM)',42X,
     & 'DAY)',38X,'(MM)')
      IF(S1.GE.3.) WRITE(M4,1010) JDAY,CT,PCT,RZ,AVM,DPLI,AV,ETRG,AKC1,
     & AKC2,AKC,ETA,DPL,DPA
 1010 FORMAT(1H ,I4,F7.1,F6.1,F7.1,F8.2,F9.2,F7.1,F6.2,1X,2F6.2,6X,F6.2,
     & F7.2,26X,2F8.2)
      IF(DPL.GE.DPA .AND. DPL.GE.XNMIN) GO TO 30
   10 CONTINUE
C          IF AN IRRIGATION IS NOT REQUIRED BEFORE HARVEST
      NXD=JDH
      NXDP=JDH
      XI=0.
      GO TO 70
C          IF AN IRRIGATION IS REQUIRED ON THE STARTING DATE
   20 NXD=JSF
      NXDP=JSF
      XI=DPLSF
      GO TO 70
C          SET IRRIGATION DATE
   30 NXD=JDAY
      NXDP=JDAY
      XI=DPL
C
C     NEXT IRRIGATION DATE WITH EXPECTED PRECIPITATION
```

```
      IF(ABS(B(I,1)).EQ.0.) GO TO 70
C           ADD IN EXPECTED PRECIPITATION UP TO THE PREDICTED DATE
      SUMPP=0.
      DO 40 NO=JSF,JDAY
      DAY2=NO
      PP=B(I,1)+B(I,2)*DAY2+B(I,3)*DAY2**2+B(I,4)*DAY2**3
     & +B(I,5)*DAY2**4+B(I,6)*DAY2**5
      DPL=DPL-PP
      SUMPP=SUMPP+PP
      IF(DPL.LT.0.) DPL=0.
   40 CONTINUE
C           CHECK IF ADDED RAINFALL CHANGES PREDICTED IRRIGATION DATE
      IF(DPL.GE.DPA .AND. DPL.GE.XNMIN) GO TO 60
C           MODIFY THE PREDICTION DATE UNTIL THE SOIL WATER DEPLETION
C               IS GREATER THAN THE ALLOWED SOIL WATER DEPLETION
      NO=JDAY+1
      DO 50 JDAY=NO,JDH
      DAY=JDAY
C           MAXIMUM AVAILABLE SOIL WATER
      CALL MAXASW(JDAY,M4,RZ,AVM)
C           ALLOWED SOIL WATER DEPLETION
      IF(S2.EQ.1.) DPA=DPAP*AVM/100.0
C           EXPECTED PRECIPITATION
      PP=B(I,1)+B(I,2)*DAY+B(I,3)*DAY**2+B(I,4)*DAY**3
     & +B(I,5)*DAY**4+B(I,6)*DAY**5
C           COMPUTE ET
      CALL ETAVG(I,JDAY,DPLSF,AVMSF,ETA)
C           SOIL WATER DEPLETION
      DPLI=DPL
      DPL=DPL+ETA-PP
      IF(DPL.LT.0.) DPL=0.
C           PRINT RESULTS
      IF(JDAY.EQ.NO .AND. S1.GE.3.) WRITE(M4,1020) SUMPP
 1020 FORMAT(1H0,'PREDICTION OF NEXT IRRIGATION DATE WITH EXPECTED',
     & ' PRECIPITATION'/1H ,5X,'EXPECTED PRECIPITATION BEFORE ',
     & 'IRRIGATION DATE:',F7.1,'  MM'
     & /1H ,'JULIAN   TS   PCT   ROOT    AVM    INITIAL   AV   ETRG',
     & '   KC1   KC2',9X,'KC4      ET',14X,'PRECIP-',10X,'DPL   ALLOWED'
     & /1H ,' DATE',15X,'ZONE   (MM)       DPL     (%)    (MM)',
     & 27X,'(MM/',13X,'ITATION',10X,'(MM)      DPL'/1H ,20X,'(CM)',
     & 12X,'(MM)',42X,'DAY)',14X,'(MM)',19X,'(MM)')
      IF(S1.GE.3.) WRITE(M4,1030) JDAY,CT,PCT,RZ,AVM,DPLI,AV,ETRG,AKC1,
     & AKC2,AKC,ETA,PP,DPL,DPA
 1030 FORMAT(1H ,I4,F7.1,F6.1,F7.1,F8.2,F9.2,F7.1,F6.2,1X,2F6.2,6X,F6.2,
     & F7.2,9X,F10.2,7X,2F8.2)
      IF(DPL.GE.DPA .AND. DPL.GE.XNMIN) GO TO 60
   50 CONTINUE
C           PREDICTED IRRIGATION DATE WITH EXPECTED PRECIPITATION
   60 NXDP=JDAY
C
   70 RETURN
      END
C
C
C
      SUBROUTINE DATEE(JD,NM,ND,JDS)
C     CALCULATES MONTH AND DAY FROM JULIAN DATE
C     SUBROUTINE NUMBER 5
C
      COMMON /CDATEE/ NND(12)
C
      DATA NND / 0,31,59,90,120.151.181.212,243.273,304,334 /
C
C     CHECK DATE RANGE
      IF(JD.LE.0 .OR. JD.GE.JDS) GO TO 30
C     DETERMINE CALENDAR MONTH AND DAY
      DO 10 L=2,12
      IF(JD.LE.NND(L)) GO TO 20
   10 CONTINUE
      L=13
   20 NM=L-1
      ND=JD-NND(NM)
      RETURN
C     DATE OUT OF RANGE
   30 NM=13
      ND=0
      RETURN
      END
C
C
```

```
C
      SUBROUTINE ETAVG(I,JDAY,DPLSF,AVMSF,ETA)
C     SUBROUTINE TO DETERMINE EXPECTED ET
C          SUBROUTINE NUMBER 6
C
      COMMON /C46/ CT,PCT,AV,ETRG,AKC1,AKC2,AKC
      COMMON /C1236/ DT1(4),DT2(4),ETRGM(4),FCT(4),JM(4)
C
C     CALCULATE BASAL CROP COEFFICIENT
      CALL KCB(JDAY,CT,PCT,AKC1)
C
C     MODIFY BASAL CROP COEFFICIENT FOR AVAILABLE SOIL WATER
C          NOTE:  SOIL WATER DEPLETION AND MAXIMUM AVAILABLE SOIL
C                 WATER ARE MAINTAINED AT THE VALUES FOR THE END
C                 OF THE PRESENT COMPUTATION PERIOD
      AV=(1.0-DPLSF/AVMSF)*100.0
      IF(AV.LT.0.) AV=0.
      AKC2=ALOG(1.0+AV)/ALOG(101.0)
      AKC=AKC1*AKC2
C
C     CALCULATE EXPECTED ET
      DLT=DT1(I)
      IF(JDAY.GT.JM(I)) DLT=DT2(I)
      ETRG=ETRGM(I)/(EXP(((JDAY-JM(I))/DLT)**2))
      ETA=AKC*ETRG
C          MODIFY ET BY FORECAST FACTOR (FIRST FIVE DAYS ONLY)
      IF(JDAY-JSF.LE.5) ETA=ETA*FCT(I)
C
      RETURN
      END
C
C
C
      SUBROUTINE SAVE(NREG,NTF,M2,S1)
C     SUBROUTINE TO RETAIN INFORMATION FOR NEXT RUN
C     SUBROUTINE NUMBER 7
C
      COMMON /C37/ WI(7,100)
      COMMON /C127/ JRSUM(4),SHFT(4,18),SUMJ(4),SUMPC(4),SUMPF(4),
     & SUMR(4)
      COMMON /C1237/ JSC(4)
C
C     PAGE CONTROL
      IF(S1.EQ.0.) WRITE(M2,1000)
 1000 FORMAT(1H1)
C
C     REGIONAL CLIMATIC CONDITION
      WRITE(M2,1010)
 1010 FORMAT(1H0,'REGIONAL CLIMATIC CONDITION ... DATA FOR NEXT RUN')
      WRITE(M2,1020) ((JSC(I),(SHFT(I,K),K=1,3),JRSUM(I),SUMPC(I),
     & SUMPF(I),SUMJ(I),SUMR(I)),I=1,NREG)
 1020 FORMAT(1H ,I5,3F6.1,I5,3F7.2,F6.1)
C
C     FIELD CONDITION
      WRITE(M2,1030)
 1030 FORMAT(1H0,'FIELD CONDITION ... DATA FOR NEXT RUN')
      WRITE(M2,1040) ((WI(K,NF),K=1,7),NF=1,NTF)
 1040 FORMAT(1H ,F6.2,3F7.2,F7.1,F8.2,F7.1)
      RETURN
      END
C
C
C
      SUBROUTINE MAXASW(JDAY,M4,RZ,AVM)
C     CALCULATES EFFECTIVE ROOTZONE DEPTH AND MAXIMUM AVAILABLE
C        SOIL WATER
C     SUBROUTINE NUMBER 8
C
      COMMON /C38/ AW(5,2),RZMIN,RZMAX,RZLIM,NSL
      COMMON /C389/ D(4,11),JDE,JDEFC,NCR
C
      IF(JDAY.GT.JDEFC .OR. NCR.GE.8) GO TO 10
C          BASAL CROP COEFFICIENT BEFORE EFFECTIVE FULL COVER
      CALL KCB(JDAY,CT,PCT,AKC1)
C          EFFECTIVE ROOTZONE DEPTH BEFORE EFFECTIVE FULL COVER
      RZ=RZMIN+PCT*(RZMAX-RZMIN)/100.0
      GO TO 20
C          EFFECTIVE ROOTZONE DEPTH AFTER EFFECTIVE FULL COVER
C            OR FOR A PERENNIAL CROP
   10 RZ=RZMAX
```

```
C          LIMITING ROOTZONE DEPTH
   20 IF(RZ.GT.RZLIM .AND. RZLIM.NE.0.) RZ=RZLIM
C
C     CALCULATE MAXIMUM AVAILABLE SOIL WATER
      AVM=0.
      DO 50 NS=1,NSL
      IF(AW(NS,1).EQ.0.) GO TO 60
      IF(RZ.LE.AW(NS,1)) GO TO 30
      AVM=AVM+AW(NS,2)
      GO TO 50
   30 IF(NS.GT.1) GO TO 40
      AVM=RZ*AW(NS,2)/AW(NS,1)
      GO TO 70
   40 AVM=AVM+(RZ-AW(NS-1,1))*AW(NS,2)/(AW(NS,1)-AW(NS-1,1))
      GO TO 70
   50 CONTINUE
C
C     PRINT ERROR MESSAGE AND STOP
C          ERROR MESSAGE:  AVM
   60 WRITE(M4,1000) RZ,AW(NS,1)
 1000 FORMAT(1H ,'* ERROR AVM *'/1H ,'ROOTZONE DEPTH OF:',
     & F6.1,' EXCEEDS INFORMATION ON MAXIMUM AVAILABLE ',
     & 'SOIL WATER'/1H ,'WHICH IS ONLY GIVEN TO A DEPTH OF:',F6.1)
      STOP
C
   70 RETURN
      END
C
C
C
      SUBROUTINE KCB(JDAY,CT,PCT,AKC1)
C     SUBROUTINE TO CALCULATE THE BASAL CROP COEFFICIENT
C     SUBROUTINE NUMBER 9
C
      COMMON /C39/ C(20,9),JDC(5,2),NCUT
      COMMON /C389/ D(4,11),JDE,JDEFC,NCR
C
      PCT=0.
      CT=0.
      IF(NCR.GE.8) GO TO 30
C     ANNUAL CROPS
      IF(JDAY.GT.JDE) GO TO 10
C          BEFORE EMERGENCE
      AKC1=D(1,NCR)
      GO TO 110
   10 IF(JDAY.GT.JDEFC) GO TO 20
C          FROM EMERGENCE TO EFFECTIVE FULL COVER
      CT=100.0*(JDAY-JDE)/(JDEFC-JDE)
      NO=IFIX(CT/10.)
      DO=0.
      IF(NO.NE.0) DO=C(NO,NCR)
      PCT=((CT-10.*NO)*(C(NO+1,NCR)-DO)/10.)+DO
      AKC1=D(1,NCR)+PCT*(D(2,NCR)-D(1,NCR))/100.0
      GO TO 110
C          FROM EFFECTIVE FULL COVER TO HARVEST
   20 CT=JDAY-JDEFC
      NO=IFIX(CT/10.)+10
      PCT=((CT-10.*(NO-10))*(C(NO+1,NCR)-C(NO,NCR))/10.)+C(NO,NCR)
      AKC1=D(3,NCR)+PCT*(D(2,NCR)-D(3,NCR))/100.0
      GO TO 110
C
C     PERENNIAL CROPS
   30 IF(JDAY.GT.JDE) GO TO 40
C          BEFORE START OF GROWTH
      AKC1=D(1,NCR)
      GO TO 110
   40 IF(JDAY.GT.JDEFC) GO TO 50
C          FROM START OF GROWTH TO EFFECTIVE FULL COVER
      CT=100.0*(JDAY-JDE)/(JDEFC-JDE)
      NO=IFIX(CT/10.)
      DO=0.
      IF(NO.NE.0) DO=C(NO,8)
      PCT=((CT-10.*NO)*(C(NO+1,8)-DO)/10.)+DO
      AKC1=D(1,NCR)+PCT*(D(2,NCR)-D(1,NCR))/100.0
      GO TO 110
C          AFTER EFFECTIVE FULL COVER
   50 DO 70 NC=1,NCUT
      IF(JDC(NC,1).NE.0) GO TO 60
      NC=NC-1
      GO TO 100
```

```
   60 IF(JDAY.LT.JDC(NC,1)) GO TO 80
      IF(JDAY.LT.JDC(NC,2)) GO TO 90
   70 CONTINUE
      GO TO 100
C            FROM EFFECTIVE FULL COVER TO CUTTING
   80 DO=JDEFC
      IF(NC.GT.1) DO=JDC(NC-1,2)
      CT=JDAY-DO
      NO=IFIX(CT/10.)+10
      PCT=((CT-10.*(NO-10))*(C(NO+1,8)-C(NO,8))/10.)+C(NO,8)
      AKC1=D(3,NCR)+PCT*(D(2,NCR)-D(3,NCR))/100.0
      GO TO 110
C            FROM CUTTING TO EFFECTIVE FULL COVER
   90 CT=100.0*(JDAY-JDC(NC,1))/(JDC(NC,2)-JDC(NC,1))
      NO=IFIX(CT/10.)
      DO=0.
      IF(NO.NE.0) DO=C(NO,9)
      PCT=((CT-10.*NO)*(C(NO+1,9)-DO)/10.)+DO
      AKC1=D(3,NCR)+PCT*(D(2,NCR)-D(3,NCR))/100.0
      GO TO 110
C            FROM EFFECTIVE FULL COVER TO END OF GROWTH
  100 CT=JDAY-JDC(NC,2)
      NO=IFIX(CT/10.)+10
      PCT=((CT-10.*(NO-10))*(C(NO+1,9)-C(NO,9))/10.)+C(NO,9)
      AKC1=D(4,NCR)+PCT*(D(2,NCR)-D(4,NCR))/100.0
C
  110 RETURN
      END
C
C
C
      FUNCTION TAN(XO)
C     FUNCTION TO DETERMINE TAN
C     SUBROUTINE NUMBER 10
      IF(COS(XO).NE.0.) GO TO 10
      TAN=1.E35
      GO TO 20
   10 TAN=SIN(XO)/COS(XO)
   20 RETURN
      END
C
C
C
      FUNCTION ACOS(XO)
C     FUNCTION TO DETERMINE ARCCOS
C     SUBROUTINE NUMBER 11
      IF(XO.NE.1.) GO TO 10
      ACOS=0.
      GO TO 30
   10 IF(XO.NE.-1.) GO TO 20
      ACOS=3.1415927
      GO TO 30
   20 ACOS=1.5707963-ATAN(XO/SQRT(1.-XO**2))
   30 RETURN
      END
C
C
C
      SUBROUTINE FREEFORM (NN,VAL,NA,VALA)
C     SUBROUTINE TO READ INPUT DATA WITH FREE FORMATTING
C     SUBROUTINE NUMBER 12
C            NOTE:  IF A NUMBER IS ENTERED IN SCIENTIFIC NOTATION,
C                   FOR EXAMPLE:  1.23E3 OR 1230.0, THEN THE ALGOL
C                   ROUTINE ONLY RECOGNIZES IT IF ENTERED AS
C                   FOLLOWS:  1.23'3
      REAL VAL(40),RDATA(80)
      LONG VALA(40),LDATA(80)
      INTEGER READALL,KIND(80)
      ZONE IN
      EXTERNAL IN
      EQUIVALENCE (RDATA(1),LDATA(1))
C     ALGOL LIBRARY ROUTINE
      NITEMS=READALL(IN,RDATA,KIND,1)
      NN=0
      NA=0
      DO 30 K=1,NITEMS
      GO TO (30,10.30,30,30,20.30,30), KIND(K)
   10 NN=NN+1
      VAL(NN)=RDATA(K)
      GO TO 30
   20 NA=NA+1
      VALA(NA)=LDATA(K)
   30 CONTINUE
      RETURN
      END
```

APPENDIX E

Example 1:

DBEVATTNO Input Data File Listing

```
 10 1 162 1970 0
 20 ULTUNA
 30 15 59.82 8.5
 40 3.1 166 70 98
 50 0.5687 -3.9'-3 1.183'-4 -3.08'-7 0 0
 60 0.7595 -4.488'-2 2.1569'-3 -1.1738'-5 1.6994'-8
 70 0 0 0 0
 80 0 0 0 0
 90 0 0 0 0
100 79 2.2 1.3 5.9
110 79 2.2 1.3 7.6
120 71 2.3 1.3 8.3
130 76 2.1 1.3 7.6
140 83 2.2 1.3 5.9
150 87 2.3 1.3 4.0
160 79 2.2 1.3 2.1
170 79 2.2 1.3 0.5
180 0 0 0 0
190 1.0
200 NORMAL CONDITIONS
210 152 13.3 15.0 13.9 121 111.42 159.18 84.46 4.5
220 10 152
230 152 11.0 16.6 12.4 17.3 8.6 97 66 73 2.0 3.4 7.1 286 8.8
240 153 8.5 12.8 14.2 15.0 8.0 70 56 44 5.3 4.3 3.5 436 0
250 154 12.4 17.5 11.5 18.0 2.1 62 37 72 3.5 6.6 5.2 624 0
260 155 11.2 21.3 20.5 21.9 2.6 87 28 30 4.2 3.1 3.0 691 0
270 156 18.9 25.0 21.9 25.2 4.3 36 28 32 1.1 2.1 3.5 674 0
280 157 20.4 25.0 22.8 26.4 7.0 42 21 37 1.0 2.7 2.3 613 0
290 158 18.2 27.5 25.2 27.7 8.0 51 22 36 2.5 2.2 4.1 658 0
300 159 20.6 28.0 23.4 28.2 10.2 59 32 48 0 2.1 4.0 649 0
310 160 20.1 25.8 22.6 26.0 7.9 51 25 50 2.1 5.0 4.0 668 0
320 161 20.7 26.3 23.4 26.8 8.2 52 29 36 2.2 2.5 4.0 693 0
330 1
340 KUNGSHAMN
350 1
360 K2
370 POTATOES
380 4 131 151 171 198 132 132 7 80 15 15 60 30
390 20 32 30 19 50 32 0 0 0 0
400 50 0 0 0 5.4 0 0 0 0 0 0 0 0 0 0 0 0 0 0
410 14.80 0 0 0.7 2.3 13.60 0
```

APPENDIX E

Example 2:

Daily Printout, Calibrated Penman ET_{rg}

```
PROGRAM CONTROL DATA
     NUMBER OF REGIONS:   1
     COMPUTATION JULIAN DATE:  162
     YEAR:  1970
     PRINT SWITCH:    3

COMPUTATION DATE:  11 JUN 1970

MON ARRAY:      JAN   FEB   MAR   APR   MAY   JUN   JUL
                AUG   SEP   OCT   NOV   DEC   ---

REGIONAL DATA
     REGION:  ULTUNA
     WEATHER STATION INFORMATION
          ELEVATION:    15.0
          LATITUDE:     59.82
          WINDSPEED MEASUREMENT HEIGHT:    8.5
     EXPECTED GRASS REFERENCE CROP ET EQUATION COEFFICIENTS
          ETRGM(I):   3.10
          JM(I):    166
          DT1(I)  70.0
          DT2(I)  98.0
     EXPECTED PRECIPITATION EQUATION COEFFICIENTS
          COEFFICIENTS:   0.569700E+00  -0.390000E-02   0.118300E-03
                         -0.308000E-06   0.000000E+00   0.000000E+00
     CLEAR SKY SOLAR RADIATION EQUATION COEFFICIENTS
          COEFFICIENTS:   0.759500E+00  -0.448800E-01   0.215690E-02
                         -0.117380E-04   0.169940E-07

     LONG-TERM CLIMATIC DATA
          MONTH   MAX RH      U     UDAY/      UDAY      RS
                   (%)      (M/S)   UNIGHT    (M/S)   (MM/DAY)
            1      0.00      0.00    0.00      0.00     0.00
            2      0.00      0.00    0.00      0.00     0.00
            3      0.00      0.00    0.00      0.00     0.00
            4     79.00      2.20    1.30      2.49     5.70
            5     79.00      2.20    1.30      2.49     7.60
            6     71.00      2.30    1.30      2.60     8.30
            7     76.00      2.10    1.30      2.37     7.60
            8     83.00      2.20    1.30      2.49     5.70
            9     87.00      2.30    1.30      2.60     4.00
           10     79.00      2.20    1.30      2.49     2.10
           11     79.00      2.20    1.30      2.49     0.50
           12      0.00      0.00    0.00      0.00     0.00
          UDAY IS A CALCULATED VALUE
```

```
CLIMATIC DATA
     REGIONAL QUANTITATIVE FORECAST INFORMATION
          FORECAST GRASS REFERENCE CROP RATIO:  1.00
     REGIONAL QUALITATIVE FORECAST INFORMATION
          FORECAST:  NORMAL CONDITIONS
     REGIONAL CLIMATIC CONDITION
          STARTING JULIAN DATE:  152
          AIR TEMPERATURE, THREE DAYS BEFORE START:   13.3   15.0   13.9
          REGIONAL SUMMATION STARTING JULIAN DATE:  121
          SUM OF CALIBRATED PENMAN ET:  111.42
          SUM OF FAO PENMAN ET:  159.18
          SUM OF JOHANSSON ET:    84.46
          SUM OF PRECIPITATION:     4.5
     PROGRAM CONTROL DATA
          DAYS OF CLIMATIC DATA:  10
          STARTING JULIAN DATE:   152

     DAILY CLIMATIC DATA
          JULIAN          AIR TEMPERATURE              RELATIVE HUMIDITY        WINDSPEED         SOLAR      PRECIPITATION
           DATE             (DEGREES C)                       (%)            (M/S AT   8.5 M)  RADIATION        (MM)
                                                                                              (LANGLEYS
                  0800   1400   1900    MAX    MIN   0800   1400   1900   0800   1400   1900     /DAY)
           152    11.0   16.6   12.4   17.3    8.6   97.0   66.0   73.0   2.00   3.40   7.10    286.0            8.8
           153     8.5   12.8   14.2   15.0    8.0   70.0   56.0   44.0   5.30   4.30   3.50    436.0            0.0
           154    12.4   17.5   11.5   18.0    2.1   62.0   37.0   72.0   3.50   6.60   5.20    624.0            0.0
           155    11.2   21.3   20.5   21.9    2.6   87.0   28.0   30.0   4.20   3.10   3.00    691.0            0.0
           156    18.9   25.0   21.9   25.2    4.3   36.0   28.0   32.0   1.10   2.10   3.50    674.0            0.0
           157    20.4   25.0   22.8   26.4    7.0   42.0   21.0   37.0   1.00   2.70   2.30    613.0            0.0
           158    18.2   27.5   25.2   27.7    8.0   51.0   22.0   36.0   2.50   2.20   4.10    658.0            0.0
           159    20.6   28.0   23.4   28.2   10.2   59.0   32.0   48.0   0.00   2.10   4.00    649.0            0.0
           160    20.1   25.8   22.6   26.0    7.9   51.0   25.0   50.0   2.10   5.00   4.00    668.0            0.0
           161    20.7   26.3   23.4   26.8    8.2   52.0   29.0   36.0   2.20   2.50   4.00    693.0            0.0

WEATHER DATA
     REGION:  ULTUNA
     WINDSPEED MEASUREMENT HEIGHT:      8.5  METERS
               CONVERSION FACTOR TO A 2 METER HEIGHT:   0.785
 DATE      JULIAN       AIR       RELATIVE   WINDSPEED     SOLAR
            DATE    TEMPERATURE   HUMIDITY    (M/S)      RADIATION
                    (DEGREES C)     (%)      AT 2 M)     (MM/DAY)
 1 JUN      152         13.3        78.7        3.27        4.89
 2 JUN      153         11.8        56.7        3.43        7.46
 3 JUN      154         13.8        57.0        4.01       10.67
 4 JUN      155         17.7        48.3        2.70       11.82
 5 JUN      156         21.9        32.0        1.75       11.53
 6 JUN      157         22.7        33.3        1.57       10.48
 7 JUN      158         23.6        36.3        2.30       11.25
 8 JUN      159         24.0        46.3        1.60       11.10
 9 JUN      160         22.8        42.0        2.91       11.42
10 JUN      161         23.5        39.0        2.28       11.85

MEAN        156.5       19.5        47.0        2.58       10.25
```

```
PENMAN METHOD ADJUSTMENT FACTOR TABLE
   0.86   0.90   1.00   1.00   0.64   0.71   0.82   0.89
   0.43   0.53   0.68   0.79   0.27   0.41   0.59   0.70
   0.96   0.98   1.05   1.05   0.78   0.86   0.94   0.99
   0.62   0.70   0.84   0.93   0.50   0.60   0.75   0.87
   1.02   1.06   1.10   1.10   0.85   0.92   1.01   1.05
   0.72   0.82   0.95   1.00   0.62   0.72   0.87   0.96
   0.86   0.90   1.00   1.00   0.69   0.76   0.85   0.92
   0.53   0.61   0.74   0.84   0.37   0.48   0.65   0.76
   0.96   0.98   1.05   1.05   0.83   0.91   0.99   1.05
   0.70   0.80   0.94   1.02   0.59   0.70   0.84   0.95
   1.02   1.06   1.10   1.10   0.89   0.98   1.10   1.14
   0.79   0.92   1.05   1.12   0.71   0.81   0.96   1.06
   0.86   0.90   1.00   1.00   0.76   0.81   0.88   0.94
   0.61   0.68   0.81   0.88   0.46   0.56   0.72   0.82
   0.96   0.98   1.05   1.05   0.87   0.96   1.06   1.12
   0.77   0.88   1.02   1.10   0.67   0.79   0.88   1.05
   1.02   1.06   1.10   1.10   0.94   1.04   1.18   1.28
   0.86   1.01   1.15   1.22   0.78   0.92   1.06   1.18
   0.86   0.90   1.00   1.00   0.79   0.84   0.92   0.97
   0.68   0.77   0.87   0.93   0.55   0.65   0.78   0.90
   0.96   0.98   1.05   1.05   0.92   1.00   1.11   1.19
   0.85   0.96   1.11   1.19   0.76   0.88   1.02   1.14
   1.02   1.06   1.10   1.10   0.99   1.10   1.27   1.32
   0.94   1.10   1.26   1.33   0.88   1.01   1.16   1.27

SUBMODELS
      ELEVATION:     15.0  METERS
      AIR PRESSURE:   1011.3  MBAR
JULIAN     VAPOR PRESSURE (MBAR)        LH      GAMMA    DELTA      WEIGHTING
 DATE     SATUR-     AIR    DEFICIT    (J/KG)  (MBAR/DEGREE C)      FUNCTION
           ATION                       (1E6)
 152      15.31    12.04      3.27      2.462    0.663    0.999        0.601
 153      13.87     7.86      6.01      2.465    0.663    0.916        0.580
 154      15.78     8.99      6.78      2.461    0.664    1.026        0.607
 155      20.21     9.77     10.44      2.453    0.666    1.274        0.657
 156      26.33     8.43     17.90      2.444    0.668    1.606        0.706
 157      27.64     9.21     18.43      2.442    0.669    1.675        0.715
 158      29.19    10.60     18.58      2.440    0.669    1.757        0.724
 159      29.84    13.82     16.01      2.439    0.670    1.791        0.728
 160      27.81    11.68     16.13      2.442    0.669    1.684        0.716
 161      28.89    11.27     17.63      2.440    0.669    1.741        0.722
LH -- LATENT HEAT OF VAPORIZATION   (MULTIPLY VALUE BY 1E6)
GAMMA -- PSYCHROMETRIC CONSTANT
DELTA -- SLOPE OF THE SATURATION VAPOR PRESSURE CURVE
```

```
CALIBRATED PENMAN METHOD
JULIAN     G      RSO    RS/RSO  EMISSIVITY      RN     WIND     PENMAN ET
 DATE    (MM/    (MM/                           (MM/    FUNC-    (MM/DAY)
          DAY)    DAY)          CLEAR  ACTUAL  DAY)     TION
                                                                1948  CALIB
 152     -0.11   11.62   0.42   0.79    0.98   3.54    0.72    3.13   2.80
 153     -0.34   11.66   0.64   0.74    0.85   3.81    0.75    4.29   3.86
 154      0.12   11.69   0.91   0.76    0.77   5.17    0.83    5.27   4.77
 155      0.70   11.72   1.00   0.76    0.75   5.57    0.64    5.50   4.98
 156      1.13   11.75   0.98   0.75    0.74   4.97    0.51    5.40   4.89
 157      0.74   11.78   0.89   0.76    0.78   4.74    0.48    5.40   4.89
 158      0.43   11.81   0.95   0.77    0.77   5.19    0.59    6.46   5.86
 159      0.19   11.83   0.94   0.80    0.81   5.59    0.49    6.06   5.50
 160     -0.09   11.85   0.96   0.78    0.78   5.46    0.67    7.06   6.42
 161     -0.00   11.88   1.00   0.78    0.76   5.51    0.58    6.84   6.22
G -- SOIL HEAT FLUX  (A NEGATIVE SIGN INDICATES HEAT FLOW FROM THE SOIL)
RSO -- CLEAR SKY SOLAR RADIATION
RS -- SOLAR RADIATION
RN -- NET RADIATION
CALIB -- CALIBRATION BY KRISTIANSEN (1979) RELATION FOR COPENHAGEN, DENMARK

FAO PENMAN METHOD
     LATITUDE:   59.82
JULIAN       AIR        C       G1       G2       G3       G4       RA       RN      WIND   FAO PENMAN
 DATE    TEMPERATURE                                                (MM/     (MM/    FUNC-      ET
         (DEGREES C)                                                 DAY)     DAY)    TION   (MM/DAY)
 152          13.0     0.98   21.57   132.79    12.29   1.0140   16.35     3.19     1.03      3.19
 153          11.5     0.98   21.70   133.13    12.29   1.0141   16.40     4.26     1.07      5.05
 154          10.1     0.98   21.82   133.46    12.29   1.0142   16.45     5.81     1.20      6.58
 155          12.3     0.98   21.93   133.78    12.29   1.0144   16.50     6.34     0.90      7.21
 156          14.8     0.98   22.04   134.08    12.29   1.0145   16.55     6.00     0.68      7.63
 157          16.7     0.98   22.14   134.36    12.29   1.0146   16.59     5.56     0.64      7.15
 158          17.9     0.98   22.24   134.63    12.29   1.0147   16.63     5.99     0.81      8.28
 159          19.2     0.98   22.33   134.89    12.29   1.0148   16.67     6.13     0.64      7.10
 160          17.0     0.98   22.41   135.13    12.29   1.0150   16.70     6.20     0.95      8.58
 161          17.5     0.98   22.49   135.35    12.29   1.0151   16.73     6.35     0.80      8.31
C -- FAO PENMAN ADJUSTMENT FACTOR
G1 -- DECLINATION OF THE SUN
G2 -- HOUR ANGLE
G3 -- DAYTIME HOURS AT ZERO DECLINATION
G4 -- RADIUS VECTOR OF THE EARTH
RA -- EXTRA-TERRESTRIAL RADIATION
RN -- NET RADIATION
```

```
JOHANSSON METHOD
JULIAN      SOLAR       WINDSPEED   AIR VAPOR   JOHANSSON
 DATE     RADIATION       (M/S)     PRESSURE       ET
          (MM/DAY)                  DEFICIT     (MM/DAY)
                                     (MBAR)
 152        4.89          3.27        3.27        1.54
 153        7.46          3.43        6.01        2.57
 154       10.67          4.01        6.78        3.49
 155       11.82          2.70       10.44        3.73
 156       11.53          1.75       17.90        3.90
 157       10.48          1.57       18.43        3.58
 158       11.25          2.30       18.58        4.59
 159       11.10          1.60       16.01        3.45
 160       11.42          2.91       16.13        4.88
 161       11.85          2.28       17.63        4.51


GRASS REFERENCE CROP ET
     REGION:  ULTUNA
     STARTING DATE:   1 JUN 1970
     COMPUTATION DATE:  11 JUN 1970
     SUMMATION STARTING DATE:   1 MAY 1970

 DATE    JULIAN   GRASS REFERENCE CROP ET (MM/DAY)    PRECIPITATION
          DATE    CALIBRATED   FAO     JOHANSSON          (MM)
                    PENMAN   PENMAN
 1 JUN    152        2.80      3.19      1.54              8.8
 2 JUN    153        3.86      5.05      2.57              0.0
 3 JUN    154        4.77      6.58      3.49              0.0
 4 JUN    155        4.98      7.21      3.73              0.0
 5 JUN    156        4.89      7.63      3.90              0.0
 6 JUN    157        4.89      7.15      3.58              0.0
 7 JUN    158        5.86      8.28      4.59              0.0
 8 JUN    159        5.50      7.10      3.45              0.0
 9 JUN    160        6.42      8.58      4.88              0.0
10 JUN    161        6.22      8.31      4.51              0.0

MEAN       156.5     5.02      6.91      3.62              0.88
PERIOD SUM (MM)     50.20     69.08     36.24              8.8
SEASON SUM (MM)    161.62    228.26    120.70             13.3

FORECAST GRASS REFERENCE CROP ET FOR NEXT 5 DAYS
  BASED ON    1.00  OF LONG-TERM VALUE:    3.10  MM/DAY
```

```
BASAL CROP COEFFICIENT ARRAY
CROP:    1
           4.8   10.5   22.9   47.6   66.7   81.9   92.4   97.1   98.1  100.0
         100.0   97.3   75.7   43.2   16.2    0.0    0.0    0.0    0.0    0.0
CROP:    2
           5.2   10.4   25.0   36.5   47.9   62.5   75.0   88.5   97.9  100.0
         100.0  100.0   65.7   31.4    9.8    5.9    0.0    0.0    0.0    0.0
CROP:    3
           3.1    4.1    6.2   12.4   24.7   42.3   60.8   77.3   91.8  100.0
         100.0   87.0   48.0   32.0   12.0    0.0    0.0    0.0    0.0    0.0
CROP:    4
          20.5   33.3   42.3   55.1   69.2   80.8   89.7   96.2   98.7  100.0
         100.0  100.0   93.0   91.5   90.1   88.7   85.9   52.1    8.5    0.0
CROP:    5
           0.0    1.0    2.9    5.8   13.6   25.2   40.8   62.1   82.5  100.0
         100.0  100.0  100.0   84.0   72.0   52.0   44.0   32.0   20.0    0.0
CROP:    6
           2.1    3.1    4.2    9.4   19.8   34.4   55.2   71.9   86.5  100.0
         100.0  100.0   98.9   96.8   94.7   87.4   78.9   20.0    6.3    0.0
CROP:    7
           0.0   12.5   27.5   40.0   55.0   67.5   82.5   90.0   95.0  100.0
         100.0   98.2   92.8   43.2   10.8    0.0    0.0    0.0    0.0    0.0
CROP:    8
          14.5   29.0   44.9   58.0   66.7   75.4   84.1   91.3   97.1  100.0
         100.0  100.0  100.0  100.0  100.0  100.0  100.0    0.0    0.0    0.0
CROP:    9
           0.0   12.0   28.3   45.7   67.4   71.7   80.4   90.2   97.8  100.0
         100.0  100.0   31.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

MINIMUM AND MAXIMUM BASAL CROP COEFFICIENT ARRAY
          0.18    1.23    0.12    0.00
          0.18    1.14    0.12    0.00
          0.18    1.15    0.12    0.00
          0.18    0.96    0.25    0.00
          0.18    1.21    0.96    0.00
          0.18    1.14    0.19    0.00
          0.83    1.23    0.12    0.00
          0.52    1.08    0.52    0.52
          0.55    1.10    0.55    0.55
          0.58    1.08    0.58    0.58
          0.53    1.22    0.30    0.38
```

```
FARM DATA
     NUMBER OF FARMS:   1
     FARM INFORMATION
          FARM NAME:  KUNGSHAMN
          NUMBER OF FIELDS:   1

          FIELD DATA
               FIELD NAME:  K2
               CROP NAME:  POTATOES
               BASIC FIELD DATA
                    CROP NUMBER:   4
                    PLANTING JULIAN DATE:  131
                    EMERGENCE JULIAN DATE:  151
                    EFFECTIVE FULL COVER JULIAN DATE:  171
                    HARVEST JULIAN DATE:  198
                    FIELD SUMMATION STARTING JULIAN DATE:  132
                    JULIAN DATE OF INITIAL SOIL WATER DEPLETION:  132
                    INITIAL SOIL WATER DEPLETION:    7.00
                    IRRIGATION EFFICIENCY:  80.0
                    MINIMUM IRRIGATION AMOUNT:  15.0
                    MINIMUM EFFECTIVE ROOTZONE DEPTH:  15.0
                    MAXIMUM EFFECTIVE ROOTZONE DEPTH:  60.0
                    LIMITING MAXIMUM EFFECTIVE ROOTZONE DEPTH:  30.0

               SOIL DATA
                    DEPTH    MAXIMUM AVAILABLE SOIL WATER
                     20.0              32.0
                     30.0              19.0
                     50.0              32.0
                      0.0               0.0
                      0.0               0.0
               FIELD IRRIGATION DATA
                    PERCENT DEPLETION ALLOWED:  50.0
                    DEPLETION ALLOWED:   0.0
                    PREVIOUS IRRIGATION JULIAN DATE:    0
                    PREVIOUS IRRIGATION AMOUNT:   0.0
                    PERIOD DAY    RAIN AND/OR IRRIGATION DIFFERENCE
                         1                      5.4
                         2                      0.0
                         3                      0.0
                         4                      0.0
                         5                      0.0
                         6                      0.0
                         7                      0.0
                         8                      0.0
                         9                      0.0
                        10                      0.0
```

```
          FIELD CONDITION
               SOIL WATER DEPLETION:   14.80
               PAST THREE DAYS ADJUSTED PRECIPITATION AND/OR IRRIGATION AMOUNTS:
                          0.00      0.00      0.70
               SUM OF PRECIPITATION:    2.3
               SUM OF CROP ET:   13.60
               SUM OF NET IRRIGATION AMOUNTS:    0.0

FIELD SOIL WATER DEPLETION CALCULATIONS
     FIELD:  K2
     CROP:  POTATOES
     CROP NUMBER:   4
JULIAN   TS   PCT    ROOT    AVM    INITIAL    AV   ETRG   KC1   KC2   KC3   KC4     ET    IRRIG-   PRECIP-   WATER   DPL    ALLOWED
 DATE                ZONE   (MM)      DPL     (%)   (MM)                            (MM/   ATION    ITATION   ADDED   (MM)      DPL
                     (CM)            (MM)                                           DAY)    (MM)     (MM)     (MM)            (MM)
 152     5.0  10.3   19.6   31.38    14.80    52.8  2.80   0.26  0.86  0.25  0.47   1.33    0.0      14.2     14.2     1.93   15.69
 153    10.0  20.5   24.2   40.03     1.93    95.2  3.86   0.34  0.99  0.60  0.94   3.63    0.0       0.0      0.0     5.56   20.01
 154    15.0  26.9   27.1   45.50     5.56    87.8  4.77   0.39  0.97  0.36  0.73   3.51    0.0       0.0      0.0     9.07   22.75
 155    20.0  33.3   30.0   50.97     9.07    82.2  4.98   0.44  0.96  0.20  0.62   3.10    0.0       0.0      0.0    12.16   25.49
 156    25.0  37.8   30.0   51.00    12.16    76.2  4.89   0.47  0.94  0.00  0.45   2.19    0.0       0.0      0.0    14.35   25.50
 157    30.0  42.3   30.0   51.00    14.35    71.9  4.89   0.51  0.93  0.00  0.47   2.32    0.0       0.0      0.0    16.67   25.50
 158    35.0  48.7   30.0   51.00    16.67    67.3  5.86   0.56  0.92  0.00  0.51   3.00    0.0       0.0      0.0    19.67   25.50
 159    40.0  55.1   30.0   51.00    19.67    61.4  5.50   0.61  0.90  0.00  0.55   3.00    0.0       0.0      0.0    22.67   25.50
 160    45.0  62.2   30.0   51.00    22.67    55.5  6.42   0.66  0.87  0.00  0.58   3.73    0.0       0.0      0.0    26.40   25.50
 161    50.0  69.2   30.0   51.00    26.40    48.2  6.22   0.72  0.84  0.00  0.61   3.78    0.0       0.0      0.0    30.18   25.50
PERIOD SUM (MM)                                                                    29.58    0.0      14.2     14.2
SEASON SUM (MM)                                                                    43.18    0.0      16.5     16.5
TS -- TIME SCALE WHICH IS: PERCENT TIME FROM EMERGENCE TO EFFECTIVE FULL COVER
                           OR DAYS AFTER EFFECTIVE FULL COVER
PCT--PERCENT FROM MINIMUM TO MAXIMUM BASAL CROP COEFFICIENT
AVM -- MAXIMUM AVAILABLE SOIL WATER
DPL -- SOIL WATER DEPLETION
AV -- PERCENT AVAILABLE SOIL WATER
ETRG -- GRASS REFERENCE CROP ET
KC1 -- BASAL CROP COEFFICIENT
KC2 -- CROP COEFFICIENT RELATED TO AVAILABLE SOIL WATER
KC3 -- CROP COEFFICIENT RELATED TO A WET SURFACE
KC4 -- CROP COEFFICIENT
```

```
IRRIGATION SCHEDULING
     FARM:  KUNGSHAMN
     COMPUTATION DATE:  11 JUN  1970

  FIELD           CROP         SOIL WATER DEPLETION      FORECAST        -- IRRIGATION DATES --    IRRIGATION
                                                       (NEXT 5 DAYS)                                AMOUNT
                                CURRENT    ALLOWED                     PREVIOUS      -- NEXT --       (MM)
                                 (MM)       (MM)       KC       ET
                                                              (MM/DAY)            WITHOUT    WITH
                                                                                   RAIN      RAIN
K2              POTATOES         30.18      25.50     0.84     2.62       0 ---    11 JUN    11 JUN      38

     EXPECTED PRECIPITATION DURING THE NEXT TWO WEEKS:      24  MM

     FORECAST:  NORMAL CONDITIONS
                GRASS REFERENCE CROP ET FOR NEXT 5 DAYS:   3.10  MM/DAY
                  BASED ON  1.00  OF THE LONG-TERM VALUE


REGIONAL CLIMATIC CONDITION ... DATA FOR NEXT RUN
  162  24.0  22.8  23.5  121 161.62 228.26 120.70  13.3

FIELD CONDITION ... DATA FOR NEXT RUN
 30.18   0.00   0.00   0.00   16.5   43.18    0.0
```

APPENDIX E

Example 3:

Summary Printout, Calibrated Penman ET_{rg}

```
COMPUTATION DATE:  11 JUN 1970

WEATHER DATA
     REGION:  ULTUNA
 DATE     JULIAN       AIR         RELATIVE    WINDSPEED      SOLAR
           DATE    TEMPERATURE     HUMIDITY      (M/S)      RADIATION
                   (DEGREES C)       (%)       AT 2 M)      (MM/DAY)
 1 JUN     152        13.3          78.7         3.27         4.89
 2 JUN     153        11.8          56.7         3.43         7.46
 3 JUN     154        13.8          57.0         4.01        10.67
 4 JUN     155        17.7          48.3         2.70        11.82
 5 JUN     156        21.9          32.0         1.75        11.53
 6 JUN     157        22.7          33.3         1.57        10.48
 7 JUN     158        23.6          36.3         2.30        11.25
 8 JUN     159        24.0          46.3         1.60        11.10
 9 JUN     160        22.8          42.0         2.91        11.42
10 JUN     161        23.5          39.0         2.28        11.85

MEAN       156.5      19.5          47.0         2.58        10.25



GRASS REFERENCE CROP ET
     REGION:  ULTUNA
     STARTING DATE:   1 JUN 1970
     COMPUTATION DATE:  11 JUN 1970
     SUMMATION STARTING DATE:   1 MAY 1970

 DATE    JULIAN   GRASS REFERENCE CROP ET (MM/DAY)    PRECIPITATION
          DATE    CALIBRATED   FAO     JOHANSSON          (MM)
                    PENMAN    PENMAN
 1 JUN    152        2.80      3.19       1.54             8.8
 2 JUN    153        3.86      5.05       2.57             0.0
 3 JUN    154        4.77      6.58       3.49             0.0
 4 JUN    155        4.98      7.21       3.73             0.0
 5 JUN    156        4.89      7.63       3.90             0.0
 6 JUN    157        4.89      7.15       3.58             0.0
 7 JUN    158        5.86      8.28       4.59             0.0
 8 JUN    159        5.50      7.10       3.45             0.0
 9 JUN    160        6.42      8.58       4.88             0.0
10 JUN    161        6.22      8.31       4.51             0.0

MEAN        156.5    5.02      6.91       3.62             0.88
PERIOD SUM (MM)     50.20     69.08      36.24             8.8
SEASON SUM (MM)    161.62    228.26     120.70            13.3

FORECAST GRASS REFERENCE CROP ET FOR NEXT 5 DAYS
  BASED ON   1.00  OF LONG-TERM VALUE:    3.10  MM/DAY
```

```
IRRIGATION SCHEDULING
     FARM:  KUNGSHAMN
     COMPUTATION DATE:  11 JUN  1970

  FIELD          CROP         SOIL WATER DEPLETION      FORECAST        -- IRRIGATION DATES --    IRRIGATION
                                                      (NEXT 5 DAYS)                                 AMOUNT
                               CURRENT    ALLOWED                      PREVIOUS      -- NEXT --      (MM)
                                (MM)       (MM)        KC       ET
                                                              (MM/DAY)              WITHOUT    WITH
                                                                                      RAIN     RAIN
K2             POTATOES         30.18      25.50      0.84     2.62      0 ---      11 JUN    11 JUN     38

     EXPECTED PRECIPITATION DURING THE NEXT TWO WEEKS:     24  MM

     FORECAST:  NORMAL CONDITIONS
                GRASS REFERENCE CROP ET FOR NEXT 5 DAYS:   3.10  MM/DAY
                  BASED ON  1.00  OF THE LONG-TERM VALUE


REGIONAL CLIMATIC CONDITION ... DATA FOR NEXT RUN
  162  24.0  22.8  23.5  121 161.62 228.26 120.70  13.3

FIELD CONDITION ... DATA FOR NEXT RUN
 30.18    0.00    0.00    0.00    16.5    43.18     0.0
```

Example 4:

DBEVATTN4 Input Data File Listing

```
 10 1 162 1970 0
 20 ULTUNA
 30 15 59.82 8.5
 40 3.1 166 70 98
 50 0.5687 -3.9'-3 1.183'-4 -3.08'-7 0 0
 60 0.7595 -4.488'-2 2.1569'-3 -1.1738'-5 1.6994'-8
 70 0 0 0 0
 80 0 0 0 0
 90 0 0 0 0
100 79 2.2 1.3 5.9
110 79 2.2 1.3 7.6
120 71 2.3 1.3 8.3
130 76 2.1 1.3 7.6
140 83 2.2 1.3 5.9
150 87 2.3 1.3 4.0
160 79 2.2 1.3 2.1
170 79 2.2 1.3 0.5
180 0 0 0 0
190 1.0
200 NORMAL CONDITIONS
210 152 13.3 15.0 13.9 121 111.42 159.18 84.46 4.5
220 10 152
230 152 11.0 16.6 12.4 17.3 8.6 97 66 73 2.0 3.4 7.1 286 8.8
240 153 8.5 12.8 14.2 15.0 8.0 70 56 44 5.3 4.3 3.5 436 0
250 154 12.4 17.5 11.5 18.0 2.1 62 37 72 3.5 6.6 5.2 624 0
260 155 11.2 21.3 20.5 21.9 2.6 87 28 30 4.2 3.1 3.0 691 0
270 156 18.9 25.0 21.9 25.2 4.3 36 28 32 1.1 2.1 3.5 674 0
280 157 20.4 25.0 22.8 26.4 7.0 42 21 37 1.0 2.7 2.3 613 0
290 158 18.2 27.5 25.2 27.7 8.0 51 22 36 2.5 2.2 4.1 658 0
300 159 20.6 28.0 23.4 28.2 10.2 59 32 48 0 2.1 4.0 649 0
310 160 20.1 25.8 22.6 26.0 7.9 51 25 50 2.1 5.0 4.0 668 0
320 161 20.7 26.3 23.4 26.8 8.2 52 29 36 2.2 2.5 4.0 693 0
330 3
340 KUNGSHAMN
350 2
360 K1
370 POTATOES
380 4 132 156 176 201 135 135 3 80 15 15 60 40
390 40 25 70 13 0 0 0 0 0 0
400 50 0 0 0 5.4 0 0 0 0 0 0 0 0 0 0 0 0 0 0
410 8.68 0 0 0.7 2.3 9.85 0
420 K2
430 POTATOES
440 4 131 151 171 198 132 132 7 80 15 15 60 30
450 20 32 30 19 50 32 0 0 0 0
460 50 0 0 0 5.4 0 0 0 0 0 0 0 0 0 0 0 0 0 0
470 14.80 0 0 0.7 2.3 13.60 0
480 LöVSTA
490 1
500 Lö
510 PASTURE
520 10 0 121 135 296 142 142 5 80 15 80 80 0
530 175 180 239 244 0 0 0 0 0 0
540 80 79 0 0 0 0 0 0 0 0
550 75 0 0 0 -0.8 0 0 0 0 0 0 0 0 0 0 0 0 0 0
560 38.60 0 0.05 0.9 3.2 61.99 0
570 ULTUNA
580 1
590 U12
600 PASTURE
610 10 0 121 135 296 125 125 12 100 15 100 100 0
620 168 173 224 229 0 0 0 0 0 0
630 50 50 70 30 100 50 0 0 0 0
640 75 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
650 101.57 0 0 0.9 2.6 92.17 0
```

APPENDIX E. Example 5: Daily Printout, Johansson ET_{rg}

```
FARM DATA
     NUMBER OF FARMS:   1
     FARM INFORMATION
          FARM NAME:  KUNGSHAMN
          NUMBER OF FIELDS:   1

          FIELD DATA
               FIELD NAME:  KZ
               CROP NAME:  POTATOES
               BASIC FIELD DATA
                    CROP NUMBER:   4
                    PLANTING JULIAN DATE:  131
                    EMERGENCE JULIAN DATE:  151
                    EFFECTIVE FULL COVER JULIAN DATE:  171
                    HARVEST JULIAN DATE:  198
                    FIELD SUMMATION STARTING JULIAN DATE:  132
                    JULIAN DATE OF INITIAL SOIL WATER DEPLETION:  132
                    INITIAL SOIL WATER DEPLETION:    7.00
                    IRRIGATION EFFICIENCY:  80.0
                    MINIMUM IRRIGATION AMOUNT:  15.0
                    MINIMUM EFFECTIVE ROOTZONE DEPTH:  15.0
                    MAXIMUM EFFECTIVE ROOTZONE DEPTH:  60.0
                    LIMITING MAXIMUM EFFECTIVE ROOTZONE DEPTH:  30.0

               SOIL DATA
                    DEPTH    MAXIMUM AVAILABLE SOIL WATER
                     20.0               32.0
                     30.0               19.0
                     50.0               32.0
                      0.0                0.0
                      0.0                0.0
               FIELD IRRIGATION DATA
                    PERCENT DEPLETION ALLOWED:  50.0
                    DEPLETION ALLOWED:   0.0
                    PREVIOUS IRRIGATION JULIAN DATE:    0
                    PREVIOUS IRRIGATION AMOUNT:   0.0
                    PERIOD DAY    RAIN AND/OR IRRIGATION DIFFERENCE
                         1                      5.4
                         2                      0.0
                         3                      0.0
                         4                      0.0
                         5                      0.0
                         6                      0.0
                         7                      0.0
                         8                      0.0
                         9                      0.0
                        10                      0.0

               FIELD CONDITION
                    SOIL WATER DEPLETION:   11.71
                    PAST THREE DAYS ADJUSTED PRECIPITATION AND/OR IRRIGATION AMOUNTS:
                             0.00      0.00      0.70
                    SUM OF PRECIPITATION:    2.3
                    SUM OF CROP ET:   10.51
                    SUM OF NET IRRIGATION AMOUNTS:    0.0
```

```
FIELD SOIL WATER DEPLETION CALCULATIONS
     FIELD:  K2
     CROP:  POTATOES
     CROP NUMBER:   4
JULIAN   TS    PCT   ROOT    AVM    INITIAL   AV   ETRG   KC1   KC2   KC3   KC4     ET    IRRIG-   PRECIP-   WATER   DPL    ALLOWED
 DATE                ZONE   (MM)     DPL     (%)   (MM)                            (MM/   ATION   ITATION   ADDED   (MM)     DPL
                     (CM)            (MM)                                           DAY)   (MM)     (MM)     (MM)            (MM)
 152    5.0   10.3   19.6   31.38    11.71   62.7  1.54   0.26  0.90  0.45  0.69   1.06    0.0     14.2      14.2    0.00   15.69
 153   10.0   20.5   24.2   40.03     0.00  100.0  2.57   0.34  1.00  0.60  0.94   2.42    0.0      0.0       0.0    2.42   20.01
 154   15.0   26.9   27.1   45.50     2.42   94.7  3.49   0.39  0.99  0.35  0.74   2.58    0.0      0.0       0.0    4.99   22.75
 155   20.0   33.3   30.0   50.97     4.99   90.2  3.73   0.44  0.98  0.20  0.63   2.34    0.0      0.0       0.0    7.34   25.49
 156   25.0   37.8   30.0   51.00     7.34   85.6  3.90   0.47  0.97  0.00  0.46   1.79    0.0      0.0       0.0    9.13   25.50
 157   30.0   42.3   30.0   51.00     9.13   82.1  3.58   0.51  0.96  0.00  0.49   1.75    0.0      0.0       0.0   10.87   25.50
 158   35.0   48.7   30.0   51.00    10.87   78.7  4.59   0.56  0.95  0.00  0.53   2.44    0.0      0.0       0.0   13.31   25.50
 159   40.0   55.1   30.0   51.00    13.31   73.9  3.45   0.61  0.94  0.00  0.57   1.97    0.0      0.0       0.0   15.28   25.50
 160   45.0   62.2   30.0   51.00    15.28   70.0  4.88   0.66  0.92  0.00  0.61   2.99    0.0      0.0       0.0   18.27   25.50
 161   50.0   69.2   30.0   51.00    18.27   64.2  4.51   0.72  0.91  0.00  0.65   2.94    0.0      0.0       0.0   21.21   25.50
PERIOD SUM (MM)                                                                   22.27    0.0     14.2      14.2
SEASON SUM (MM)                                                                   32.78    0.0     16.5      16.5
TS -- TIME SCALE WHICH IS: PERCENT TIME FROM EMERGENCE TO EFFECTIVE FULL COVER
                           OR DAYS AFTER EFFECTIVE FULL COVER
PCT--PERCENT FROM MINIMUM TO MAXIMUM BASAL CROP COEFFICIENT
AVM -- MAXIMUM AVAILABLE SOIL WATER
DPL -- SOIL WATER DEPLETION
AV -- PERCENT AVAILABLE SOIL WATER
ETRG -- GRASS REFERENCE CROP ET
KC1 -- BASAL CROP COEFFICIENT
KC2 -- CROP COEFFICIENT RELATED TO AVAILABLE SOIL WATER
KC3 -- CROP COEFFICIENT RELATED TO A WET SURFACE
KC4 -- CROP COEFFICIENT

PREDICTION OF NEXT IRRIGATION DATE
     MINIMUM NET IRRIGATION AMOUNT:   12.0
JULIAN   TS    PCT   ROOT    AVM    INITIAL   AV   ETRG   KC1   KC2         KC4     ET                                   DPL    ALLOWED
 DATE                ZONE   (MM)     DPL     (%)   (MM)                            (MM/                                  (MM)     DPL
                     (CM)            (MM)                                           DAY)                                          (MM)
 162   55.0   75.0   30.0   51.00    21.21   58.4  3.09   0.77  0.89        0.68   2.09                                 23.30   25.50
 163   60.0   80.8   30.0   51.00    23.30   58.4  3.09   0.81  0.89        0.72   2.22                                 25.52   25.50

PREDICTION OF NEXT IRRIGATION DATE WITH EXPECTED PRECIPITATION
     EXPECTED PRECIPITATION BEFORE IRRIGATION DATE:    3.5  MM
JULIAN   TS    PCT   ROOT    AVM    INITIAL   AV   ETRG   KC1   KC2         KC4     ET             PRECIP-             DPL    ALLOWED
 DATE                ZONE   (MM)     DPL     (%)   (MM)                            (MM/            ITATION             (MM)     DPL
                     (CM)            (MM)                                           DAY)             (MM)                       (MM)
 164   65.0   85.3   30.0   51.00    22.05   58.4  3.10   0.84  0.89        0.75   2.32              1.75              22.61   25.50
 165   70.0   89.7   30.0   51.00    22.61   58.4  3.10   0.88  0.89        0.78   2.41              1.76              23.26   25.50
 166   75.0   93.0   30.0   51.00    23.26   58.4  3.10   0.91  0.89        0.80   2.48              1.77              23.97   25.50
 167   80.0   96.2   30.0   51.00    23.97   58.4  3.10   0.93  0.89        0.82   2.55              1.78              24.74   25.50
 168   85.0   97.5   30.0   51.00    24.74   58.4  3.10   0.94  0.89        0.83   2.58              1.79              25.53   25.50
```

```
IRRIGATION SCHEDULING
     FARM:  KUNGSHAMN
     COMPUTATION DATE:  11 JUN  1970

  FIELD          CROP         SOIL WATER DEPLETION      FORECAST        -- IRRIGATION DATES --    IRRIGATION
                                                     (NEXT 5 DAYS)                                  AMOUNT
                               CURRENT    ALLOWED                     PREVIOUS      -- NEXT --       (MM)
                                (MM)       (MM)       KC      ET
                                                           (MM/DAY)                WITHOUT    WITH
                                                                                    RAIN      RAIN
K2             POTATOES         21.21      25.50     0.84    2.62       0 ---    12 JUN    17 JUN     32

     EXPECTED PRECIPITATION DURING THE NEXT TWO WEEKS:     24  MM

     FORECAST:  NORMAL CONDITIONS
                GRASS REFERENCE CROP ET FOR NEXT 5 DAYS:   3.10  MM/DAY
                  BASED ON  1.00  OF THE LONG-TERM VALUE


REGIONAL CLIMATIC CONDITION ... DATA FOR NEXT RUN
  162  24.0  22.9  23.5  121 161.62 228.26 120.70  13.3

FIELD CONDITION ... DATA FOR NEXT RUN
 21.21   0.00   0.00   0.00   16.5   32.78    0.0
```

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