MANAGEMENT OF WATER IN AGRICULTURAL DRAINAGE DISTRICTS

J. E. Parsons, C. W. Doty, and R. W. Skaggs[1]

INTRODUCTION

Many areas in the Southeastern Coastal Plains of the United States require drainage for sustained crop and timber productivity. The lack of suitable drainage outlets in these areas limits the applicability of many water management systems on a fieldwide and areawide scale. A number of these areas have been drained by channelization; the natural channels are dug deeper, widened, and straightened.

During the crop growing season, deep channels draw the water tables down in excess of 1 to 2 m from the soil surface. This, complicated by the fact that the soils are sandy with low water holding capacity in the root zone, greatly limits the water available to the crop. Farmers in these areas have installed irrigation systems to help counteract this. Primary water sources for such irrigation systems are wells and water stored in the drainage channels. But as the crop growing season progresses, drainage channels do not always provide a sufficient water source for the irrigation systems.

An example is the Conetoe drainage district in eastern North Carolina, where 26,000 hectares of land are drained by a network of channels which in some sections are 2.5 m deep. The channel system provides adequate drainage for the area and prevents the once frequent flooding. These deep channels have increased the drought stresses on the crops because the upward movement of water to the root zone in these sandy soils is small for the deeper water tables. Furthermore, with the increased number of irrigation systems in the area, the water available in the channels is often insufficient as the growing season progresses.

A cooperative project between Federal, State, and local groups was initiated in 1979 to study the effects of channel water level control on water management. The federal cooperators are the Agricultural Research Service and the Soil Conservation Service of the U. S. Department of Agriculture. The biological and agricultural engineering department and the soil science department of North Carolina State University are representing the State as cooperators. The local cooperators include the Edgecombe County Drainage District #2, and the local farmers and land owners of the area.

Chosen for detailed study was a 2-mile section of Mitchell Creek, one of the main drainage channels, which has a drainage area of approximately 800 hectares. The land area is flat to gently rolling, with the largest elevation difference being approximately 1.5 m. A dam was installed on Mitchell Creek in 1982. The water level in Mitchell Creek is controlled automatically by the dam. The dam has enabled accurate control of the channel water levels along with providing the required drainage during periods of excess rainfall (Doty et al. 1982).

The overall project objectives are to study the present methods for the design and operation of water management systems and to develop better criteria for such systems. One of the specific project objectives is to develop and test a comprehensive water management model for the analysis and evaluation of agricultural drainage district designs.

A number of models have been developed for describing water flows and storage on a watershed scale and a regional scale. Two such models are those of Freeze (1971) and de Laat et al. (1981).

Freeze (1971) used solutions to the three-dimensional Richard's equation to simulate water movement in a watershed. The difficulty in obtaining the input parameters and the time and expense of the computer simulations make this approach unfeasible in large areas where a number of years of simulation are required. On a regional scale, de Laat et al. (1981) developed a model for the evaluation of water management policies. Their model separates the system into interacting components to simulate the effects of water management policies on regions on the order of 1000 square kilometers. The use of this model on an agricultural drainage district would be difficult without making major modifications. Therefore, we decided to develop a comprehensive model utilizing the appropriate assumptions from the existing models. The purpose of this report is to give an overview of the present model.

THE WATER MANAGEMENT MODEL

The main objective of the model is the simulation of water table changes in response to channel water levels and the weather, specifically, breakpoint rainfall over periods greater than 10 minutes and daily potential evapotranspiration. The channel networks in these areas consist of both parallel and intersecting channels. A typical geometry is given in figure 1. The various channel networks make a two-dimensional saturated flow model necessary to accurately describe water movement near intersecting channels.

Other specific objectives of the model include estimates of water availability in the crop root zone in response to water table changes. Also, for an accurate accounting of water flows within the system, the model should have components to estimate infiltration and surface water storage and flow. The model should be modular so that subsystems, in the form of subroutines, can be easily exchanged with new ones reflecting different assumptions. The computer time should be such that simulations of a year are not cost prohibitive.

---

[1] J. E. Parsons and C. W. Doty, Agricultural Engineers, USDA-ARS, Florence, SC. R. W. Skaggs, Professor, N. C. State University, Raleigh, NC.

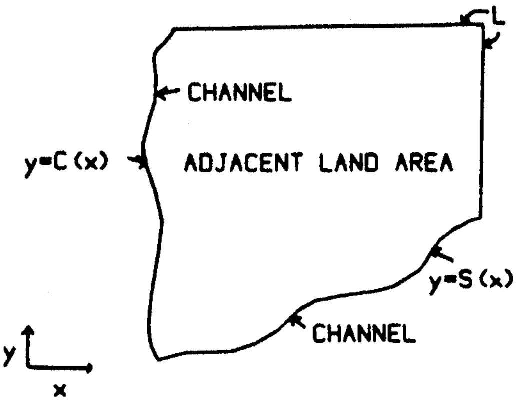

Figure 1. A typical channel geometry.

The overall structure of the model consists of components for water movement in the saturated zone, in the root zone, and on the soil surface. Model input is the first major portion of the model executed. Routines dealing with the root zone water flows consist of calculating the water available in the root zone, finding the amount of upward water movement from the water table, and estimating the amount of infiltration and runoff from rainfall events. The routing of runoff over the area is done by the overland flow component. The saturated soil component simulates the water table changes in response to channel water level changes in main and lateral drainage channels, to field scale water management systems such as surface irrigation and subsurface irrigation and drainage systems, and to the vertical water movement due to addition of rainfall and extraction of water to meet evapotranspiration demands.

A flow chart showing the execution flow of the model is given in figure 2. Short descriptions of the major model components and the assumptions made for their development are given in the following paragraphs.

The saturated soil water movement component consists of the solution of the two-dimensional Boussinesq equation using the finite element method (FEM). This entails assuming that water flows parallel to a horizontal impermeable layer at a given depth. The formulation of the Boussinesq equation is

$$f \frac{\partial}{\partial t} = \frac{\partial}{\partial x} \left(K h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y} \left(K h \frac{\partial h}{\partial y}\right) + R \qquad (1)$$

where f = drainable porosity,
h = height of the water table above the impermeable layer in m,
t = time in days,
K = lateral saturated hydraulic conductivity in m/day,
x, y = cartesian coordinates in m, and
R = rate water enters or leaves the water table vertically in m/day.

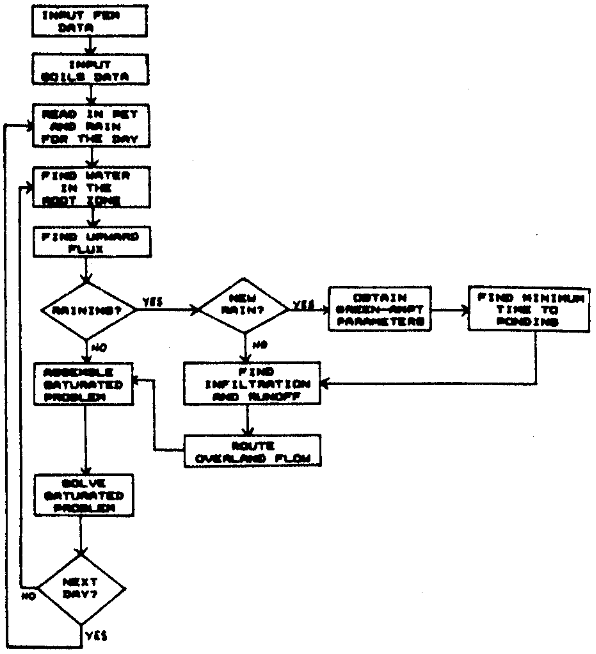

Figure 2. A flow chart of the model.

The drainable porosity, f, and the lateral saturated hydraulic conductivity, K, depend on the soil type and on water table height, h. The rate water enters or leaves the water table vertically, R, is negative for movement of water into the root zone and positive for deep drainage from infiltration water. This rate is assumed to be at the unsaturated soil-saturated soil interface. The boundary conditions are the channel water levels in the drainage channels throughout the area. The finite element solution procedure has been described in detail by Parsons et al. (1982).

In the root zone, the horizontal water movement is assumed to be negligible. At each node throughout the area, the water is balanced in the root zone in response to evaporative demands and rainfall inputs. The mass balance of water in the root zone is done similarly to the methods of Skaggs (1978). The main difference is that the model balances the water by layers, thereby enabling the use of soil horizon data.

To satisfy potential evapotranspiration demands, the upward water movement from the water table into the root zone is computed. This amount replenishes water removed from the root zone to meet the evapotranspiration demands. Any additional water required is withdrawn from the root zone. In cases where the amount in the root zone is not sufficient, the actual evapotranspiration will be less than the potential. The amount which supplied from the water table is used as the recharge term, R, in the solution of equation 1 at the next time step. This provides a coupling between the unsaturated zone and the saturated zone components.

During periods of rainfall, the infiltration rate at each node is estimated using the Green-Ampt equations in the same manner as Skaggs (1978). The portion of the rainfall that infiltrates consists of two parts. The first part is the amount required to bring the soil water in the root zone to a maximum as determined from the soil water characteristic. The remaining infiltrated water is assumed to be available at the unsaturated soil-saturated soil interface as vertical recharge to the water table. This is converted to a rate and provides the term, R, in the solution of equation 1.

The excess water, amount of rainfall not infiltrated, is made available for surface storage and runoff. Surface depression storage is filled, and the remaining excess water goes into surface retention storage on the area represented by the node. The surface retention storage is the portion of water on the soil surface which is available to move in response to surface slope and roughness. This retention storage is available for runoff.

Surface water available for runoff is routed to surrounding nodes, based on the slope of the water on the surface and the land areas associated with each node. The slopes are computed between the nodes using the elevation of the soil surface plus the depth of water in the surface depressions and in the surface retention storage. Although this surface retention component is called a storage, the amount of water in this component will be routed to surrounding nodes at the end of the current time step. The surface water is balanced on a volume basis. Head losses due to surface flow are assumed to be negligible. There are provisions for including surface roughness and frictional head losses. Water arriving at the channel boundaries is assumed to be lost to the channel with no change in channel water level, thereby exiting the system.

The model is mechanistic in nature and the inputs are extensive. Inputs for the saturated component consist of a finite element grid of the study area and the channel boundary nodes where the channel water level will be specified. At each node in the area, the model requires the surface elevation, the maximum depth of surface depression storage, and the initial water table height. The soil type at each node in the area is also specified. This is done by overlaying a soils map onto the finite element grid of the area. The input information for each soil type consists of lateral saturated hydraulic conductivity profiles, K, the relationship of drainable porosity, f, with water table depth, soil water characteristics by soil layer in the deepest root zone expected, amount of vertical water movement from the water table versus water table depth, and the relationship of the Green-Ampt parameters with water table depth.

For each simulation, the output from the model consists of water table depth, soil water in the root zone, vertical recharge to the water table, upward movement of water from the water table to the root zone, infiltration into the root zone, surface depression storage, and surface retention storage at each node. For the channel boundaries, the lateral seepage into the channels and the runoff water into the channels are available.

Presently, the model testing is being done using the Conetoe Creek project data. Details of the current field project are presented elsewhere (Doty et al. 1982 and Doty et al. 1983). For these tests, the time steps are 4 hours for days without rainfall events. On days with rainfall events, a time step of 1 hour is used for periods with rain and 2 hours for periods with no rainfall. Tests are being made to determine the model sensitivity to these time steps.

APPLICATION AND FUTURE MODIFICATIONS

A comprehensive water management model for the evaluation of the design and management of water resource projects has been developed. In particular, the analysis of water management d management of water resource projects has been developed. In particular, the analysis of water management systems for agricultural drainage districts with parallel and intersecting channels can be made. Model development has focused on relatively flat land with naturally high water tables. These areas can be characterized by a network of channels used for drainage.

The model consists of components for the integration of water movement in the saturated soil zone, the root zone, and on the soil surface. These components are coupled in time. Since each of the model's components require different time steps, the choice of time steps for the coupled model takes these into account.

The modular design of the model enables easy testing of the different assumptions and submodels for the respective components. For example, the use of the Richard's equation in place of the present one-dimensional water balance in the unsaturated soil zone has been considered and not been done because of the computational requirements and the cost. Additionally, investigations are being made into coupling an existing channel flow model as a submodel to the hydrologic system we have outlined.

At this time, we are testing and evaluating the model applicability and effectiveness in simulating water table response to the weather patterns and varying channel water levels. After this has been accomplished, the model will be used to evaluate various submodels incorporating different levels of assumptions from more sophisticated to less sophisticated. The end result is to obtain a cost effective model for evaluating water resource project designs based on a number of years of climatic record.

Contribution from the Coastal Plains Soil and Water Conservation Research Center, U. S. Department of Agriculture, Agricultural Research Service, Florence, SC, in cooperation with the North Carolina Agricultural Research Service, North Carolina State University, Raleigh, NC.

REFERENCES

de Laat, P. J. M.; Atwater, R. H. C. M.; and Bakel, P. J. T. 1981. GELGAM - A model for regional water management. In Water Resource Management on a Regional Scale, Proc. of Technical Meeting 37. Versl. Meded. Comm. Hydrol. Onderz. TNO 27. The Hague, Netherlands. pp. 23-53.

Doty, C. W.; Parsons, J. E.; Nassehzadeh-Tabrizi, A.; Skaggs, R. W.; and Badr, A. W. 1982. Deep ditch overdrainage affects water table depth and crop yield. Proc. ASCE, Conference on Environmentally Sound Water and Soil Management, Orlando, Florida.

Doty, C. W.; Parsons, J. P.; Nassehzadeh-Tabrizi, A.; Skaggs, R. W.; and Badr, A. W. 1983. Stream water levels affect field water tables and corn yields in sandy soils. Submitted ASAE, 10/83.

Freeze, R. A. 1971. Three dimensional, transient, saturated-unsaturated flow in a groundwater basin. Water Resources Res., Vol 7(2):347-366.

Parsons, J. E.; Skaggs, R. W.; and Doty, C. W. 1982. Predicting water table elevation adjacent to intersecting channels. ASAE 1982 Winter Meetings, Chicago, ILL, Paper No. 82-2509.

Skaggs, R. W. 1978. A water management model for shallow water table soils. Water Resources Institute of the University of North Carolina, Riddick Hall, N. C. State University, Raleigh, NC 27650, Report No. 134.