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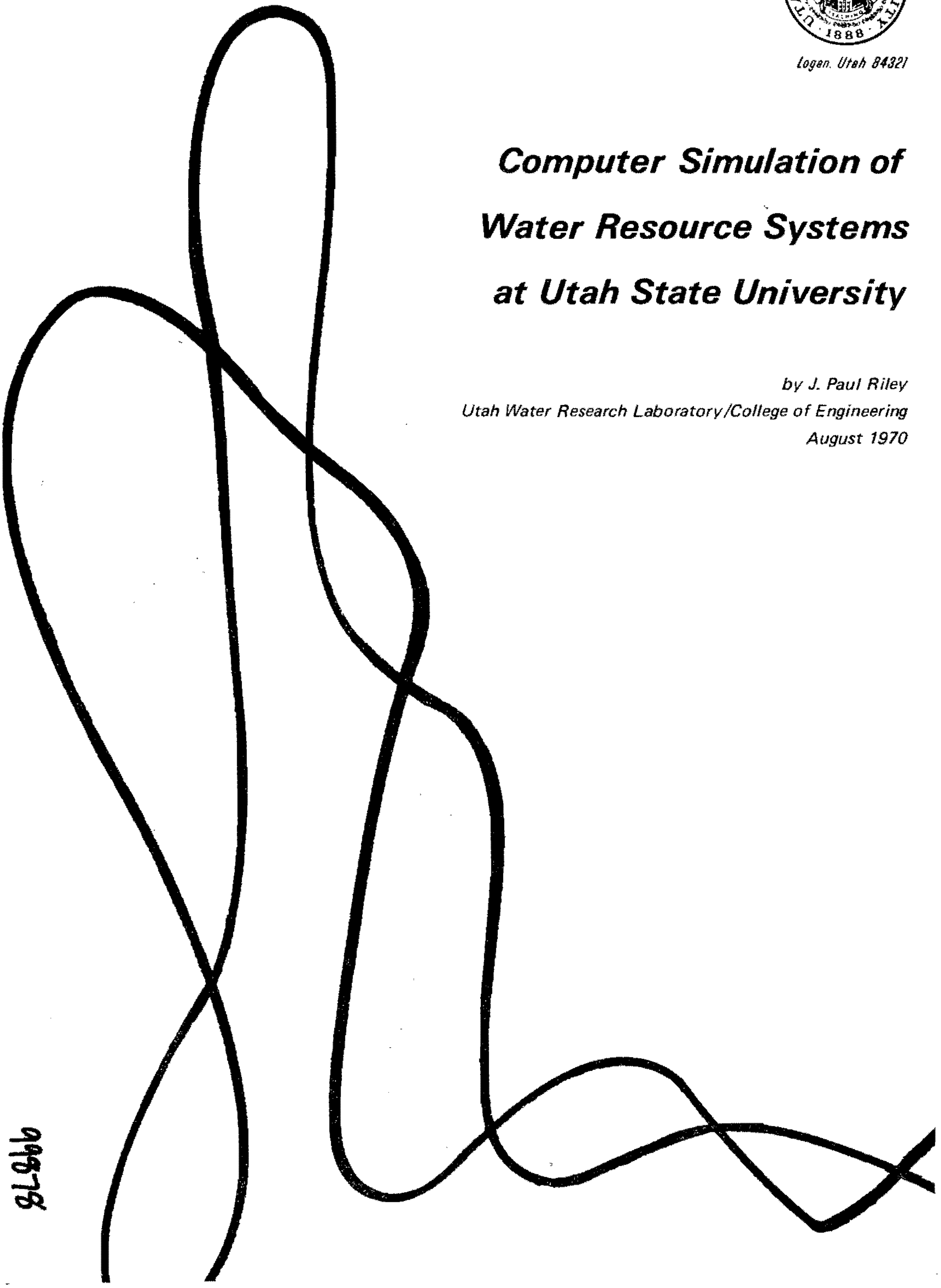

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COMPUTER SIMULATION OF WATER RESOURCE SYSTEMS AT UTAH STATE UNIVERSITY

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Introduction

The problems of managing water-resource systems are basically those of decision making based upon a consideration of the physical, economic, and sociological processes involved. These processes are strongly interrelated and constitute a dynamic and continuous system. Any combination of these interrelated and numerous system variables yields a management solution. At Utah State University the problem of investigating system response to various possible management alternatives is being approached by hybrid computer simulation.

The concept of simulation is fundamentally simple. Basically, it is a technique of analysis whereby a model is developed for investigating the behavior or performance of a dynamic prototype system subject to particular constraints and input functions. The model behaves like the prototype system with regard to certain selected variables and can be used to predict probable responses when some of the system parameters or input functions are altered. The model represents the interrelated processes of the system by arithmetic and algebraic functions, and by non-mathematical logic processes. Simulation is a useful tool for the creative manipulation of highly complex systems and thus can greatly facilitate appraisals of proposed changes within the corresponding prototypes.

In a computer model the various functions and operations of the different parts of the system are interrelated by the concepts of continuity of mass and momentum. These concepts are applied over the particular increments of time and space adopted for the model. It should, therefore, be emphasized that the adequacy of a simulation model is dependent upon the theory and the field data upon which the model is based. Consequently, both the mathematical relationships and the physical input data constitute major constraints in a simulation analysis. In addition, simulation alone does not readily provide optimal solutions. However, each computer run for a set of model parameters and inputs yields an estimate of the probable response of the prototype under the particular conditions established. Thus, through numerous and repetitive computer runs, it is possible to investigate many combinations of system variables and thereby to evolve optimal or near-optimal system design and operation procedures.

Electronic Computers

Electronic models based upon mathematical relationships which describe the prototype system have been made possible by recent developments in high-speed computing techniques. Through electronic computers, comprehensive simulation of entire hydrologic systems is now being achieved. A computer model does not directly simulate the real physical system. The model is analogous to the prototype, however, because both systems are described by the same mathematical relationships. A mathematical function which describes a basic process, such as evapotranspiration, is applicable to many different hydrologic systems. The simulation program developed for the computer incorporates general equations of the various basic processes which occur within the system. The computer model, therefore, is free of the geometric restrictions which are encountered in simulation by means of network analyzers and physical models. The model is applied to particular prototype system by establishing, through a verification procedure, appropriate constant values for the equations required by the system.

Electronic computers fall into one of three general classifications, namely analog, digital, and hybrid. The computing components of an analog computer execute the basic operations of addition, multiplication, function generation, and, most important in the study of dynamic or time variant systems, high-speed integration. By connecting computing components through a program "patch panel," it is possible to form an electronic model of a differential equation or a series of differential equations which describe the dynamic performance or operation of a physical system.

The modern general-purpose digital computer processes information which is reported by combinations of discrete or instructive data, as compared with the analog computer which operates on continuous data. While the analog computer is a "parallel" system in which all problem variables are operated on simultaneously, the digital computer is basically a "sequential" system performing step by step operations at high speed.

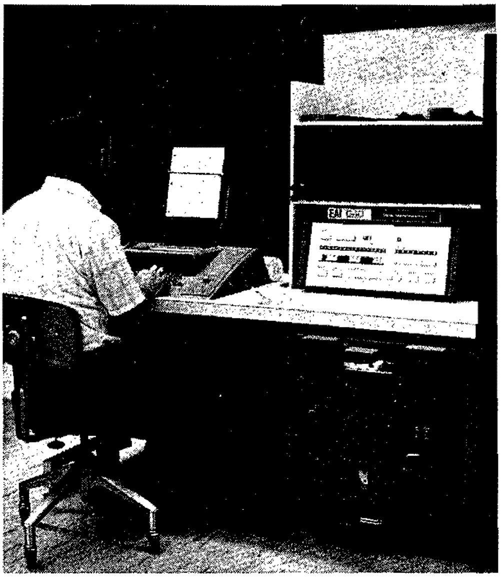
The digital computer is useful in processing large quantities of data or in solving complex mathematical problems which can be converted to a large number of simple arithmetic operations by the operator or by the computer. The digital computer can perform sequences of arithmetic and logical operations, not only in data, but also in its own program, and is, therefore, an immensely powerful device for processing or manipulating large amounts of discrete data and for performing precise arithmetic calculations at high speed.

In analog simulation, the operator communicates with, or controls, the simulation by means of hardware controls, while viewing the continuous problem solution. The digital computer programmer communicates with the computer primarily through "software" or programming languages. The design of software has become of equal or greater significance than hardware design. The development of "higher-order" or problem-oriented languages, in which one programming statement triggers a large number of sequential computer operations, has helped to simplify the interface problem between user and digital system.

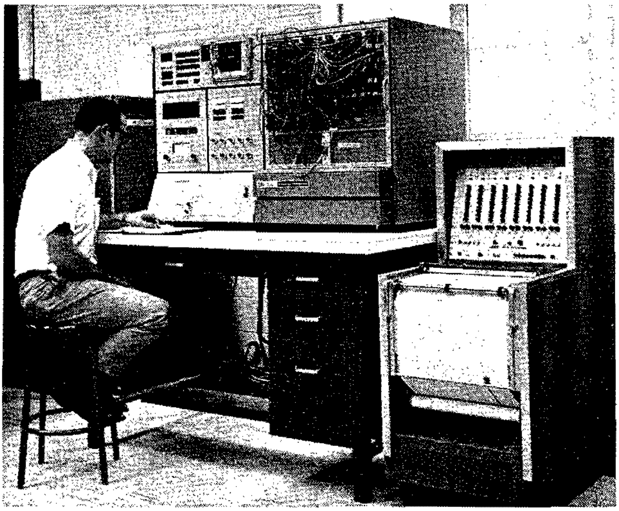
The hybrid computer combines the memory and logic capabilities of the digital with the high speed and nonlinear solution capabilities of the analog. In addition, the high speed iterative solutions and graphic display which are characteristics of the hybrid computer provide close interaction between the hydrologist and the model. These features make the hybrid a very powerful computer in the development and verification of simulation models. Two views of the hybrid computer available at the Utah Water Research Laboratory are shown by Figure 1.

Some Examples of Simulation Studies

Development of the hydrologic simulation research program at Utah State University began in 1963 (Bagley et al., 1963), and has proceeded in stages to increasingly detailed models. The important



The console of the digital unit.



A view of the analog unit showing the servo-set pots, digital voltmeter, program board, and output devices.

Figure 1. Views of the hybrid computer at the Utah Water Research Laboratory.

underlying feature throughout the entire program has been that all of the separately described processes and phenomena are interlinked into a total system. Thus, for each model it is possible to evaluate the relative importance of the various parameters, explore critical areas where data and perhaps theory are lacking, and establish guidelines for more fruitful and meaningful study in subsequent phases of the work. A listing of all reports and papers resulting from this research program is appended to this statement. Some specific studies are mentioned in the following paragraphs.

The first hydrologic model, using monthly time measurements, gave good results for interbasin effects. The second model was designed for an investigation of in-basin problems, but still utilized a large time increment (Riley et al., 1966). Under the third phase of the program, models have been developed which simulate the hydrologic processes over small geographic units and short periods of time (Riley et al., 1967; Narayana et al., 1968; and Amisial et al., 1968). Time increments for studies in this category have ranged from five minutes to a single day. A general conceptual model of a hydrologic system based upon short increments of space and time is shown in Figure 2. The hydrograph of rainfall excess is obtained by chronologically deducting the losses due to interception, infiltration, and depression storage. Routing of the rainfall excess is based on either the general continuity equation and stage-discharge relationship (Narayana et al., 1968), or by solving the unsteady state flow equations in accordance with Amisial et al. (1968). Other examples include a model which simulates the snow accumulation and melt processes over short intervals of space and time (Eggleston et al., 1970). Typical output from the programs of Narayana (1968), Amisial (1968), and Eggleston (1970) are shown by Figures 3, 4, and 5 respectively. All models have been verified or calibrated on the basis of data from other events so that the agreement between the measured and simulated output functions shown by these figures represents a test of each model.

An illustration of the utility of a simulation model for a model sensitivity analysis is shown by Figure 6 (Amisial et al., 1968). This figure, which consists of computer plots, illustrates the relative sensitivity of the model to various hydrologic parameters which influence the runoff characteristics of a southwest watershed.

The current computer simulation program at Utah State University has been expanded from the hydrology dimension, and

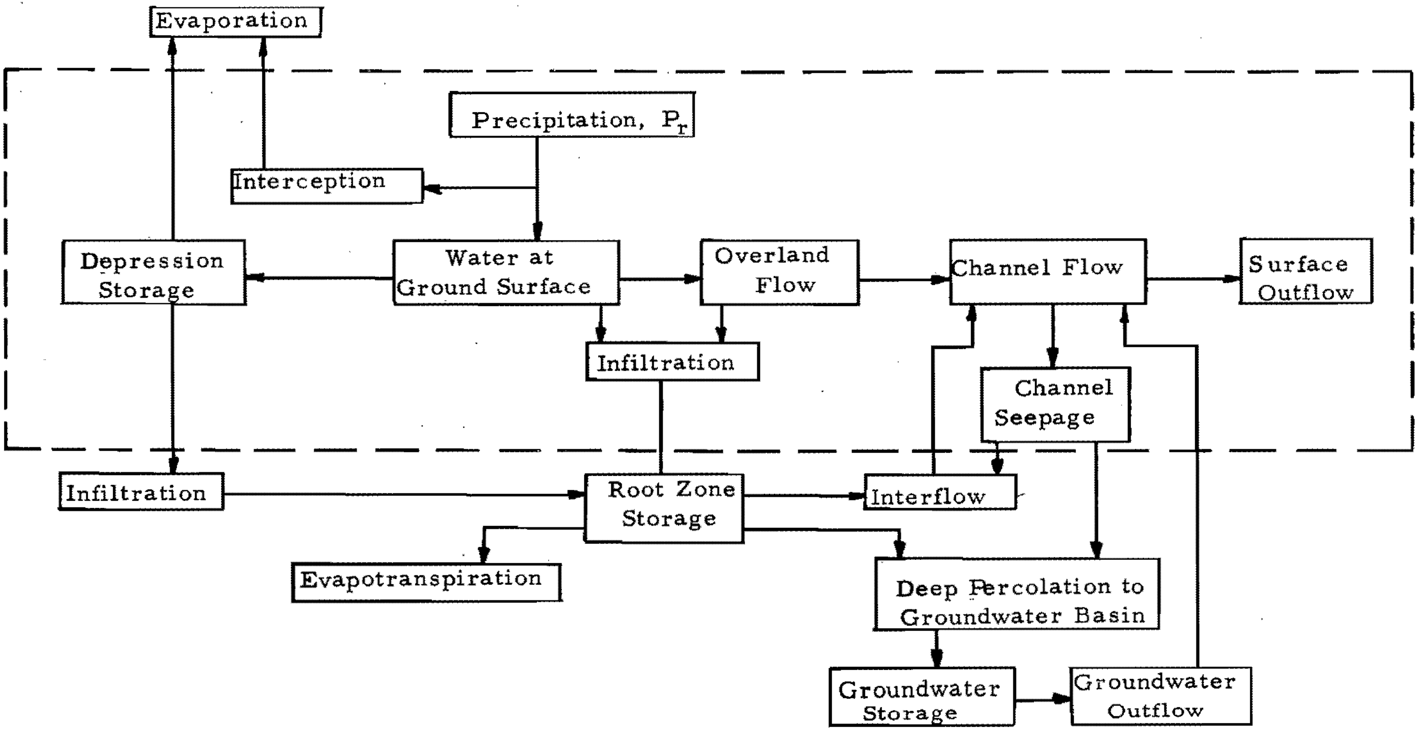


Figure 2. A flow diagram of a typical hydrologic system using small increments of space and time.

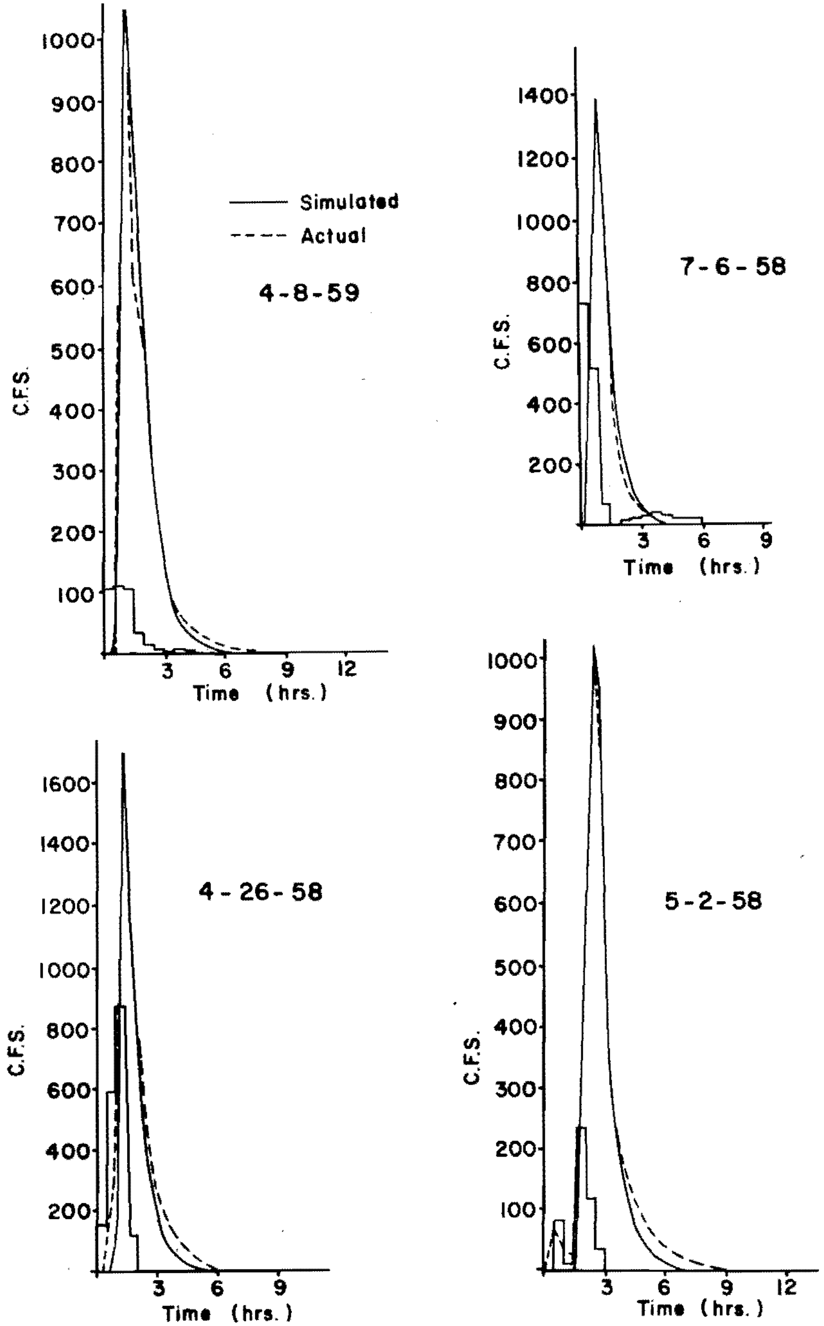


Figure 3. Comparison between simulated and observed runoff hydrographs, Waller Creek at Austin, Texas.

includes gross salinity and economic models superimposed upon the hydrologic model (Hyatt et al., 1968 and Packer et al., 1968). To illustrate, typical output from the hydro-salinity model is shown in Figure 7 and which comparisons are made between computed and measured mean monthly outflow rates for water and salts from two hydrologic units within the Upper Colorado River drainage.

In the study by Packer et al. (1968) fundamental hydrologic and economic processes were synthesized into a single working model. A general flow chart of the total hydrologic-economic system is shown in Figure 8. With this simulation model, effects of parameter changes on any part of the system are readily observed. By

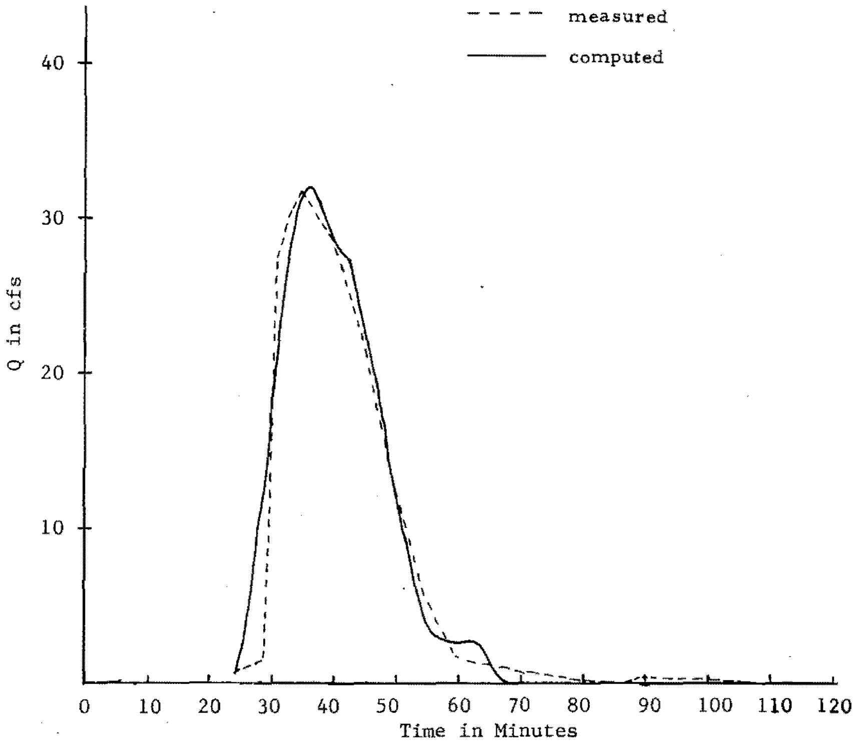


Figure 4. Outflow from Walnut Gulch subwatershed 11 for the event of July 29, 1966.

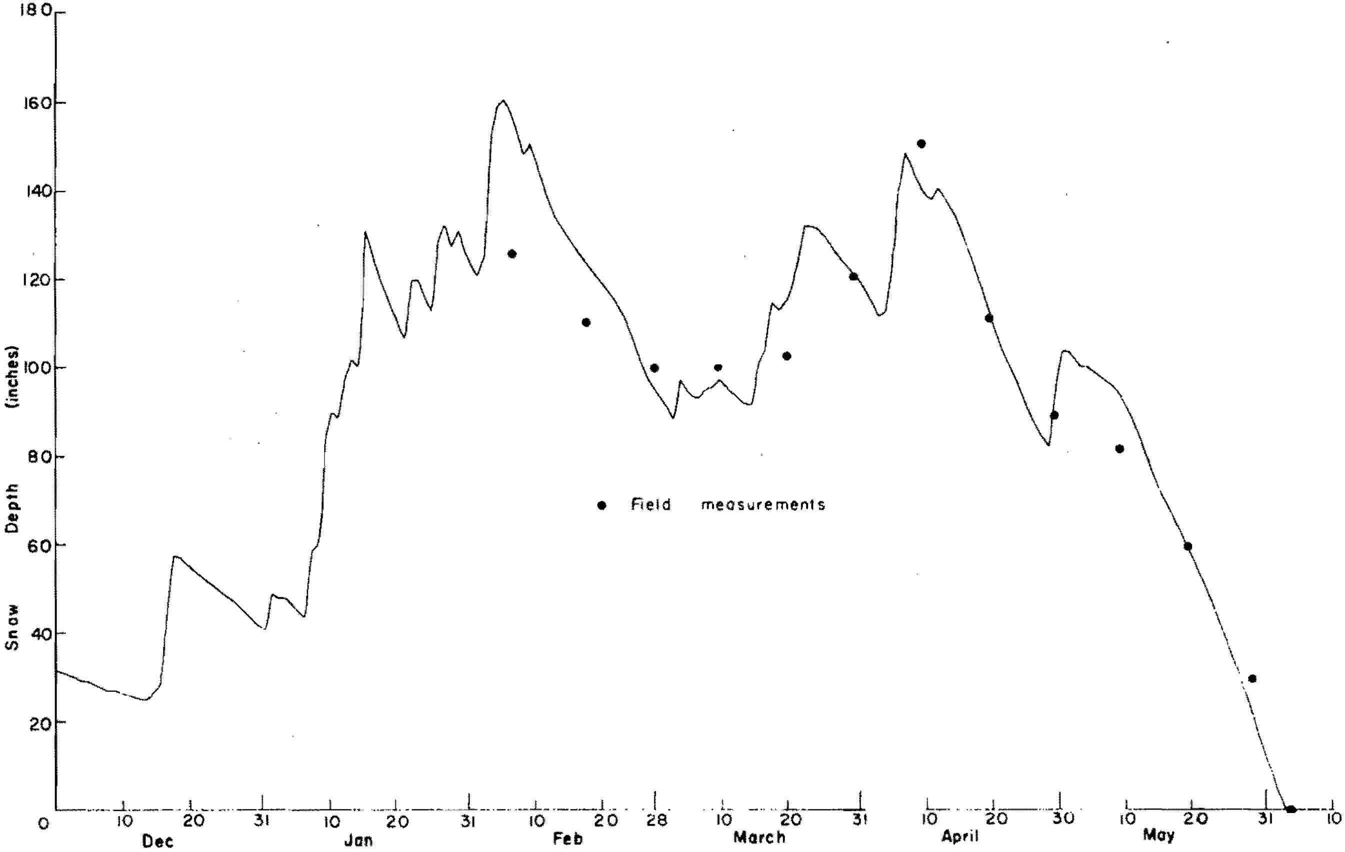


Figure 5. A comparison between computed and observed snow depths for a site at the Central Sierra Snow Laboratory, 1949-50.

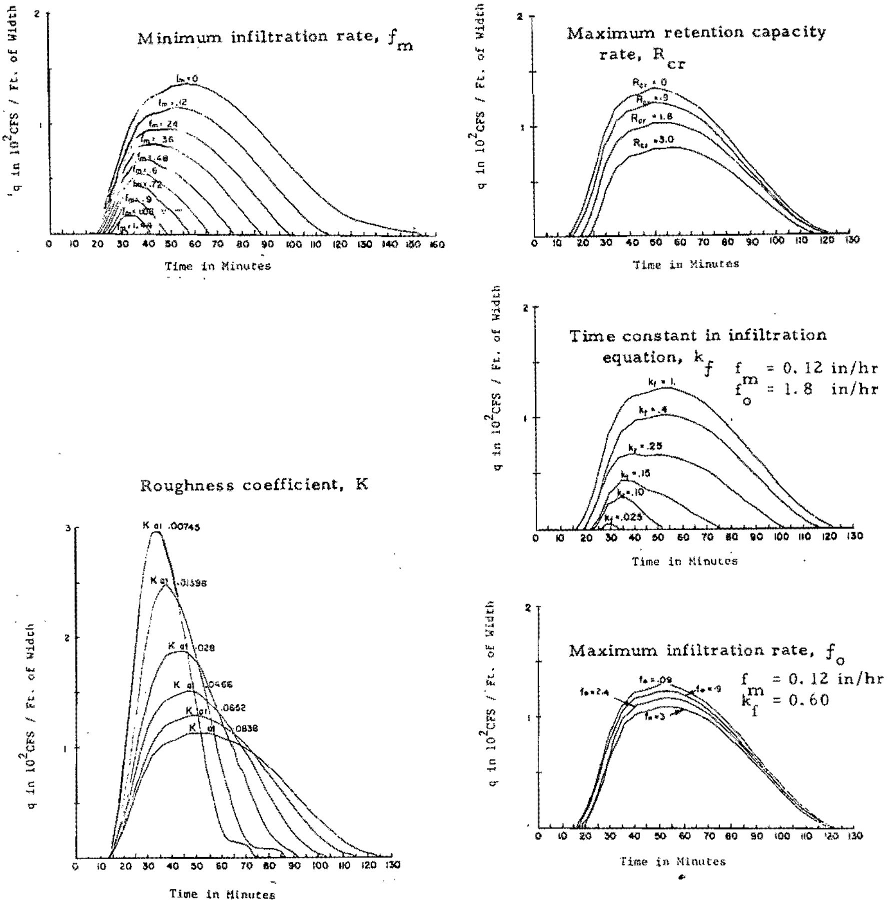
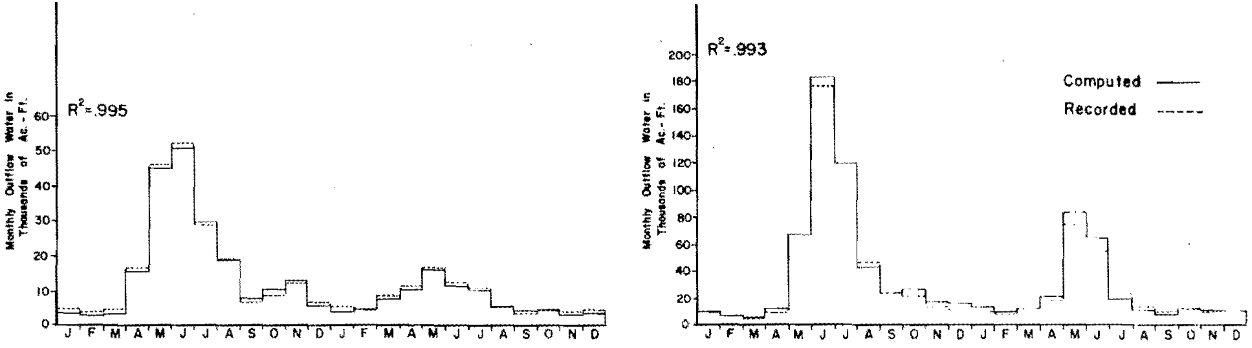
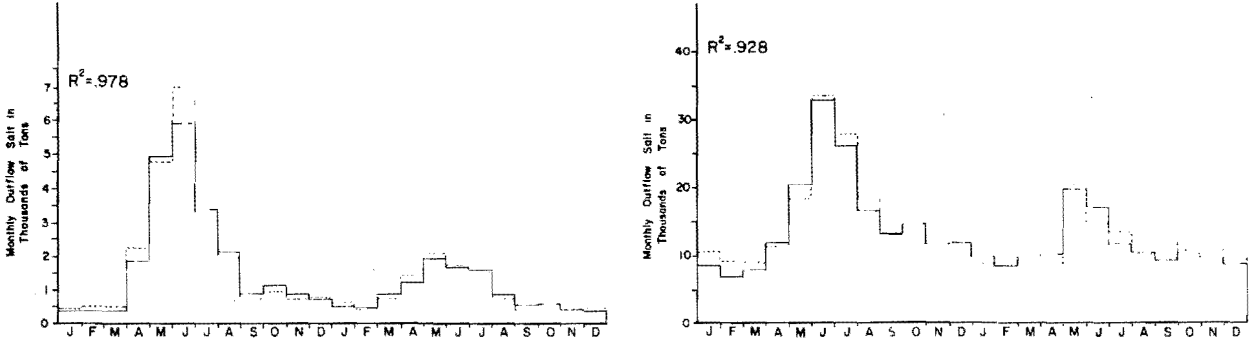


Figure 6. Overland flow hydrograph for a subzone of Walnut Gulch watershed, Arizona, as affected by changes in certain parameters.



Outflow Hydrograph – Colorado River ab. Hot Sulphur Springs 1965-1966

Outflow Hydrograph – Eagle River Basin 1965-1966



Salt Outflow – Colorado River ab. Hot Sulphur Springs 1965-1966

Salt Outflow – Eagle River Basin 1965-1966

Figure 7. Computed and observed mean monthly outflow rates for water and salts from two hydrologic units within the Upper Colorado River Basin.

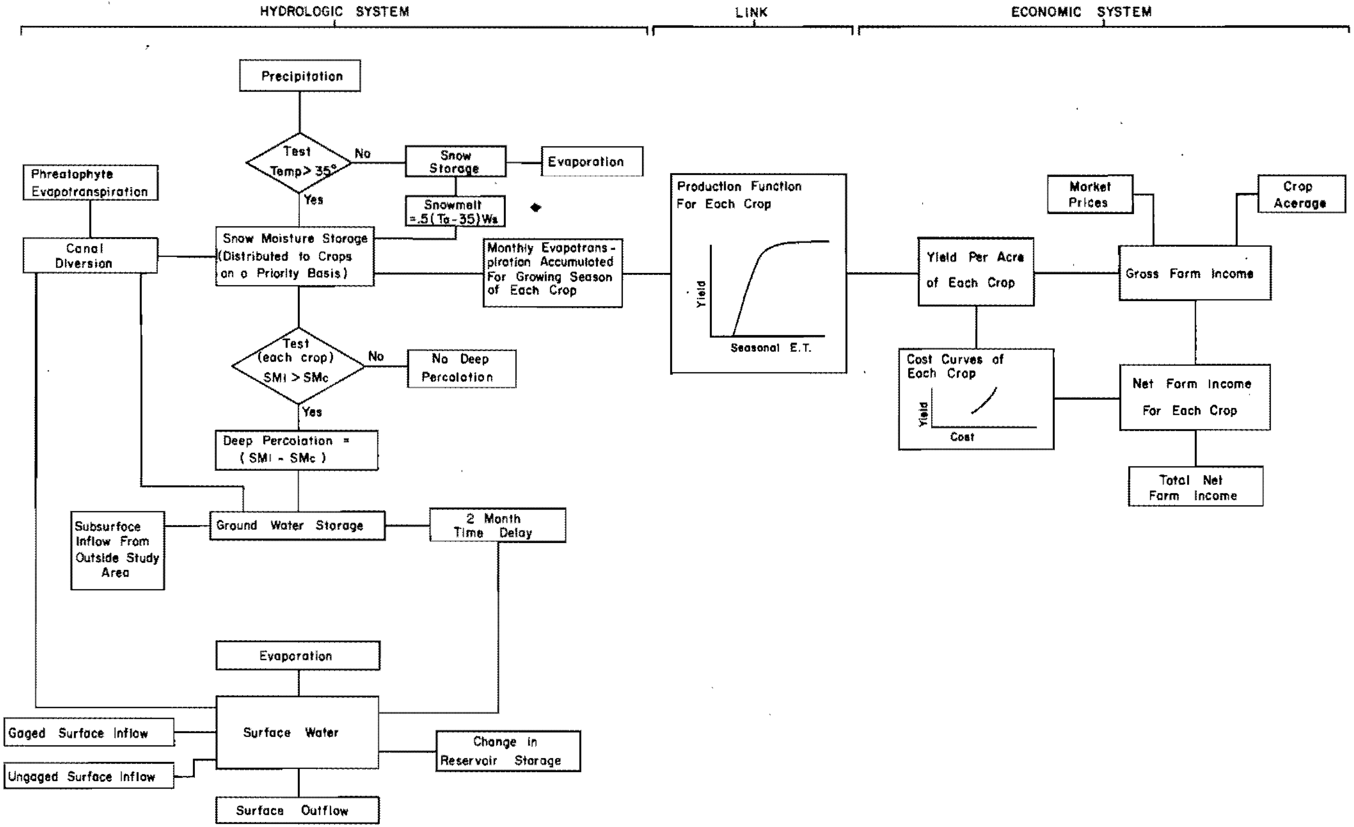
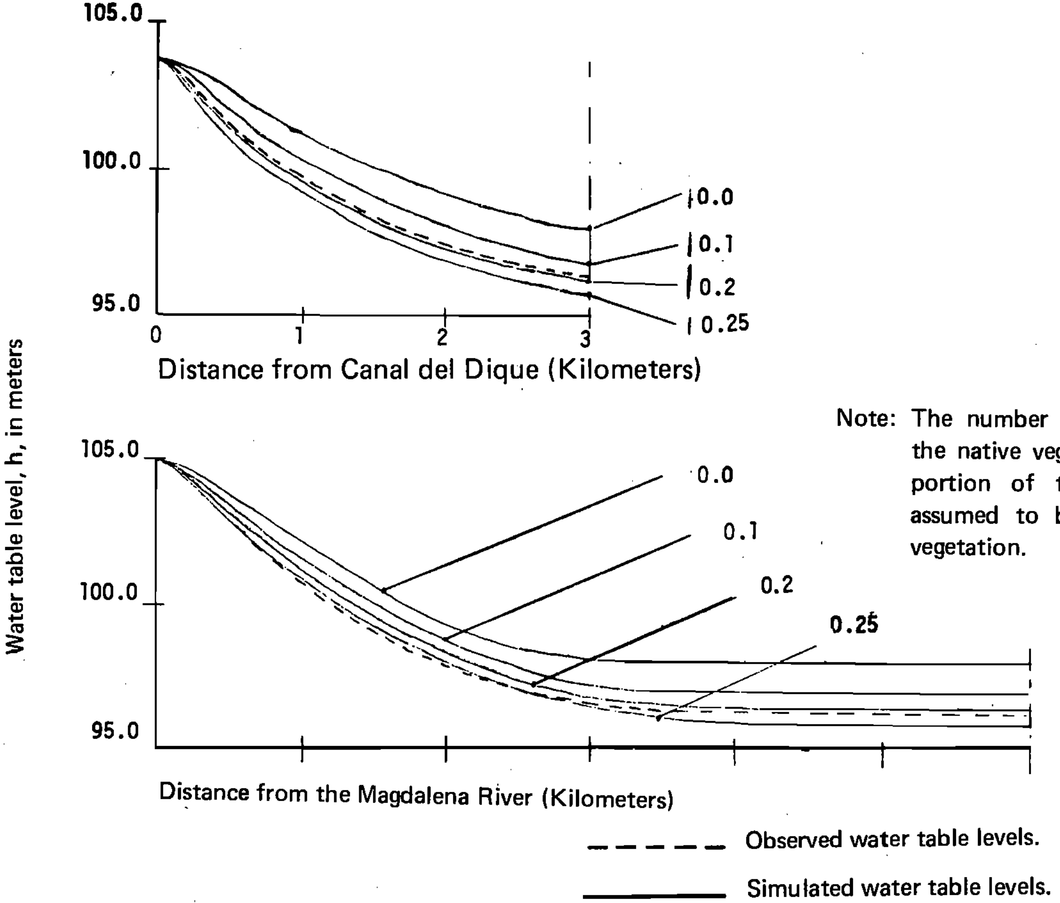


Figure 8. Hydrologic-economic flow system showing the production function as a link between the two systems.

utilizing the model, it is possible to estimate the marginal primary benefits of water by computing incremental changes in net return to the farm unit as the result of changes in the water supply. Cropping patterns also can be varied within the model and the resulting changes in net returns computed. Other management possibilities which might be investigated by the means of the model include water export or import alternatives with respect to the area under consideration.

Recently a general approach has been developed in which the hybrid computer is used to simulate the surface water-groundwater system. The model provides for detailed definition of both the surface and subsurface hydrology in terms of a grid network. Areal variations in hydrologic parameters, boundary conditions, vegetative distribution, and aquifer parameters are input variables at the grid nodes. The time varying responses of water table levels are obtained as output at each node. Typical output for a model of this nature is shown in Figure 9 (Morris and Riley, 1970).

Achievements at Utah State University in the simulation of hydrologic and related systems have demonstrated the soundness and validity of this approach to the operation and management of systems which involve many complex and interrelated processes. The broad experience and facilities available provide a basis for a sound and fundamental approach to water resource problems which are ammenable to solution by computer simulation.



Note: The number on each plot refers to the native vegetation density or that portion of the total surface area assumed to be occupied by native vegetation.

Figure 9. Observed and simulated water table levels for December 1969, Atlantico 3 Project, Colombia, South America.

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