COMPUTER-BASED IRRIGATION SCHEDULING METHOD FOR HUMID AREAS

C. R. Camp
Member ASAE

E. J. Sadler
Affiliate ASAE

T. P. Harvey[1]
Assoc. Member ASAE

Computers have been used in arid and semi-arid areas for several years to compute water balances and to estimate daily evapotranspiration (ET) from weather data (Jensen et al. 1970). Advantages of computer-based methods over other irrigation scheduling methods include the potential for using forecast or long-term weather data (including probability of rainfall), management of multiple fields or irrigation systems with the same program, application to a wide range of soils, crops, and climates, and the potential for planning irrigation schedules several days in advance. Some crop growth models include soil water content in the simulation of crop growth and yield and some, such as GOSSYM/COMAX for cotton, include the capability for managing irrigation (Baker et al. 1983; Lemmon 1986). The most common type of computer-based irrigation scheduling program uses some form of water balance for that portion of the soil profile available for root growth. In these programs, water inputs (rainfall and irrigation) are measured and water extraction (ET) is estimated or computed from equations based on weather variables, measured pan evaporation, or long-term averages.

Although efforts have been made to adapt computer-based water balance technology to humid regions, the use of computers to schedule irrigation is not widely practiced in the southeastern U. S. (Rochester and Busch 1972; Lambert 1980; Camp and Campbell 1988). This may be because of difficulties in estimating daily ET and in calculating infiltration, runoff, and deep percolation from humid-area soils. Calculating runoff can be particularly difficult for high-intensity thunderstorms; consequently, assuming all rainfall infiltrates into the soil can cause significant errors in calculated soil water storage. Most computer-based scheduling methods must be corrected periodically using measured soil water content; this is particularly true in high-rainfall humid areas. The objective of this research was to develop a modular computer-based water balance program that could be easily modified, would be user friendly, would account for infiltration and runoff, and would operate on most desktop personal computers. Field evaluation of this method for cotton is reported by Camp et al. (1990).

PROGRAM ORGANIZATION

The <u>P</u>recipitation, <u>R</u>unoff, and <u>I</u>rrigation <u>S</u>cheduling <u>M</u>anager (PRISM) is controlled by the Irrigation Scheduling Manager (ISM), which is a menu-driven shell designed to assist the user in operating the Water Balance Model (WBM), the primary computational component of PRISM. A variety of options in the ISM increase user flexibility for creating and editing data files, operating the WBM for selected time intervals, and displaying or printing results. All data required by the WBM are entered within the ISM and data are checked by the ISM to ensure quality.

---

[1] C. R. CAMP, Agricultural Engineer, E. J. SADLER, Soil Scientist, and T. P. HARVEY, Agricultural Engineer, USDA-ARS, Florence, SC.

WBM is a model for estimating soil water storage on a daily basis. The user provides soil and site parameters and initial values of rooting depth and soil moisture content to start the model. Daily balances are calculated by extracting ET and adding rainfall and irrigation amounts, after correcting rainfall for runoff. The user specifies the maximum depletion of the soil water to be allowed. When the calculated soil water storage falls below this value, the need for irrigation will be indicated in the output. To improve the accuracy of the WBM, the user may periodically re-initialize the model by providing measured values for soil water content during the season. PRISM was developed with Ryan-McFarland[2] RM/Fortran and requires 256 kB memory for operation.

PROGRAM STRUCTURE

Irrigation Scheduling Manager

The ISM consists of a series of screens, each menu-driven, that allow the user to reach the desired utility quickly. When the user provides a field or project name, ISM prompts for the data required to operate the WBM. Once these required data are entered, the user is allowed access to the **Main Menu**. At the **Main Menu**, the user has a choice of five operations: **Create/Edit**, **Set Parameters**, **Run WBM**, **Review Output**, and **Select Another Field Name**. (In this paper, menu names are boldfaced and underlined and menu options are bold- faced.) The menu hierarchy of the ISM is illustrated in Fig. 1. Most computations occur in the WBM for which a standard flow chart is given as Fig. 2.

Choosing **Create/Edit** provides the **File Editor Menu**, which lists the six data file types shown in Fig. 1, indicating which files have not been created, and allows creation and editing of each file type. Choosing a file type automatically selects the editor for that file type. From any file editor, a **File Options Menu** allows sharing of data files among fields or copying data files from one field name to another. Sharing files helps eliminate redundancy when several fields need the same weather or soil data. Copying files speeds data entry when two fields need the same or similar data files but must be managed independently. The **File Options Menu** also allows the user to save data files temporarily (for a run) or permanently (for future use). The **Temporary** option allows the user to create a "what-if" scenario without permanently affecting the data files.

Choosing **Set Parameters** allows the user (1) to choose the type of weather data (measured, forecast, normals, or a combination of these), (2) to select re-initialization, (3) to utilize rainfall on re-initialization dates, and (4) to invoke automatic irrigations (13 mm) when scheduled by the WBM. Default settings will be used if none are selected by the user. When the **Run WBM** option is selected, the ISM provides a summary of the last WBM cycle (dates and weather data used) and gives current parameter settings. It also requests initial and final dates for the next WBM cycle. Generally, this cycle starts with the last computation previously made with measured weather data; continues up to the current date using recently-measured weather data; switches to forecast weather data until exhausted; and then continues to the final date using computed normals. During operation, the WBM screen shows progress through the period selected. After completion, the ISM displays the **Main Menu**, where **Review Output** can be selected to provide the **Output Menu**. This menu provides two output choices: a **Summary Report** and a **Detailed Report**. For example, the **Summary Report** shows the fraction of

---

2 Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty or the product by the U. S. Dept. of Agr. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

available water stored in the soil profile while the **Detailed Report** shows daily water content by soil layer. The user may also select the units for the output (English or SI). When the output is displayed on the screen, the user may print either all or a selected portion of it.

Water Balance Model

When the WBM is initiated via the ISM, it operates in daily time steps for the selected period (Fig. 2). It reads appropriate data files, computes runoff and infiltration, adds infiltration, calculates and extracts actual ET (ET_a), compares calculated stored water with the allowed depletion level, and sets the irrigation flag, if required. If set, the irrigation flag is shown in the output for that date.

Two types of input data are required by the WBM: site data (field description and initial conditions) and daily data. Field data, which do not change throughout the season for a particular field, include crop, location, planting date, days to maturity, depth of soil layers, field capacity, wilting point, and SCS Curve Number (SCS, 1954). Initial conditions are starting values for other soil and site parameters such as allowable depletion, rooting depth, daily root growth interval, maximum rooting depth, number of days to hold excess water, and water content by soil layer. These values may be updated at any time during the growing season through re-initialization. Field and initial data files are accessed from the **File Editor Menu** by selecting **Field** and **Initial**, respectively. Field and initial data files are mandatory for operating the WBM.

Daily data include values for parameters that change daily, such as irrigation and weather data. Daily rainfall and irrigation amounts are included in a file separate from other weather data. If there is no weather data file, normal maximum and minimum temperature, dewpoint, pan evaporation and solar radiation can be calculated for specific locations using historical data. Currently, values for these variables are calculated for five locations in the southeastern U. S. using fourth-degree polynomials (Lambert et al. 1988). The method to be used for estimating reference crop ET (ET_r) will determine which variables are needed. Polynomial coefficients for other locations may be added so that normal weather can be computed for a desired site or one that adequately represents it.

Computations

Rooting depth may be updated through the re-initialization procedure; otherwise, rooting depth will increase linearly at the rate entered initially up to the maximum depth specified. During the re-initialization procedure, the user can alter the root growth rate, maximum rooting depth, and rooting depth for a specific date. Root growth functions for specific crops will be added in the future.

Daily infiltration is computed from daily rainfall using the SCS Curve Number in a manner similar to that used in CREAMS (Knisel 1980). Irrigation and infiltration amounts are added to the soil profile one layer at a time, starting at the soil surface. The water storage capacity of each soil layer is computed using soil field capacity from the field data file and soil water contents. When the water added to the soil profile exceeds the storage capacity of the first layer, the excess is added to other layers successively until either the water to be added is depleted or the storage capacity is filled. If water in excess of storage is available, it may be retained in the soil profile for 0 to 3 days (selected by user). During this time, it is available to satisfy ET requirements. Any excess water remaining after the retention period is lost as deep percolation.

Daily ET_a is extracted from the profile in a manner analogous to that used for adding water to the profile. ET_a is extracted first from the top layer, then successively from the next lower layer until each is depleted to the wilting point. If excess water (rainfall or irrigation) exists, ET_a is extracted from it first, before extracting from the soil layers.

Daily ET_r values are currently computed using the modified Jensen-Haise method (Jensen 1974), which requires site-specific inputs and coefficients to modify ET_r for specific crops and soil conditions. These site-specific inputs are provided by the user and are included in the field data file. Crop coefficient parameters are provided for specific crops based on user input. Currently, crop coefficient data are available for corn, cotton, and wheat. Parameters for corn and wheat are similar to those used by Lambert et al. (1988). Parameters for cotton were computed from a regression of cotton growth stage data (SCS 1967). This cotton growth curve can be described by a two-part equation as follows:

$$K_c = 0.24 - 1.29\ T_f + 10.83\ T_f^2 - 10.84\ T_f^3 \qquad \text{for } T_f < 0.66$$

and

$$K_c = 1.95 - 1.44\ T_f \qquad \text{for } T_f \geq 0.66$$

where

K_c = crop coefficient,
T_f = fraction (0 to 1) of crop growing season (planting to maturity).

The multiplier K converts ET_r to ET_a for specific crop and soil conditions and is the product of the crop and soil coefficients, K_c and K_s, as follows:

$$K = K_c \cdot K_s$$

and

$$ET_a = K \cdot ET_r$$

The soil coefficient (K_s) used in the WBM was computed using equations derived by Jensen et al. (1971). The soil water profile used in the calculation and for the water balance itself is defined as the rooting depth, plus 0.1 m to allow for capillary rise. After rainfall or irrigation, soil evaporation from a wet soil surface increases ET_a to near ET_r. If $K < 0.9$ and $R + I > 6$ mm, then K is adjusted for the following 1-3 days (Jensen et al. 1971).

Irrigation Flag

Soil water storage capacity and user-specified allowable depletion value determine the water available for crop use before irrigation is required. Allowable depletion is the fraction of soil water storage capacity that can be extracted before irrigation is to be applied. Each day the computed soil water content is compared to the storage capacity less the allowable depletion amount; if the soil water content is smaller, an irrigation flag is set and a message included in the output file.

PLANNED IMPROVEMENTS

Improvements to PRISM will include alternate methods for computing or estimating daily ET. One option will be the direct input by the user of ET_r values that may be available locally. Also, other methods for computing daily ET from weather data will be included. Historical weather regression coefficients for additional locations will be added as they become available. A root growth simulator that will provide more realistic daily rooting depth data is planned. As crop coefficient and crop water requirement data for additional crops become available, they will also be included.

To be of maximum benefit in humid areas, an irrigation scheduling program should include a procedure for including forecast rainfall (probability and amount) in the decision-making process. This information could be included as either regular weather forecasts, long-term patterns, or real-time data such as that obtained from digitized radar images.

Acknowledgement: The authors wish to acknowledge the assistance of L. W. Cook and K. C. Stone in the development of this irrigation scheduling program.

REFERENCES

1. Baker, D. N., J. R. Lambert, and J. M. McKinion. 1983. GOSSYM: A simulator of cotton crop growth and yield. Tech. Bull. No. 1089. S. C. Agr. Exper. Stn., Clemson Univ., Clemson, SC.

2. Camp, C. R., W. M. Thomas, and C. C. Green. 1990. Scheduling irrigation for cotton in humid areas. (These Proceedings).

3. Camp, C. R., and R. B. Campbell. 1988. Scheduling irrigation for corn in the southeast. ARS-65. USDA, Agr. Res. Service, Washington, DC.

4. Jensen, M. E. 1974. Consumptive use of water and irrigation water requirements. Amer. Society of Civil Engrs., New York, NY. 215 pp.

5. Jensen, M. E., D. C. N. Robb, and E. Franzoy. 1970. Scheduling irrigation using climate-crop-soil data. J. Irrig. & Drain. Div., Am. Soc., Civ. Engr. 96(Ir):25-38.

6. Jensen, M. E., J. L. Wright, and B. J. Pratt. 1971. Estimating soil moisture depletion from climate, crop and soil data. Trans. of the ASAE 14(5):954-959.

7. Knisel, W. G. 1980. CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. Conservation Research Report No. 26. USDA, Science and Education Admin., Washington, DC.

8. Lambert, J. R. 1980. Irrigation management--Humid areas. Proc. 2nd Nat'l. Irrig. Symp., Irrigation Challenge of the 80's. ASAE Pub. #6-81, ASAE, St. Joseph, MI 49085. pp. 175-184.

9. Lambert, J. R., I. Israel, and I. Meirson. 1988. Computer program for scheduling irrigation by water budget. In Scheduling irrigation for corn in the southeast. Camp, C. R. and R. B. Campbell, coordinators. ARS-65. USDA, Agr. Res. Service, Washington, DC. pp. 7-22.

10. Lemmon, H. 1986. COMAX: An expert system for cotton crop management. Science 233:29-33.

11. Rochester, E. W., and C. D. Busch. 1972. An irrigation scheduling model which incorporates rainfall predictions. Water Resources Bull. 8(3):608-613.

12. Soil Conservation Service. 1954. National Engineering Handbook, Section 4, Hydrology, Supplement A. USDA, SCS, Washington, DC.

13. Soil Conservation Service. 1967. Irrigation Water Requirements. Tech. Release No. 21. USDA, SCS, Washington, DC.

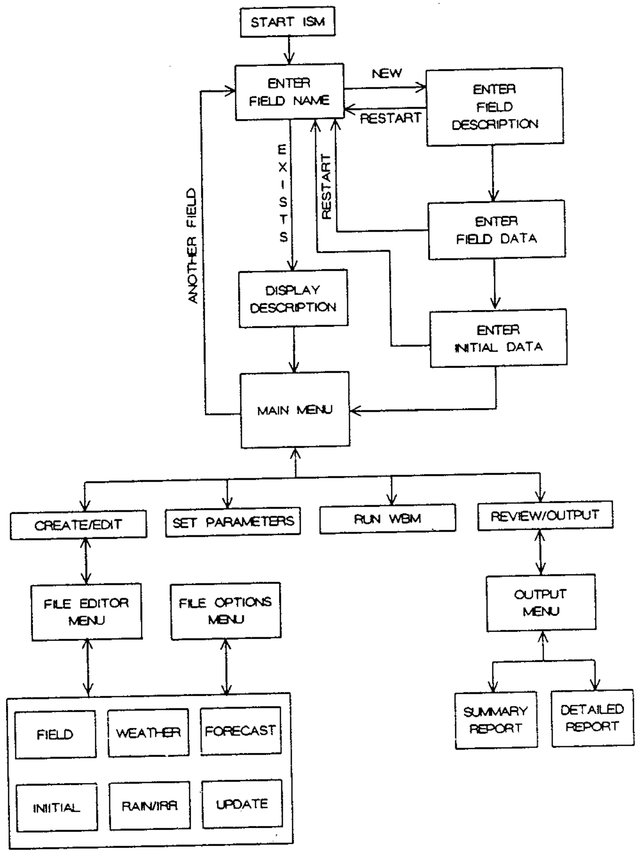

Figure 1. Schematic of menus in the Irrigation Scheduling Manager (ISM).

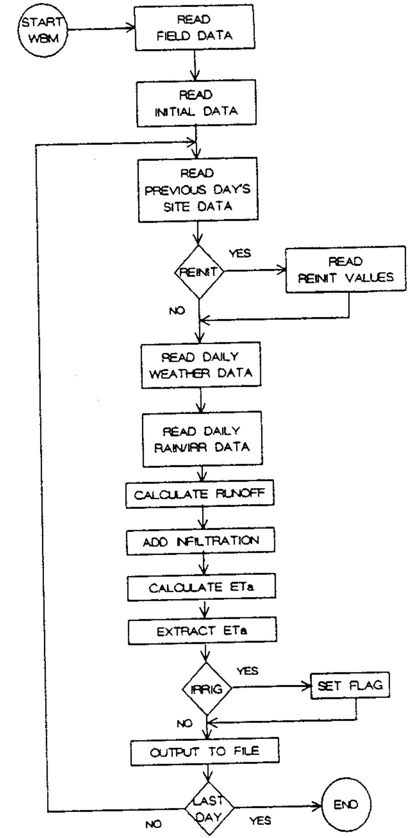

Figure 2. Flow chart for the Water Balance Model (WBM).