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General Purpose Simulation Model of Water Flow in the Soil-Plant-Atmosphere Continuum

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Abstract. GAPS is a general purpose simulation model of water flow in the soil-plant-atmosphere continuum. It has been developed to make simulation modeling more accessible to users and adaptable to various research objectives. The program contains "user-friendly" input/output routines and allows the user to select from procedures to simulate various components of the soil-plant-atmosphere system. In addition, the user can choose from a variety of procedures with differing representations of the same component of the system. Program structure allows the user to incorporate additional procedures into the program, linking them to procedures already present. Procedures can be selected on the basis of the data available to the user, the particular modeling objective, or the level of complexity required. Extensive documentation of the simulation procedures accompanies the software package.

Introduction

Understanding of water movement in the soil-plant-atmosphere continuum (SPAC) has been greatly advanced by the ability to develop dynamic simulation models that use numerical techniques to solve equations, based on a mechanistic view of the system. Such models are essential to evaluate reasonably how changes in any one component of the system, such as root depth and density, soil hydraulic properties, leaf area index, or frequency of rainfall or irrigation, will affect the water budget of a soil-plant system. Over the past 15 years many simulation models of water movement in the soil-plant atmosphere have been developed, as either independent models [6, 7, 9, 10] or subcomponents of larger models [4, 13]. These models have most often been developed for fairly specific purposes, such as predicting evapotranspiration for a particular crop [2, 3, 5, 12] or for predicting leaching of solutes in a particular system [8, 11, 14].

Although a particular modeling effort should have a well-defined purpose, the computer program supporting this modeling effort need not be written explicitly for this purpose. The high degree of specifity incorporated into the code of simulation models is one major reason use of simulation models by individuals other than those that developed the model has been extremely limited [1]. It might be argued that simulation models being developed are conceptually very different from one another and the diversity of models represents significant differences in the manner in which different researchers conceive of water movement in SPAC. However, we would suggest that important conceptual differences in deterministic models of water movement in SPAC are relatively few. We believe that development of more general, flexible simulation models of SPAC will lead to increased use of these models by those who are not currently involved in developing them. This, in turn, will increase the rate of progress in our understanding of water movement in the soil-plant-atmosphere system.

Approach

The approach we used was first to consider major reasons that simulation models are not more widely used. Three reasons appeared most important: 1) most programs are not flexible enough to accommodate relatively easily a variety of objectives, 2) most programs are not well documented, 3) most programs contain little, if any, "user-friendly" interfacing. Our objective, therefore, was to develop a software package for simulating water movement in SPAC that addresses these problems.

There are several aspects of existing simulation models that make them inflexible. Some require a rigid set of input requirements to run; these inputs may not be available to the user. This, in turn, is due to the lack of alternative representations of various components of the model. For example, some SPAC simulation models require pan evapo-

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ration rates as input for calculating evapotranspiration. The user may not have these data, but may have other data available that could be used for predicting evapotranspiration. In addition, most SPAC simulation models do not give the user the option to simulate easily only parts of the system, such as evapotranspiration or water flow without evapotranspiration. Our approach was to create a program that would supply the user with more than one option to simulate a particular process, the choice being dependent on available input data, desired level of complexity, and objectives. GAPS (*General Purpose Simulation Model of the Soil-Plant-Atmosphere System*) allows the user to construct a situation-specific simulation model from existing components. Furthermore, the program allows users with some programming experience to add their own components, either to substitute for existing components or in addition to them, and to link them to existing routines relatively easily.

Clear programming and documentation also support flexibility and encourage use in several ways. These features of GAPS allow users with some programming experience to make changes and add procedures easily. Good documentation helps the user make educated choices regarding the selection of model components. Additionally, such documentation is useful in quickly and easily determining precisely how the model simulates various components.

Providing a user-friendly interface between the simulation model and the user is perhaps scientifically the least necessary component of GAPS. User-friendly interfaces can require large amounts of programming in comparison to the simulation program itself. However, lack of such an interface could be a major deterrent in the use of simulation models by a wider group of people. Our general purpose simulation model is interfaced with user-friendly menus.

Program Structure

GAPS is divided into three major components (Fig. 1): the editor, simulator, and plotter. The editor allows the user to create or edit all files that are necessary input to the simulator. In the current version the plotter prints selected results of the simulation and the content of the input data files. Variables printed can be selected by the user. The simulator contains the library of procedures from which users can select and design their own systems (Table 1).

The GAPS documentation is organized so that

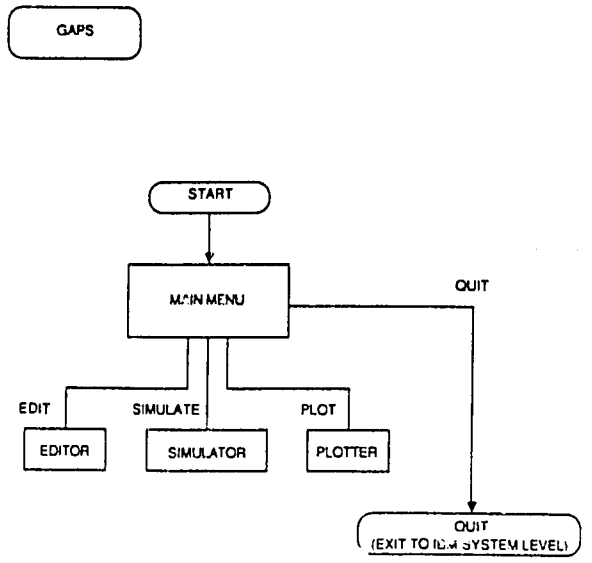

Fig. 1. General structure of GAPS.

Table 1. List of procedures currently included in GAPS

Solar angles
Atmos trans
Air temperature
Priestly-Taylor ETP
Penman ETP
ETP partitioning (canopy)
Richards equation
Tipping bucket
Water budget
Water uptake
Simple water uptake
Soil temperature

every subroutine/procedure is documented in detail in separate chapters. Each chapter includes presentation and explanation of all equations, using the same symbols as those used in the code, definition of all symbols as they are presented, explanation of numerical techniques used where necessary, references to relevant publications, the procedural code, a dependency diagram where necessary to illustrate how the procedure is linked to other procedures and internal flow (Fig. 2), and a summary list of all symbols used in the procedures along with their definition. In addition to documentation of the procedures currently contained in the simulator, the GAPS user's manual includes instructions on how to change existing procedures and how to add procedures to the simulator library.

GAPS contains several user-friendly features. First, the simulator routines in GAPS (the simulator) are linked to input (the editor) and output (the plotter) routines. The editor, simulator, and plotter all interface with the user through a series of menus. The menus have a similar design (Fig. 3)

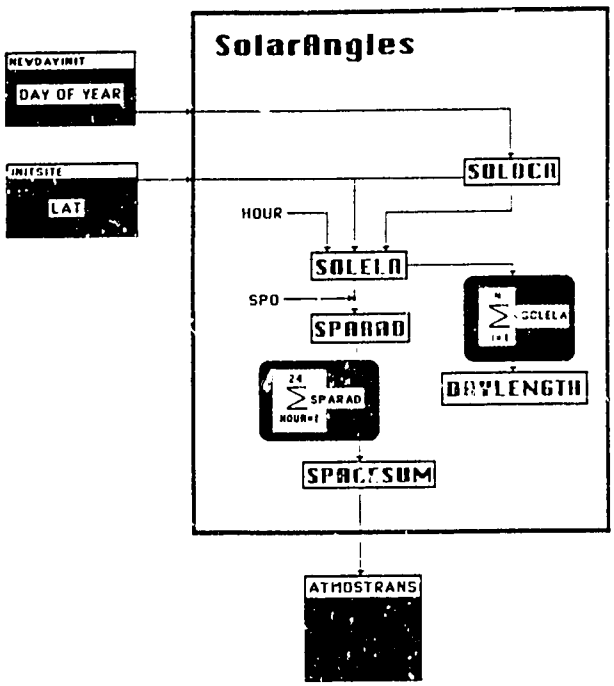

Fig. 2. Example of dependency diagram.

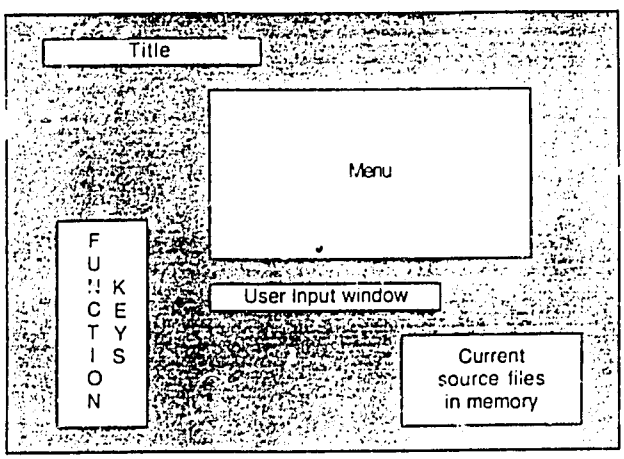

Fig. 3. General format of menu screens.

which facilitates a clear presentation of the options available to the user at any point within the program. A title section in the upper left-hand corner of the screen informs the user of current location in the program. A menu in the center displays the options available to the user, for example, to load, save, edit, or delete a data file while in the editor. Function keys are utilized for user input. Abbreviated versions of the options displayed in the menu are repeated in the function keys window. The user has the option to respond by hitting either the appropriate function key or the first letter of the respective choice. If there is user input of text or numbers, the user can enter those into the user input window. Names of data files that are cur-

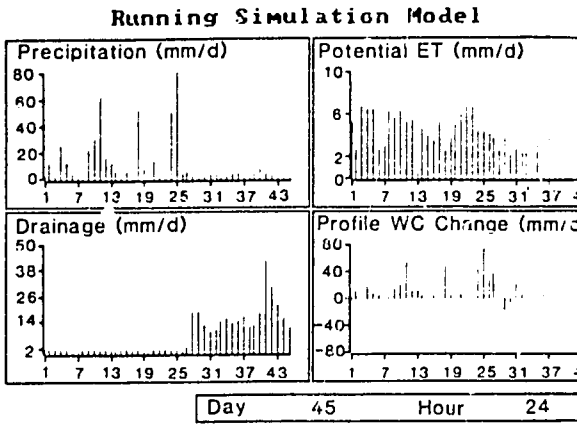

Fig. 4. Runtime simulation plotter output.

rently in memory are displayed in the small winc in the lower right-hand corner of the screen. In dition, strings used in the GAPS menus were fined in a manner that involves only minor edi to change them from English to another languag to change statements in the menus.

The editor is structured to allow users to cre and edit quickly input files necessary to run variou procedures in the GAPS simulator. Ther a runtime plotter associated with the simulator the user can use to view simulator results instan The user can choose to view up to four graphs multaneously (Fig. 4).

The user can choose to save simulated outpu a file before running a simulation. The plotter be used after the simulation to print speci output files (Table 2) or input files (Table 3).

Applications

GAPS can be used for a number of different poses. As a research tool, GAPS can be used n easily to build a simulation model for interpre and analyzing field experiments. In addition, u can use GAPS as a water flow shell (e.g., Fig. 5 which they can add components, such as r growth models or solute flow models, of major terest to them. They can also compare diffe mathematical representations of the same p cesses, such as ETP or water flow, under a par ular set of conditions. This can produce insight when it is or is not appropriate to use certain re sentations of a process.

GAPS can be used as a teaching tool to introd students to simulation modeling. Students have opportunity to work with individual component the system as well as linking components toget They can explore the effect of changing specific

Best Available Document

Table 2. Examples of GAPS output data file

****
******GAPS OUTPUT DATA******
****

Output Data File Name: TESTOUT.SIM
Input Data used in Simulation:
Location : cpac, brasilia
Soil : Dark Red Haplustox
Climate : Wet Season 1982/83

Day	PotET	PotTrans	ActTrans	PotEV (mm day^{-1})	ActEV	Drainage	WC-change
1	5.2	0.0	0.0	5.2	1.4	0.0	−0.0
2	2.7	0.0	0.0	2.7	2.7	0.0	7.9
3	6.6	0.0	0.0	6.6	1.9	0.0	−0.4
4	6.3	0.0	0.0	6.3	6.3	0.0	18.6
5	6.4	0.0	0.0	6.4	5.5	0.0	4.6
6	2.7	0.0	0.0	2.7	2.5	0.0	0.8
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
42	0.3	0.0	0.0	0.3	0.3	32.4	−17.2
43	0.3	0.0	0.0	0.3	0.3	22.8	−19.9
44	0.3	0.0	0.0	0.3	0.3	16.3	−14.0
45	5.2	0.0	0.0	5.2	1.4	12.1	−13.5

Table 3. Example of GAPS input data file

****
****CLIMATE INPUT DATA****
****

Climate Data File Name: TESTCLI.CLI
Climate Name : Wet Season 1982/83

Day of year	AirTemp (max) (degree Celsius)	AirTemp (min) (degree Celsius)	Solar radiation (MJ/(m2 day))	Rainfall (mm/d)	Rel. humidity (fraction)
1	24.9	15.5	18.6	1.4	0.80
2	23.4	17.4	9.3	10.6	0.86
3	27.2	15.7	24.7	1.5	0.77
4	27.5	16.4	23.0	24.9	0.74
5	27.0	15.8	23.6	10.1	0.79
6	23.2	16.6	9.3	3.3	0.88
.	.	.	.	.	.
.	.				
.	.	.	.	.	.
.	.				
.	.	.	.	.	.
.	.				
42	19.5	16.3	1.0	15.4	0.99
43	25.5	16.0	1.0	3.2	0.86
44	27.9	16.7	1.0	2.6	0.77
45	28.5	17.5	17.6	0.0	0.77

rameter values, such as saturated hydraulic conductivity, or changing input data, such as climate files, to see how various aspects of the water budget, such as evaporation from the soil surface and movement of water below the root zone, are changed.

Future Development

The core of GAPS is the simulator, which contains the library of procedures available to construct simulation models. In this version only procedures relating to water flow in SPAC have been included.

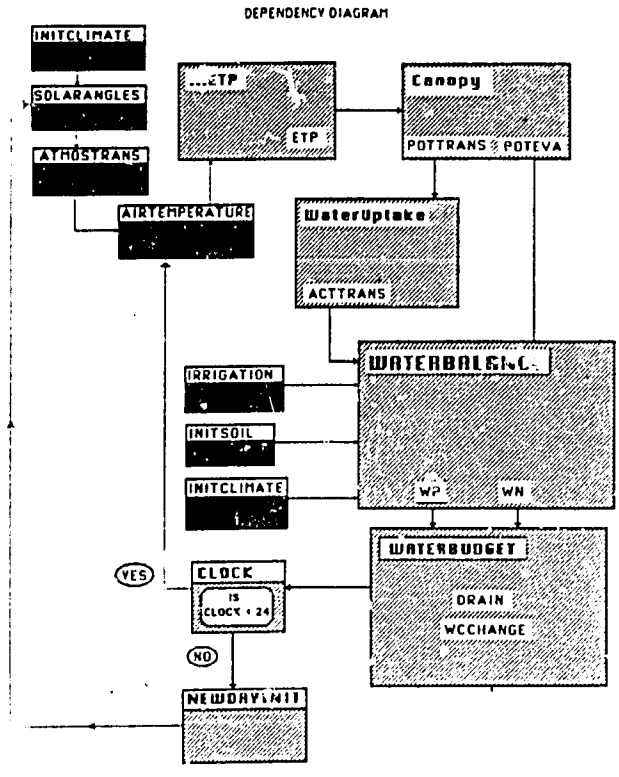

Fig. 5. Example of possible configuration to simulate water flow through SPAC.

Work is currently being conducted on simulation models of nitrogen transformation and transport and reaction routines that will be incorporated into GAPS. We envision that those who use GAPS will add or modify procedures and make these available to other GAPS users.

Some aspects of the current version have been identified as needing improvement in future versions. For example, using a spreadsheet format in the editor that will not scroll horizontally limits the maximum number of variables that can be included in any one file. The plotter is still in an early stage of development. Currently, the editor and plotter, and the global routines they access, represent the bulk of the GAPS program. In the future we may consider interfacing the simulator of GAPS with commonly available database management software and graphics software.

There appears to be an increasing demand for simulation modeling of soil-plant-atmosphere systems. Additionally, development of these models will become increasingly a multidisciplinary effort. Such effort requires clear, fully documented programming and a programming style as independent as possible of the author's disciplinary affiliation. A modular structure to simulation models, such as that represented by GAPS, will also facilitate multidisciplinary development and use.

Software and Hardware Requirements

GAPS is written by TURBO PASCAL and can be implemented on an IBM PC or PC compatible system with a color graphics adapter, DOS 3.0 or higher and 256K of memory. Requests for this program and documentation should be directed to Dr. Susan Riha, 907 Bradfield, Cornell University, Ithaca, NY, 14853, USA.

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