HYDROLOGIC DIGITAL SIMULATION - A WATER RESOURCES MANAGEMENT TOOL

by

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INTRODUCTION

The amount of available water in the state of Mississippi is relatively constant over the long term. Proper use of this valuable resource will ensure a sufficient supply for the use of the citizens of Mississippi for a long period of time. In recent years there have been considerable advances in the science of hydrology. One evidence of this is the use of modern techniques of modeling and, in particular the application of digital modeling, for forecasting the flow of rivers by the National Weather Service.

The Lower Mississippi River Forecast Center, located at Slidell, Louisiana is currently employing a modified version of the conceptual digital simulation Stanford Watershed Model to forecast the flow of the rivers in the state of Mississippi. Forecast of the volume of water that will be flowing in the Pascagoula, Pearl, Big Black, and Yazoo Rivers in Mississippi is available daily for use by state and municipal authorities to aid them to efficiently utilize the available streamflow.

DEVELOPMENT OF THE DIGITAL MODEL

The task of applied hydrology is the development of methods to better estimate hydrologic regimes and the application of these methods in actual practice.

Basic data are available in a reasonably extensive network but measured against the diversity of hydrologic regimes, data are often inadequate. Projections and correlations based on limited data are necessary and are commonly used. Adequate forecasts involve extensive numerical analysis and can be profitably programmed for digital computers. Some manual methods, although complex, are trivial in this medium; and with the removal of the traditional limitations of calculating speed, methods of greatly expanded scope are possible.

The principal components of the hydrologic cycle are not difficult to describe qualitatively. The principal components and their interactions are well known, but the extention of qualitative knowledge to obtain realistic spatial and temporal quantitatively results is vastly more difficult.

Research in digital modeling of the hydrologic cycle began at Stanford University in 1959 (1,2,3,4,5). The aim of this inquiry, directed by Professors Linsley and Crawford, was to develop a general system of quantitative analysis of hydrologic regimes through establishment of continuous mathematical relationships between various elements of the hydrologic cycle. The operation of these relations was observed and improved, using digital computers to carry calculations forward in time. As mathematical relations are developed, physical processes may be reproduced realistically.

Precipitation and potential evapotranspiration are the basic inputs to these digital models and actual evapotranspiration, streamflow, and soil moisture levels are obtained as outputs. Calculations are made on selected short time intervals and are carried out continuously--in periods of no precipitation as well as storm periods--to simulate the entire broad scope of basin behavior.

While comprehensive digital simulation models are of recent development, they are highly dependent on previous work in hydrology. Just what is simulation? It is the indirect investigation of the response or behavior of a system: The physical system is analyzed and expressed as a collection of mathematical terms and parameters, and the mathematical representations are improved and verified by simulating system behavior with known input and output. This is continued until the simulation model is judged to be an adequate representation of the physical systems it models. Time scales are most often compressed.

Simulation is dependent on the accuracy of data. The computer augments, but cannot substitute for, analysis, experiment or intelligent judgement in development of the mathematical representation of the system.

THE NATIONAL WEATHER SERVICE RIVER FORECAST SYSTEM

The National Weather Service River Forecast System (NWSRFS) consists of several components; data acquisition, forecast procedures, and forecast dissemination. Work on conceptual models, as well as studies on the physical processes involved in the hydrological cycle, has been underway for several years in the National Weather Service Hydrologic Research Laboratory (HRL). In 1971 development had progressed to the point where it was feasible to attempt employment of a River Forecast System based on conceptual hydrologic models. The Stanford Watershed Model IV (5) with modifications of the HRL (6), was selected as the tool, and the River Forecast Center at Slidell, Louisiana was established as the first center to utilize these techniques.

DESCRIPTION OF THE NWSRFS

The NWSRFS is a conceptual model, i.e., it attempts to digitally reproduce the mechanics of the hydrologic cycle from the onset of precipitation to the discharge of surface water past the last stream gage forecast point into the ocean.

Figure 1 shows a typical river basin that will be used as the basis of this discussion of the digital model. The first computations are those required to determine the average amount of precipitation that has occurred over a basin (MBP).

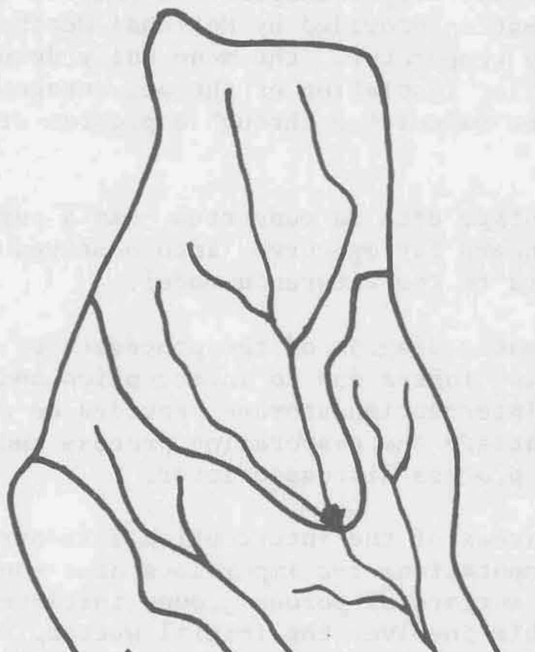

FIGURE 1. LEAF RIVER nr COLLINS, MS

Rainfall reports from the National Weather Service Offices and cooperative observers are entered as the basic data. A Thiessen Polygon (7) precipitation analysis over the basin is made by the computer. This result is the MBP value used in the model.

The next computations are those to determine the potential evapotranspiration of the basin. The potential evapotranspiration (PE) is computed on the basis of meteorological information provided by National Weather Service offices. These are the mean daily temperature, the mean daily dewpoint, average daily wind speed and either solar insolation or the percentage of possible sunshine. These data are calculated through a program of the Penman 'et' Formula (8).

Next the observed stage data is converted, via a current Geologic Survey or Corps of Engineers rating curve, into observed discharge. These data are the basic inputs to the watershed model.

Figure 2 is a schematic diagram of the processes of the land phase of the model. First, initial losses due to interception and interception storage are computed. Interception storage provides an available source of water to partially satisfy the evaporation process and is combined with the evapotranspiration loss process discussed later.

Precipitation in excess of the interception loss arrives at the surface of the earth and the computations for impervious area runoff are next made. Water which reaches the surface of porous ground initiates the infiltration process computation. This involves the initial wetting of the soil and the movement of the water into the upper zone of the soil, based upon the capacity of the upper zone. Under the acceleration of gravity this water will percolate toward the river channel through the process designated as interflow. Some of the water will be retained in upper zone storage. A portion of it, dependent upon upper zone storage capacity, will move to the river channel as overland flow. The infiltration process continues into the lower zone of the soil. These zones are not true geomorphological zones, but rather time-of-water-movement zones. In the lower zone, the water will also percolate towards the river channel theough the active ground water storage, based upon the storage capacity within the lower zone. This zone will also provide water to the root systems of the larger trees for the evapotranspiration process of course, does continue even on the deep groundwater where some water is brought to the surface through root systems and capillary action.

The principal inflows to the river channel then are: 1) Water arriving at the channel as direct runoff from impervious areas, which include the stream surface and connected bayou and lake surfaces; 2) through overland flow; 3) through the infiltration processes from the upper zone, and 4) the percolation process from deep groundwater storage.

In the model, the differential equations of soil mechanics have been reduced to algebraic form with temporal iterations of one hour. Much of the movement through the soil is controlled by the ratios UZS/UZSN and LZS/LZSN, where UZS is the index of water in inches in upper zone storage; UZSN is the nominal value of upper zone storage for the basin; LZS and LZSN are corresponding indices for the lower zone of storage.

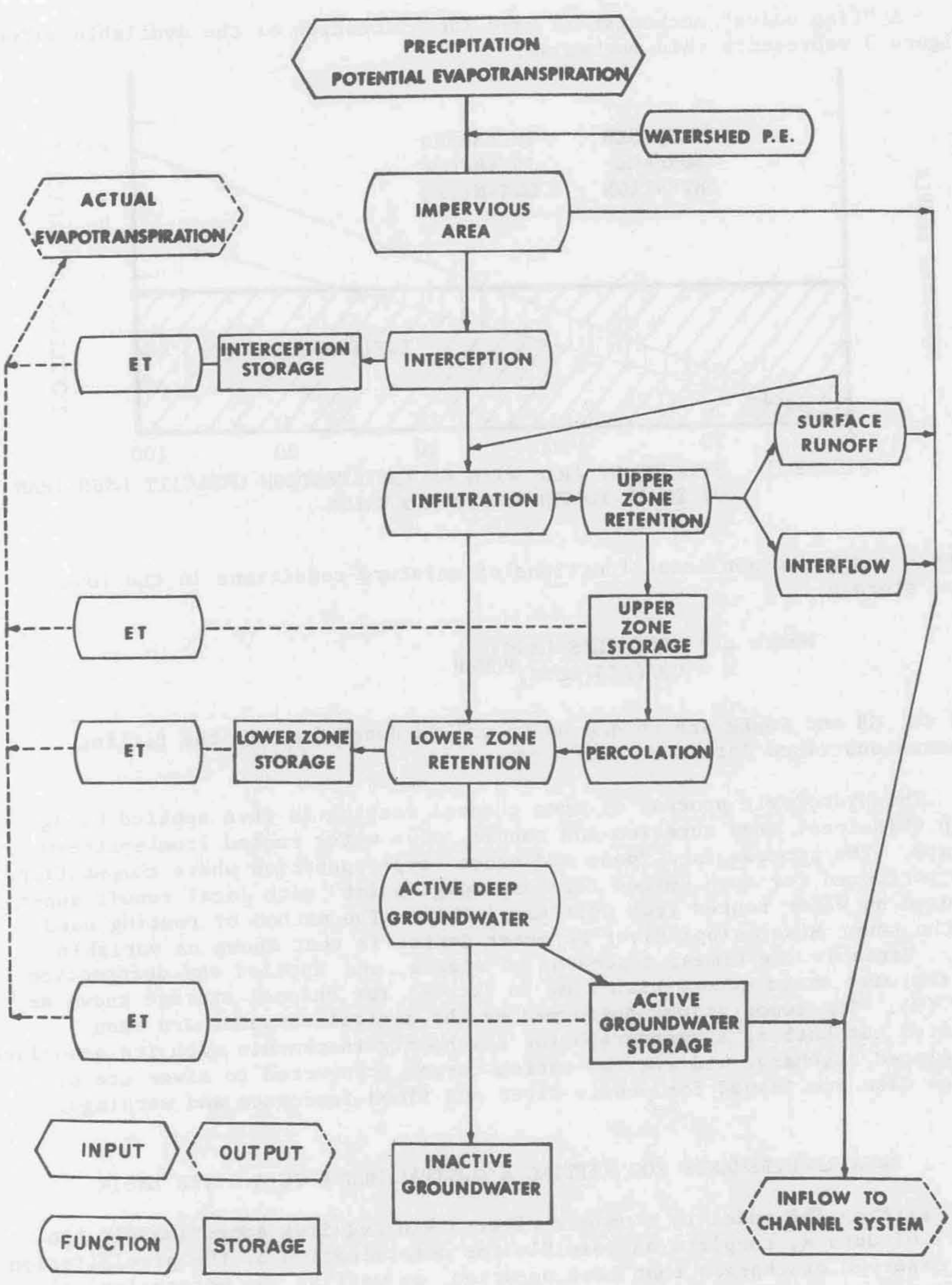

FIGURE 2. LAND PHASE OF HYDROLOGIC CYCLE

A "flap valve" mechanism is used for allocation of the available water. Figure 3 represents this mechanism.

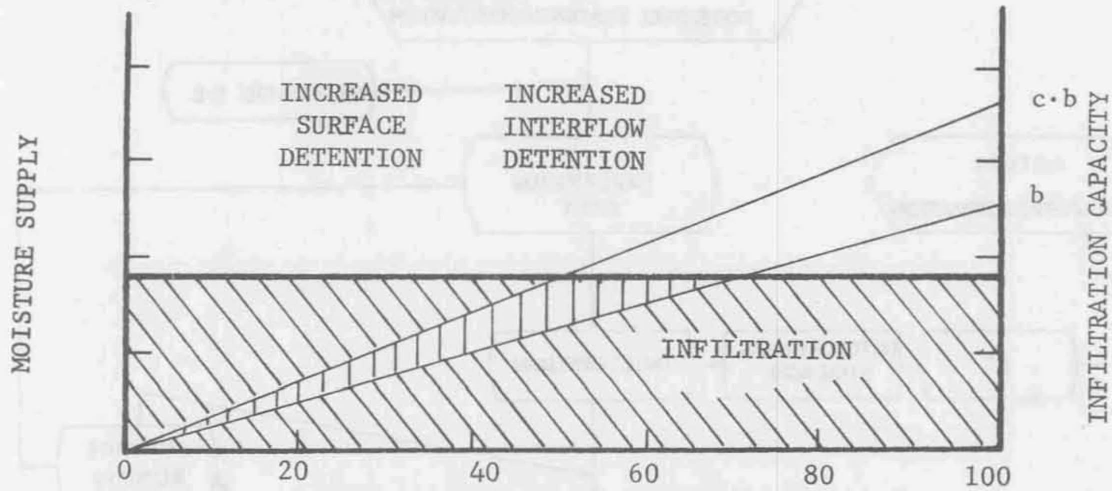

FIGURE 3. PERCENT OF AREA WITH AN INFILTRATION CAPACITY LESS THAN OR EQUAL TO THE INDICATED VALUE

Both c and b are nonlinear functions of moisture conditions in the lower zone storage.

Where $c = CC*2\ (LZS/LZSN)$
$b = CB/(LZS/LZSN)^{POWER}$

and CC, CB and POWER are unique basin values determined in the fitting process described later.

The hydrologic process of open channel routing is then applied using both this local area acretion and runoff, plus water routed from upstream points. The process is a "pass and store" type operation where computations are performed for each unique forecast "gage point" with local runoff superimposed on water routed from upstream points. The method of routing used by the Lower Mississippi River Forecast Center is that known as variable L&K. Variable lag times, dependent on stages, are applied and deformation of the wave shape occurs with time to account for channel storage known as "K" (9). The computations performed by the digital computer are then printed out both as a hydrograph for six-hourly increments with its associated simulated discharge and via the rating curves, converted to river stage. These data are issued for public river and flood forecasts and warnings.

DATA REQUIREMENTS FOR FITTING A DIGITAL MODEL TO A RIVER BASIN

Fitting the model to a unique river basin requires approximately ten years of data as complete as possible for determination of the precipitation and observed discharges that have occurred, as well as the meteorological parameters for evapotranspiration. The Lower Mississippi River Forecast Center, in our development process utilized six years of this data to fit the 23 variable parameters in the equations as dependent data. The most recent four years of data are used as independent data for verification and final fitting.

The principal parameters to be fit in each basin for the digital model are:

Variable Name	Definition
A	Percent of impervious area in the basin.
EPXM	Maximum amount of interception storage (inches)
CB	Infiltration index (inches/hour)
CC	Interflow index. Determines the ratio of interflow to surface runoff.
LIRC6	Percent of interflow detention reaching the channel each six hours.
LKK6	Percent of groundwater storage reaching the channel each six hours.
SRC1	Percent of surface detention reaching the channel each hour.
POWER	Exponent in the infiltration curve.

Each of the parameters should represent a universal optimum for each basin. The optimization process is done by computer and requires 300-500 iterations. These "best fits" must then be subjectively adjusted to meet the needs for which the forecast model is to be employed; i.e., flood peak forecasting, ground water recession, monthly mean discharge, etc. In our usage of the model, we tend to a best fit for flood crest forecasting.

A WATER RESOURCES TOOL

Figure 4 is a typical output of the forecast program. It provides quantitative information in six-hourly increments on the discharge in cubic feet per second that is forecast to occur at a specific gage point. The abscissa of the hydrograph is in cubic feet/second, the ordinate is time by day and six-hourly increments.

The column headed "SIMUL" is the model output in cubic feet/second. The first four lines of the column headed "FCST" is the past 24 hours observed discharge. Succeeding lines are the forecast discharges. Corresponding to these discharge values are the observed and forecast stages. We normally print out a seven day forecast, but we can extend this to a 30 day output when needed.

LEAF NR COLLINS

SIMUL	FCST	STAGE	TIME
578.7	578.7	5.5	20-1
566.6	566.7	5.5	20-2
559.7	554.8	5.4	20-3
566.1	543.6	5.4	20-4
589.4	546.6	5.4	21-1
637.5	592.1	5.5	21-2
711.9	682.0	5.8	21-3
798.5	798.5	6.1	21-4
880.1	880.1	6.3	22-1
937.8	937.8	6.4	22-2
964.9	964.9	6.5	22-3
966.1	966.1	6.5	22-4
949.5	949.5	6.4	23-1
924.0	924.0	6.4	23-2
895.8	895.8	6.3	23-3
863.1	863.1	6.2	23-4
828.8	828.8	6.2	24-1
797.3	797.3	6.1	24-2
765.6	765.6	6.0	24-3
737.5	737.5	5.9	24-4
713.5	713.5	5.9	25-1
691.9	691.9	5.8	25-2
672.0	672.0	5.8	25-3
653.5	653.5	5.7	25-4
636.4	636.4	5.7	26-1
620.4	620.4	5.6	26-2
605.4	605.4	5.6	26-3
591.4	591.4	5.5	26-4
578.3	578.3	5.5	27-1
566.0	566.0	5.5	27-2
554.9	554.9	5.4	27-3
543.5	543.5	5.4	27-4

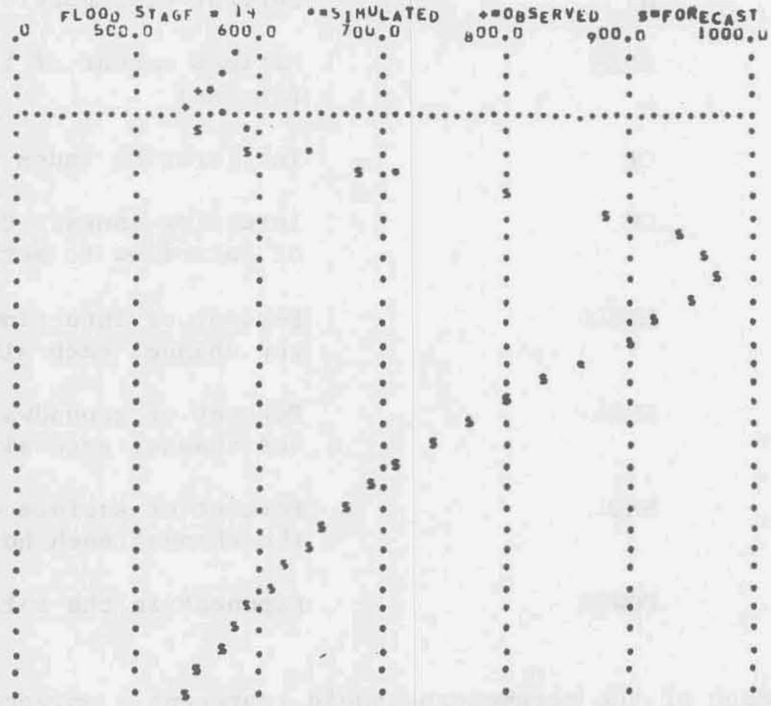

FIGURE 4. TYPICAL OUTPUT OF THE FORECAST PROGRAM

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