專　論

農業需水量之系統設計

Systems Design for Agricultural Water Demand

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中文摘要

水資源和農業已被公認爲與國家經濟有密切之關係。惟水資源之供應和農業生產之直接關係常被忽略而未加深入之研究。本文之介紹着重於如何收集龐大之資料並關連水資源和農業生產兩者之間的關係。進而設計有系統之數種理想農業需水量之方案。然後由當政者根據當時之環境及其他種種因素選擇此數種政策中之一種實施或合併數種方案共同執行。

INTRODUCTION

It has long been recognized that both water resources and agriculture are crucial to the economic well being of our nation. Unfortunately, adequate information which relates the two is not available. A through understanding of the relationship between water availability and agricultural requirement for water are essential in planning for optimum use of water resources. There are three major physical factors which affect the agricultural water demand in any location whether it be an individual farm or a region of the development area. These factors are: 1. soil type, 2. crops grown and, 3. climatic conditions, ie. rainfall and temperature. Once the demand has been determined, information is needed on groundwater and surface water supplies to see if this demand can be met with existing supplies.

Major rural uses of water are: irrigation of crops, woodland and pasture; livestock production; and domestic municipal and industrial requirements in rural and non-urban communities. Factors which affect requirements for rural water are population of rural and non-urban areas, size and type of industry, types and numbers of livestock, acres of woodland, acres of pasture, types and acres of soil available for cropland, types and acres of crops grown (by soil type), irrigation and other management decisions, and climatic factors. In order to quantify the requirements for rural water at some time, either for the present or in the future, each of these factors must either be known or predicted for that time.

In a crops oriented area, a tool is needed to make decisions relating water resources and levels of agricultural production. This tool should possess the capability of rapidly analyzing many alternative types and levels of agricultural production and of comparing results for the alternatives considered. The logical tool for making such decisions is a computer model. Analysis of this type of problem by computer modelling permits the imput of many large arrays of data, e.g. acres and types of soils and crops, climati data, etc. Also many alternatives can be studied and sensitivity analyses made on imput parameters and decision rules.

OBJECTIVES

The long range objectives of this study are: 1. To determine economically feasible irrigation water requirements for each crop grown in an area; 2. to determine total water requirements for a given level of agricultural activity in an area; and 3. to determine for a given quantity of water available to agriculture in a specified area, the optimum level of agricultural activity.

PROCEDURES

To meet these long range objectives, the following general procedures are required:

1. Exploratory study (Phase 1)
   - A. Develop general logic for computer models and determine input data requirements
   - B. Develop input data case representing a specific area of the state for use in testing the models.
2. Model Development (Phase 11)
   - A. Develop procedures for determining irrigation water requirements for individual crops.
   - B. Program and debug computer models for determining total water requirements.
   - C. Run computer models using the data developed in phase 1.
   - D. Analyze results of model exercises.
3. Model Development and Application (Phase 111)
   - A. Develop and debug program for determining optional water use in an area.
   - B. Develop input data cases for additional study areas.
   - C. Run computer models using these inputs.
   - D. Analyze results of computer runs and make recommendations relating the availability of and the requirements for agricultural water in a study area.

The exploratory phase of this study has been studied in some area termed a pilot area. The basic data include four parts:

1. Depths, texture, reaction, pH, and water holding capacity of the different layers within the soil profile along with the soil drainage characteristics
2. Type, level, trends in agricultural activity, the response of a particular crop to soil type, irrigation practices and other management decisions for each crop presently grown or predicted to be grown in the study area.
3. Climate data which include daily rainfall statistics along with daily maximum temperture statistics for major weather stations in the study area.
4. Statistics of livestock, forestry production, population, industry.

As in most modelling efforts there may be some items of data that are either unavailable or unreliable. In such cases data will be estimated and varied and the models will determine the sensitivity of results to estimated values. If results are very sensitive to values of the estimated data, this would indicate a need for concentrated effort to begin collecting the data. If results are not sensitive to estimated values then it can be assumed that the unavailable data is of little consequence.

Phase 11 of this research will be devoted primarily to development and debugging of computer models. At least two computer models will be developed. The first model will use as imput available land by soil types, level of agricultural activity, forest land, and population in a well defined area of a region. Input data will also match crops with a soil type and reflect a management decision regarding irrigation police, i. e. at what moisture deficit level does irrigation begin. Other input data will include livestock and poultray activity, domestic use of water, forest and grassland water needs, and climatic data for the area. The model will determine water requirements on a time basis, e.g., weekly, monthly or seasonably.

The second model will use much the same imput data as the first model except that available water will be an input and agricultural activitv an output. The model will determine the optimum number of acres of each crop/soil combination and optimum levels of livestock and poultry production in a specific area for a given quantity of available water. (optimum implies maximum net return to the area from agriculture). Mathematical optimization techniques such as linear programming will be used in the development of this model.

A schematic diagram of model inputs and logic is included in Appendix 1, a subroutine of model development is shown in Annex A.

Management decisions such as irrigation, fertilization, and plant population levels and variety selection, choice of soil types for a crop, etc, and their interaction with climatic factors have a direct effect on economic returns from the use of water resources in agriculture. The models described above will provide a tool for evaluating and quantifying the effects of alternative management decisions on economics returns.

While the models developed in phase 11 of this study will be general in the sense they can be applied to different areas in the nation, their application during phase 11 will be limited to the one or two detailed data cases developed in phase 1. The primary emphasis during phase 11 will be devoted to development of the models and verification that they are performing as expected. Validation of models of this type is somewhat difficult since short term experiments to check the models are impossible. Attempts to validate the models will be made through consultation with agricultural scientists, plant, soil and animal scientists and economists, and agricultural workers intimately familiar with the study area. Verification from these specialists that model results do appear feasible for particular imput conditions will lend credibility to the models.

Phase 111 of the study will involve further running and refining of the models. Input data cases for areas larger than a pilot area will be developed and analyzed. It is anticipated that these areas will have different crops, soils, and climatic conditions than those considered in phase 11.

MODELS DEVELOPMENT

A large percentage of agricultural water is used for the irrigation of crops. A study of irrigation requirements should therefore, be based on a thorough understanding of the soil-plant-water relationships including such factors as depth of soil profile, depth of the plant's root zone as a function of time and the plant water requirements for optimum production as a function of time. Unfortunately, the available data concerning these relationships are scarce and not uniformly distributed in a given time interval, i.e. Most of the data represent only a few observations in a while growth season, and the data are so sparse that the short term and total water requirement for each crop can not be estimated. Therefore, models which relate these factors should be developed for each crop grown in the study area so that the water requirement for optimum crop yields can be estimated more accurately.

All models are formulated on a daily basis in a whole growth season, that is all days between planting and harvesting. Shih (1972) developed two models. The first model is designed to simu late thewater requirement for each crop as a function of time, and the second model is devised to simulate the rooting depth for each crop as a function of time. The other model is presented herein to determine total water requirements for specified levels of agricultural activity.

Water Use Model:

A mathematical model was formulated by utilizing the techniques of a modified Fourier series to simulate the water use rate for different crops. The form of the equation for the jth kind of crop is

$$F_j(t)=G_j+B_jt+\sum_{i=1}^{N_j} C_{ji}\ \mathrm{Sin}\ (iwt+\theta_{ji}) \qquad (1)$$

in which G_j is a constant; B_j, the slope of water use; N_j, the number of allowable harmonic; i, harmonic index; t, time factor; $C_{ji}=(a_{ji}^2+b_{ji}^2)^{\frac{1}{2}}$, the magnitude of amplitude; $\theta_{ji}=\arctan\ (a_{ji}/b_{ji})$, the phase angle; a_{ji}, Fourier cosine coefficient; b_{ji}, Fourier sine coefficient; $w=360/P_j$, in which P_j is the period of the fundamental cycle. In this study it was found that two or three harmonics were quite satisfactory in Fourier approximation. For example, the simulated results for tabacco and small grains as shown in Figure 1 are compared to the observation results (Sneed, 1971).

Rooting Depth Model:

A mathematical model was developed using the the techniques of asymtotic expansion to simulate the rooting depth changing with time. The form of the equation for the jth kind of crop is $Y_j(t)=\alpha_j+\beta_j\gamma_j^t$ (2)

in which Y_j (t) is the rooting depth of the jth kind of crop at time, t; α_j, β_j and γ_j, the constants of the jth kind of crop. The simulated results of corn and soybeans as given in Figure 2 are compared to the experimental results (Weaver, 1926 and 1927).

Total Water Requirements Model:

This model will determine agricultural water requirements for given levels of agricultural activity in a specified area. Water requirements will include that of crops,

animals, and human. Water requirements imposed by human and animal population will be based on a per capita consumption times the appropriate populations. Water requirements for crop growth will be based on certain soil-water-plant interaction during various stages of growth of the plant. Crop water requirements will be satisfied by rainfall and supplemental irrigation. The water balance at the end of time period k can be written as follows. $M_k = M_{k-1} - ET_k + R_k$ (3)
in whick M_k is the inches of moisture in soil at end of time period k; ET_k, the evapotramspiration during time period k; and R_k, the rainfall during time period k.

After the moisture balance is calculated the height of available moisture in the soil is determined. If this height does not reach the root zone then irrigation water is added to bring the water level to the desired height. To find total irrigation water requirements for a given time period, water requirements for each plant are accumulated. Annual irrigation requirements for all the time period designated. A flow chart depicting the basic logic for this model is shown in Figure 3.

DISCUSSIONS

In any water resources planning there is a need for reliable data and techniques for making projections and evaluating alternatives. Future rural water requirements in a region are subject to many variables that are presently unknown and comparison of alternative appears to be the most logical way to make decisions. A large portion of rural water use will be for irrigation. Since future irrigation requirements are a function of crops grown, weather patterns, and irrigation decisions, assumptions must be made regarding each and comparisons of the results of each set of assumptions should be made before firm water resources plans are made.

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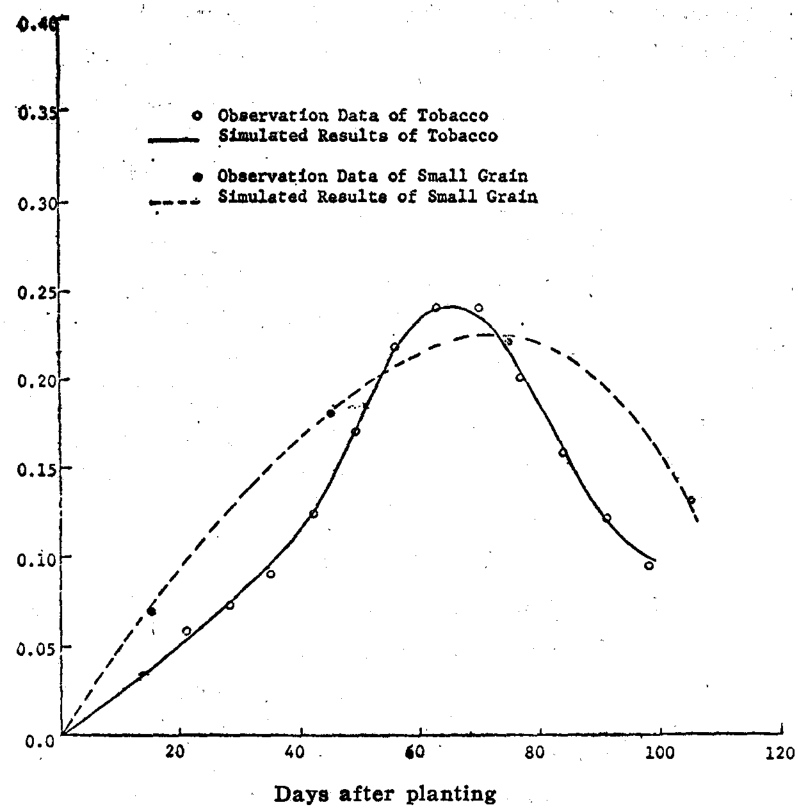


Fig. 1. Soil moisture use curve for tobacco and small grains.

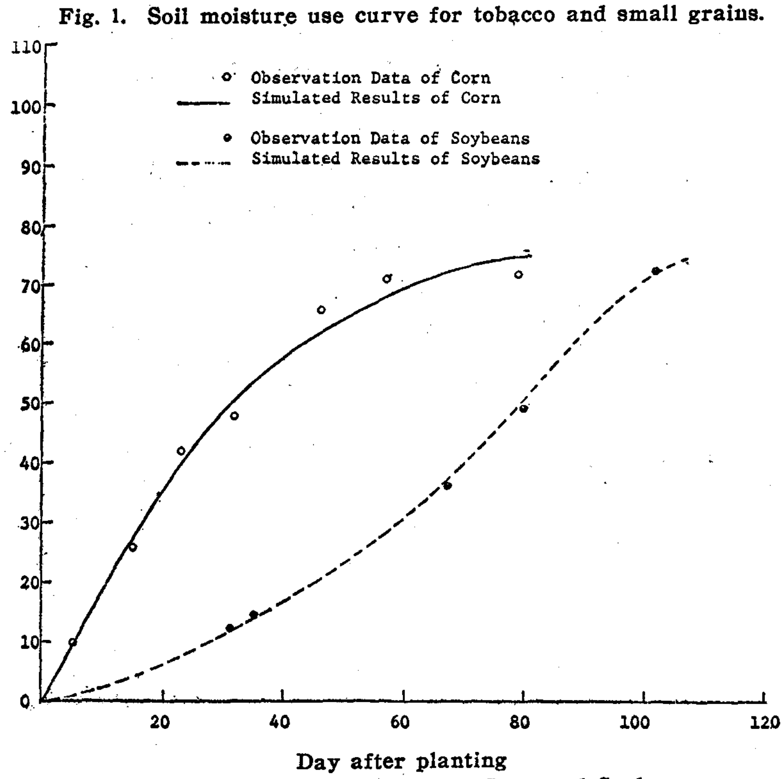


Fig. 2. Rooting depth curve for Corn and Soybeans

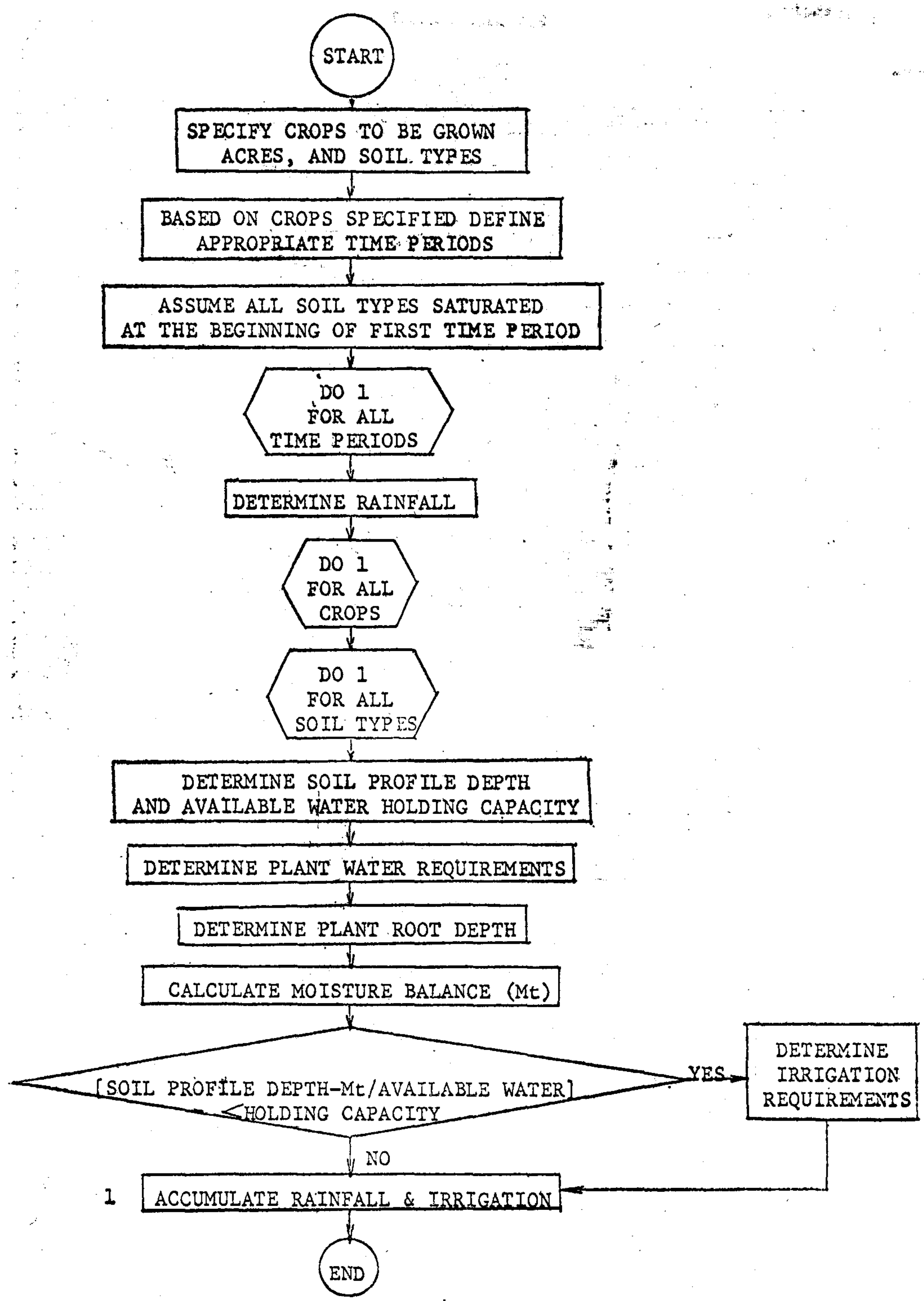
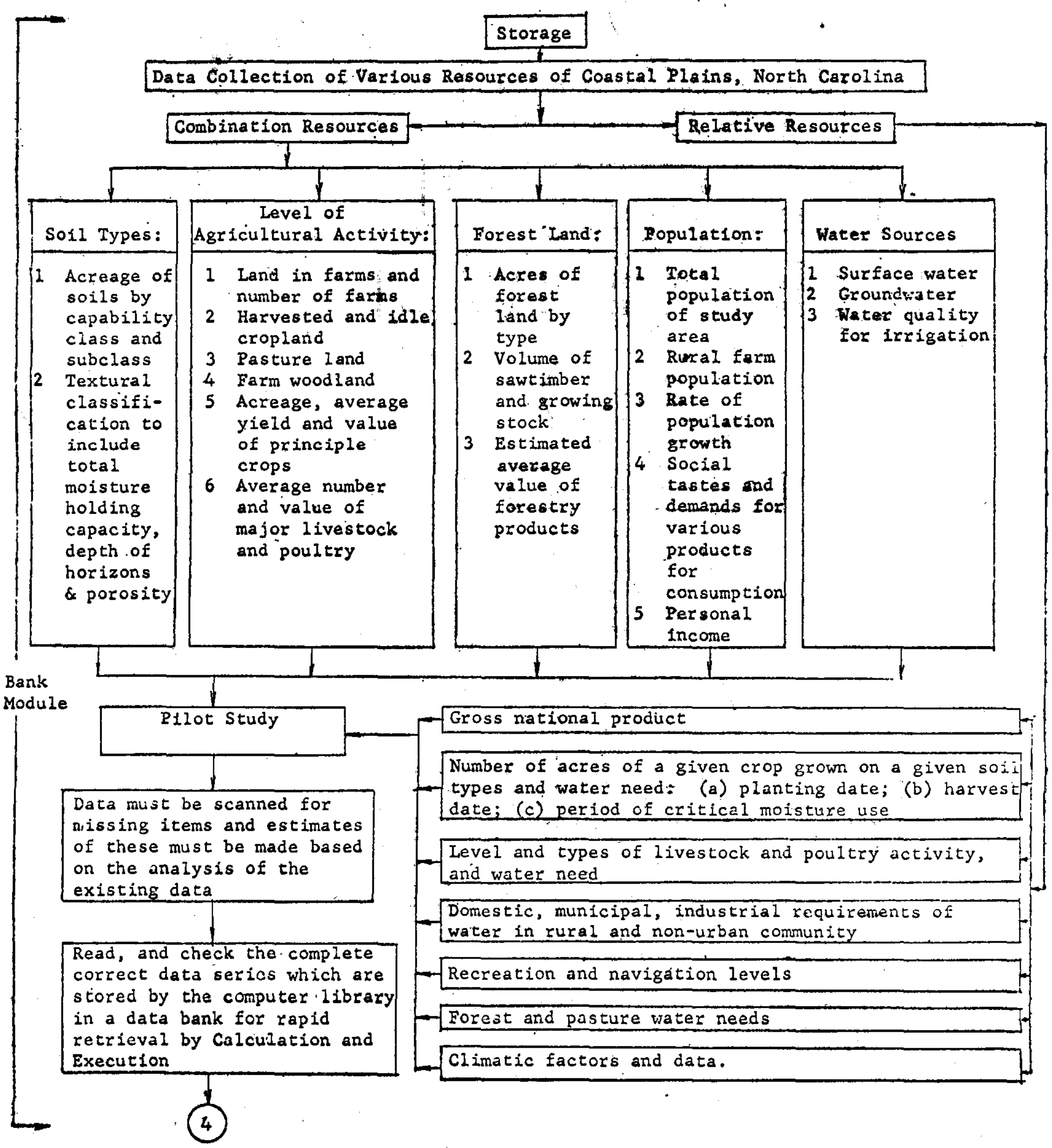
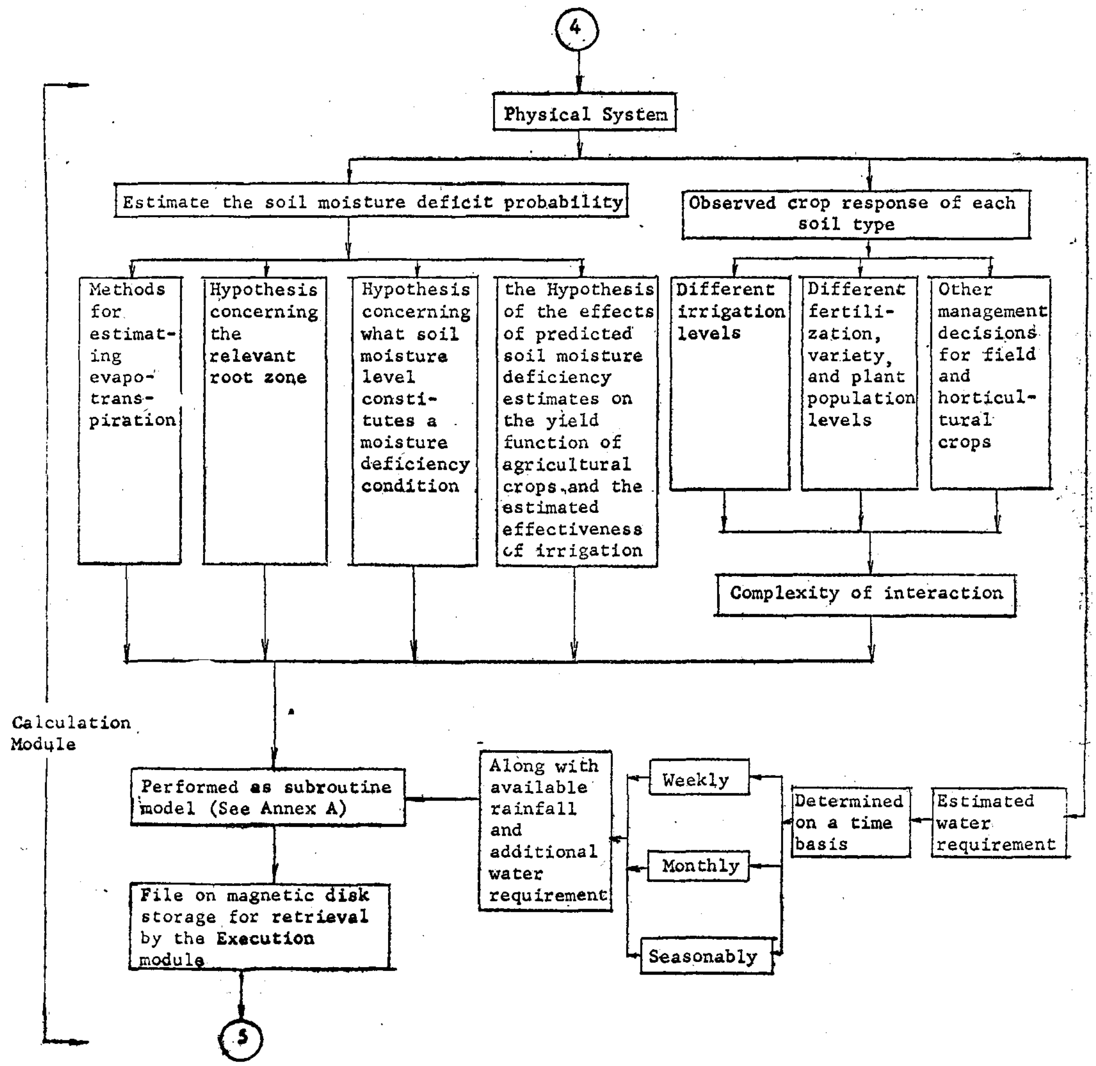


Fig. 3. Flow hart of logic for model for determining total water requirements of crops

Appendix I

Systematic Model

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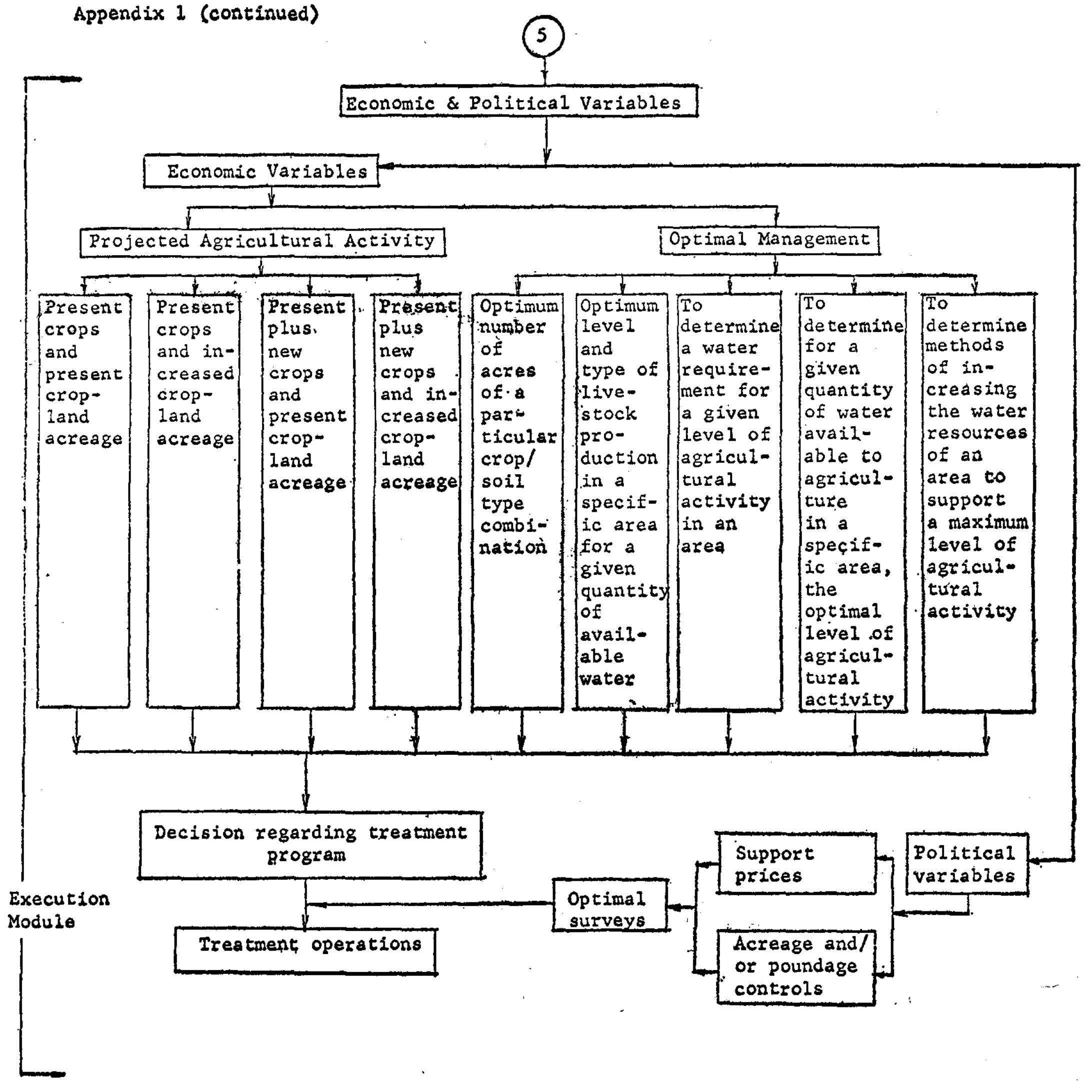
Physical System
Estimate the soil moisture deficit probability
Observed crop response of each soil type
Methods for estimating evapo-transpiration
Hypothesis concerning the relevant root zone
Hypothesis concerning what soil moisture level constitutes a moisture deficiency condition
the Hypothesis of the effects of predicted soil moisture deficiency estimates on the yield function of agricultural crops, and the estimated effectiveness of irrigation
Different irrigation levels
Different fertilization, variety, and plant population levels
Other management decisions for field and horticultural crops
Complexity of interaction
Calculation Module
Performed as subroutine model (See Annex A)
Along with available rainfall and additional water requirement
Weekly
Monthly
Seasonably
Determined on a time basis
Estimated water requirement
File on magnetic disk storage for retrieval by the Execution module
5

Appendix 1 (continued)



Annex A

Appendix 1 (continued)

Subroutine Model Development