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INTERACTIVE FORECASTING WITH THE NATIONAL WEATHER SERVICE RIVER FORECAST SYSTEM

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SYNOPSIS

The National Weather Service River Forecast System (NWSRFS) is a set of interrelated computer programs developed to simulate the rainfall/runoff relationship as a continuous process. The programs can perform a wide variety of hydrologic, hydraulic and data processing functions, and are used by hydrologists in River Forecast Centers to prepare river forecasts. The NWSRFS has been under development for several years. Experience gained from using various versions of the system led to the realization that NWSRFS needed to be made more comprehensive and flexible. A redesign effort was initiated in 1979 to develop a version of NWSRFS called NWSRFS Phase II which would be a more modular system of hydrologic functions. NWSRFS Phase II consists of components designed to perform three basic functions: data entry, data preprocessing, and forecasting. When implemented operationally, the Forecast Component (FC) will perform hydrologic functions necessary to simulate a river system. A series of functions, called operations, will be selected to represent the hydrology of a catchment. The sequence of operations defines a segment. The NWSRFS FC will be run as a batch program, forcing the forecaster to make decisions before the run is submitted to account for contingencies in any of the numerous segments needed to simulate a river system.

An Interactive Forecast Component (IFC) has been developed to demonstrate an alternative mode of operation. By modifying the FC to include interactive capabilities and computer-generated graphics displays, the forecaster can scan the results of each segment's computations and, if necessary, modify and resimulate that segment before proceeding with the rest of the river system. The program and its applications are described in the paper and an example is presented to show how the procedures can be used.

INTRODUCTION AND BACKGROUND

The National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), is responsible for providing accurate and timely hydrologic information and forecasts for rivers throughout the United States. The major offices involved in the National Weather Service hydrology program are 13 River Forecast Centers (RFC's) and the Office of Hydrology (O/H) at the central NWS headquarters in Silver Spring, Maryland. The RFC's are located throughout the U.S. as shown in Figure 1

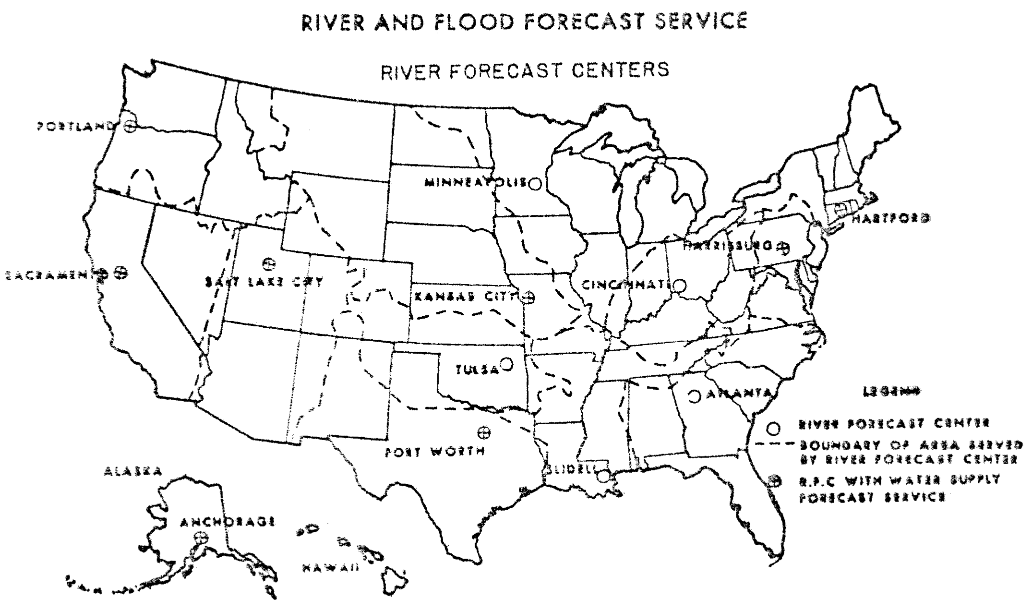

Figure 1. The 13 NWS River Forecast Centers and their respective forecast areas (from NOAA, 1979)

and issue hydrologic forecasts for over 2,500 forecast locations. Each RFC maintains a staff of professional hydrologists responsible for preparing hydrologic forecasts within the RFC's forecast area. The forecast information prepared by each RFC is used for issuing flood forecasts and warnings and for input to daily operational decisions concerning water supply, reservoir operation, power production, irrigation, navigation, recreation, and water quality. Seasonal snowmelt forecasts are issued in areas where snowmelt is a significant component of the streamflow.

One of the major components of the O/H is the Hydrologic Research Laboratory (HRL) which conducts research in support of RFC activities. The mission of the HRL is to advance the state-of-the-art of river forecasting used by the NWS. Originally, RFC's were primarily responsible for deriving their own forecasting techniques. A decision was made in the late 1960's to develop a system of hydrologic components which could be used for forecasting by all the RFC's. The HRL tested several hydrologic models and began developing the National Weather Service River Forecast System (NWSRFS), a system of hydrologic computer models and data handling and display facilities to aid forecasting by RFC hydrologists. Several publications have been written describing the development of NWSRFS and some of its uses (NOAA, 1972; Monro and Anderson, 1974; Curtis and Smith, 1976; Ostrowski, 1979; and Brazil and Hudlow, 1980).

Experience gained from the first several years of development work on NWSRFS led to the realization that a comprehensive, flexible, and more modular system of hydrologic functions was needed than was provided by the existing NWSRFS. Accordingly, a major redesign effort was initiated in January 1979 to develop a new NWSRFS which is being called NWSRFS Phase II. This system will be outlined in the following section. A major element of NWSRFS Phase II is the Forecast Component (FC). This portion of the forecast system performs all the hydrologic computations and displays the resultant tables and plots. The work presented in this paper is a preliminary attempt to make use of computer graphics to allow the FC to run interactively. This permits an RFC hydrologist to produce a forecast for an entire river system by comparing simulated and observed flows for one basin at a time. Corrections can be made and results displayed before moving to the downstream basins.

NWSRFS PHASE II

This version of NWSRFS is based largely on a modular design concept. The basic software components and their interrelationships are shown in Figure 2. The diagram shows the forecast system as consisting of

Figure 2. Software components of NWS River Forecast System Phase II

three main components: Data Entry, Preprocessor, and Forecast. The Data Entry and Preprocessor components are still under development. A Phase II version of the FC exists currently as a batch program. The focus of this paper is to show how the FC can be used as an interactive program for river forecasting. Before demonstrating this capability, some general discussion of river forecasting with Phase II of NWSRFS is necessary.

RFC's receive input to their operational river forecast system through several means. Data are received through telephone calls from observers, teletype information from other offices, communication links with automatic and interrogated gages, and radar and satellite sources. Much of the data is transferred to cards for input to the currently used preprocessing computer programs. The programs transform the data from the various sources into a format acceptable for use by the forecast programs. An example of this change is the transformation of various point precipitation observations into a mean areal precipitation value. When Phase II of NWSRFS becomes operational, many of the data input functions currently being handled manually will be performed automatically by the Data Entry Component. The Preprocessor Component will create input compatible with the forecast programs. The preprocessor will access the raw data stored by the Data Entry subprograms and produce time series such as mean areal precipitation, temperature and evaporation, and observed discharge. A variety of functions will be required (essentially one for each type of time series produced) for the preprocessor to accomplish these tasks.

River forecasts are usually made based on the results obtained from the operational forecast program. Typically, a forecast program is set up to simulate runoff from the headwaters of a river basin first. The runoff amounts from the headwater areas are routed downstream and combined with the runoff from local areas along the stream. Different watersheds are joined together to form river systems. The forecast program is contained within the FC. The FC performs the hydrologic functions necessary to simulate a river system. A set of hydrologic and/or display functions, called operations (i.e., soil moisture accounting, snow accumulation and ablation, channel routing, plotting, etc.), is selected to represent the hydrology of a given catchment. A sequence of operations defines a segment which is typically analogous to a catchment. Segments can be aggregated into forecast groups which are simply ordered lists of segments. A forecast group typically will represent the catchments contributing to one river.

With this structure a hydrologist can, for example, request the simulation of a specific forecast group. The FC can generate a list of segments to be executed. The major processing in the FC occurs within a loop where the segments are simulated one at a time by performing the actions specified by the operations of each segment. The mechanism for temporarily changing values of parameters or data for a segment is called TMODs (Temporary MODifications). These are modifications to the input which can be read in at run time in an attempt to improve the simulation. These changes are in force only during the current simulation. If display operations are included for a segment, printer output is produced and is available for analysis at the end of the simulation of the forecast group. The FC is executed by submitting batch input to the computer on cards. Computations generally require several minutes of clock time and are performed at a rate dependent on the types of other programs being executed on the computer system. The results of the FC initially are displayed on line printers and consist of tables and graphs.

INTERACTIVE FORECASTING

The use of complex hydrologic computer models has created an environment in which river forecasters often supply to and receive from computers vast amounts of information. A forecaster's responsibilities typically include calibration of hydrologic simulation models and development of procedures to improve forecasts, as well as the day-to-day operational river forecasting. These activities usually require some type of computer interaction. The forecaster-computer interface is being recognized as an important element in today's forecasting procedures. New techniques designed to enhance this interaction should improve the overall forecasting effort.

Current forecast and calibration techniques which include submitting batch programs to computers on cards and receiving computer output on line printers have several disadvantages. Card input is a relatively slow procedure and large card decks are inconvenient to use. Line printers are limited in the type of graphical output that can be generated, and hydrologic simulation models can produce an abundance of information that should be displayed graphically. Operational forecasting and model calibration are procedures which often require iterative approaches. In performing either function, the user may want to create input to a program, execute the program, analyze the results, and rerun the program with revised input. Often this sequence is repeated numerous times, particularly in calibration. Although the time factor is more critical in operational forecasting than in calibration, the forecaster-computer interaction is a key element in both procedures (Smith and Brazil, 1980).

Interactive computer programming is a subject which has received considerable attention within the past few years, and the incorporation of computer-generated graphics into interactive programs has become widely used. Interactive computer graphics programs provide a means by which users can supply input to the computer and immediately react to its output. The numerous types of input and output devices provide a flexibility that is not available in the batch program environment. In the case of hydrologic model calibration, a user can input data and model parameters to a computer through a graphics terminal, have the computer perform simulations, analyze the graphical output, and recycle through the process to study the effect of parameter changes. The key advantages of using interactive graphics in calibration are the capability to display complex components of conceptual models and the option to allow the user to perform parameter sensitivity analyses interactively. A project currently is under way to develop an interactive calibration program to be used with the NWSRFS models.

Interactive computer graphics has the potential to be especially useful in operational forecasting. In a flood situation where the amount of time required to issue a forecast is critical, interactive programs may provide the forecaster with information that would not have been obtained using traditional batch programs. In a batch system the forecaster must make decisions before the forecast run is submitted, to account for contingencies in any of the areas which are part of the river system being simulated. As mentioned previously, operational river forecasting often is an iterative process. Multiple executions of large river systems may be required if the forecaster determines that changes are needed after a simulation is completed.

An interactive version of the NWSRFS FC (IFC) has been developed to demonstrate the importance of interactive forecasting. The IFC receives input and displays output through a computer terminal equipped with a graphics scope. The program was designed to allow a river forecaster to specify input data to the program (i.e., precipitation, evapotranspiration, temperature, etc.), execute the simulation portion of the program, compute runoff and route or combine flows for a single segment, and display the results. Comparisons can be made between the simulated and observed flows using computer-generated graphics. If analyses show that adjustments should be made to the input, the modifications can be made and the simulation can be performed again. Such modifications might, for example, include raising or lowering mean areal precipitation values, changing unit hydrograph ordinates, or adjusting zone contents in the soil moisture accounting model. A segment can be resimulated until the forecaster is satisfied with the results. This sequence of simulation-adjustment-resimulation can be continued throughout the entire river system.

INTERACTIVE FORECAST COMPONENT

The interactive capability was introduced into the Phase II Forecast Component by intercepting the program flow at two points within the segment-by-segment loop. The first point of interception is before any hydrologic computations have occurred. The forecaster is shown the current TMODs that will apply to this segment and is allowed to make any changes or additions desired via commands entered at the interactive terminal. The hydrologic computations are performed and the second interception point is encountered. Here the forecaster can display any time series for the current segment. At this point, a decision can be made to go back and make changes to the current segment with TMODs, or to go on to the next segment.

An example of a possible interactive session wherein a forecast group is being executed follows. In this case, a three-segment forecast group for the French Broad River in North Carolina is simulated. This forecast group consists of two headwater segments (Rosman and Brevard) which flow into the Blantyre segment as shown in Figure 3.

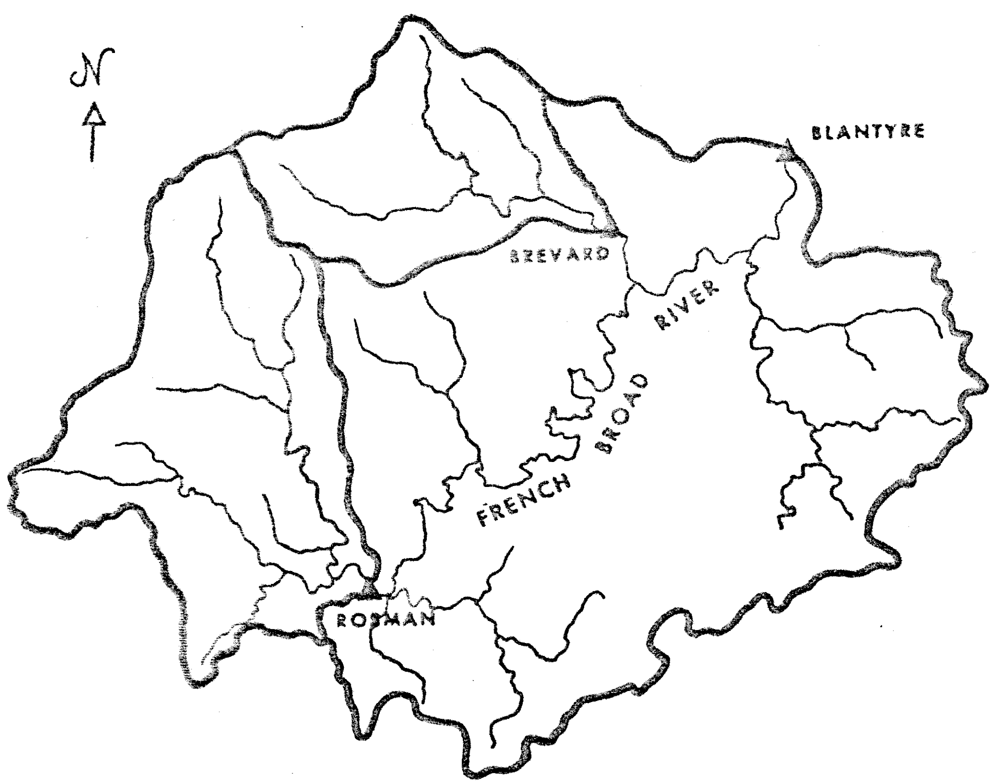

Figure 3. Map of the French Broad River system above Blantyre, North Carolina, U.S.

Data for this example session correspond to the historical period January 20-23, 1954. For purposes of this example, the current date is assumed to be January 23rd, after stage observations for the 23rd have been obtained. The example forecaster is attempting to look back over the event of the past few days and improve the simulation in order to make sure the states of the conceptual hydrologic models (i.e., the zone contents of the soil moisture operation or the runoff values input to the unit hydrograph operation) are as accurate as possible given all of the available data. This procedure is performed to improve the forecast which will be issued based on a simulation into the future using the hydrologic models.

The unmodified estimates of mean areal precipitation for this 4-day period are shown in Table 1. The original simulation for each segment used these precipitation values as input.

Table 1. Original and Modified Mean Areal Precipitation Estimates (millimeters) for Rosman, Brevard, and Blantyre Areas

Date (1954)	Hour	Rosman Original	Rosman Modified	Brevard Original	Brevard Modified	Blantyre Original	Blantyre Modified
Wed, Jan 20	6	0.0		0.0		0.0	
	12	0.0		0.0		0.3	
	18	1.3		2.3		5.3	
	24	18.5	22.0	25.7	18.0	23.9	
Thurs, Jan 21	6	31.7	22.0	24.1	17.0	29.0	
	12	9.4	6.0	4.8		6.9	
	18	0.0	4.0	0.0		0.0	
	24	2.8	4.0	6.4		10.2	
Fri, Jan 22	6	22.4	65.0	25.1	48.0	21.6	50.0
	12	41.9	47.0	40.6	52.0	53.3	60.0
	18	10.2		6.1		12.2	0.0
	24	7.6		3.6		4.8	0.0
Sat, Jan 23	6	0.0		0.0		0.0	
	12	0.3		0.3		0.0	
	18	0.0		0.0		0.0	
	24	0.0		0.0		0.0	

Note: Only the precipitation values that have been changed are shown in the modified columns.

No TMODs are initially made to any of the segments in this example, so the forecaster first requests a simulation for the Rosman segment. The simulated and observed instantaneous flows for this segment appear in Figure 4. The major concern of the forecaster is to track the event as closely as possible so that forecasted flows routed downstream will be as accurate as possible. Figure 4 shows that the models overestimated the Friday peak. Let's assume that our example forecaster decides that the precipitation input to the models must be in error. This assumption was the basis of previous work on forecast adjustments (Sittner and Krouse, 1979). Accordingly, data TMODs are entered to change the mean areal precipitation estimates as shown in Table 1. Another Rosman simulation produces the results in Figure 5. These are judged acceptable and the forecaster moves on to the other headwater segment, Brevard.

Again, a no-TMOD simulation is made. The results appear in Figure 6. Again, the volume discrepancy points to a precipitation input error. After making the data TMOD changes shown in Table 1, a simulation produces flows shown in Figure 7. Even though a small discrepancy (3 hours) in time of peak appears, the resimulation for this segment is also judged acceptable.

The Blantyre segment, with inflows from both Rosman and Brevard, is now simulated without TMODs. The volume is low in the larger peak and, as before, adjustments to precipitation (see Table 1) are made. The resulting simulation produces Figure 9. Improvement can be seen over the Figure 8 results. The forecaster can either call this satisfactory and move downstream, or can attempt further adjustments in the hope of matching Saturday's recession slope more precisely. A parameter TMOD of the unit hydrograph may be in order.

The only TMODs used in this example were modifications to input time series (mean areal precipitation estimates). TMODs can also be used to temporarily modify selected parameters (i.e., unit hydrograph ordinates) or initial conditions (i.e., soil moisture zone contents). In addition, time series which are created in one segment and used in another (i.e., the discharges passed from Rosman and Brevard to the Blantyre segment as upstream inflows) can be modified. Only a small, select set of parameters can be changed with TMODs as it is not the purpose of the IFC to allow daily recalibration. TMODs are intended only to permit adjustments to account for temporary discrepancies between observed data and hydrologic simulations.

This example demonstrates how, on one session at the interactive terminal, a forecaster can make the necessary adjustments and produce a satisfactory forecast. Multiple-batch jobs are eliminated with one use of the Interactive Forecast Component.

CONCLUSIONS AND RECOMMENDATIONS

The IFC provides a means by which a river forecaster can simulate a portion of a river system, examine the results, make modifications and resimulate if necessary, and then continue simulating the rest of the river system. This mode of operation appears to have several advantages over the traditional batch forecasting system. Forecasters are able to compare simulated and observed flows at intermediate points in the river system and make corrections to the simulations without having to rerun the entire system. This forecasting procedure should result in more flexibility for the forecaster, an overall saving of forecast time, and improved forecast accuracy.

Interactive programming should be pursued as a means for improving flood forecasting procedures and increasing the efficiency of model calibration. Future research in river forecasting should include the development of new programming techniques or the utilization of new computer interaction devices which improve the forecaster-computer interface.

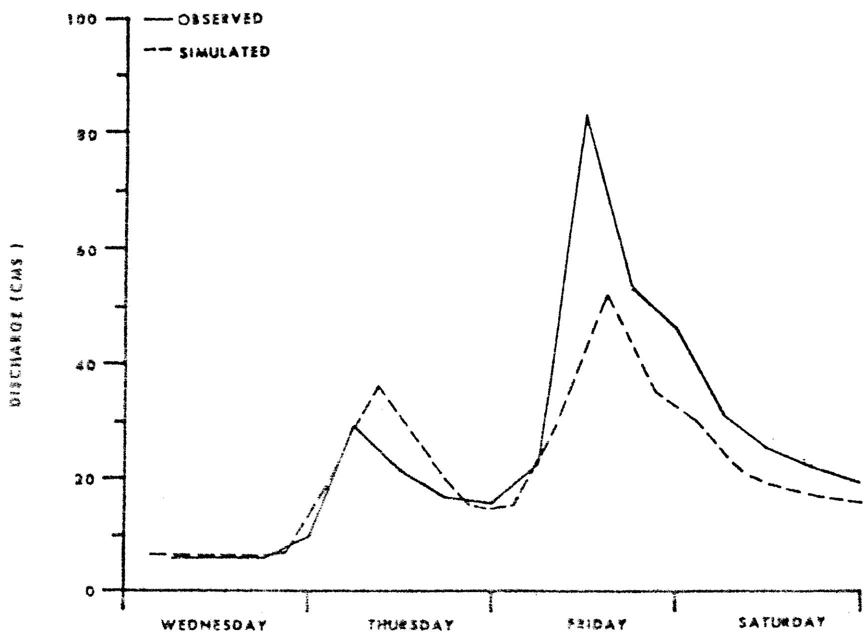

Figure 4. Observed and simulated hydrographs for Rosman segment with no input modifications

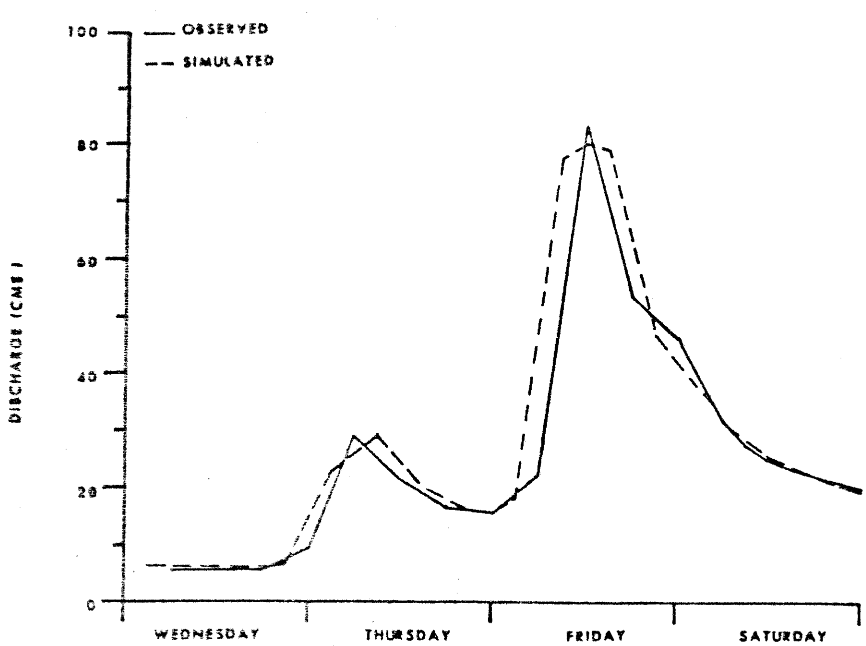

Figure 5. Observed and simulated hydrographs for Rosman segment showing results of temporary modifications to input

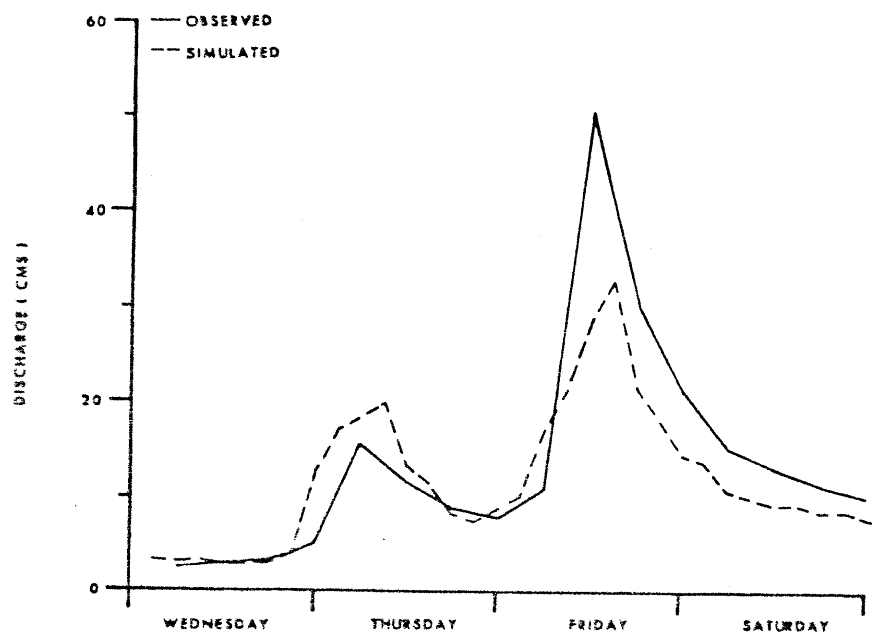

Figure 6. Observed and simulated hydrographs for Brevard segment with no input modifications

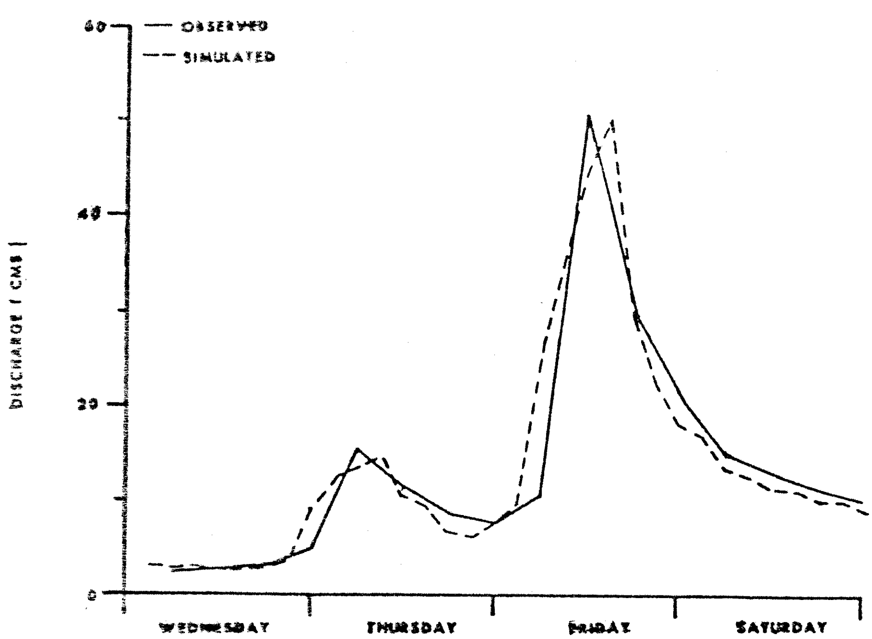

Figure 7. Observed and simulated hydrographs for Brevard segment showing results of temporary modifications to input

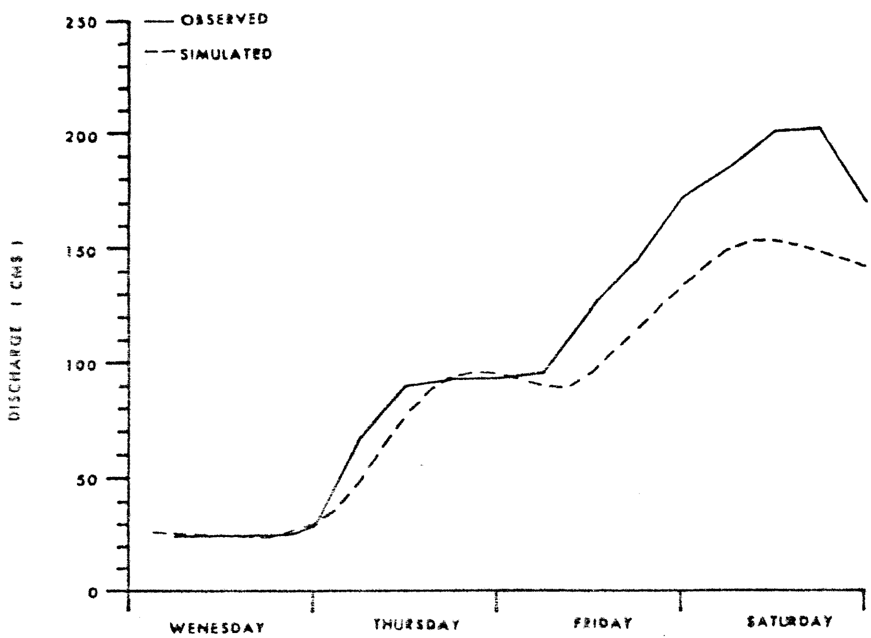

Figure 8. Observed and simulated hydrographs for Blantyre segment with no input modifications

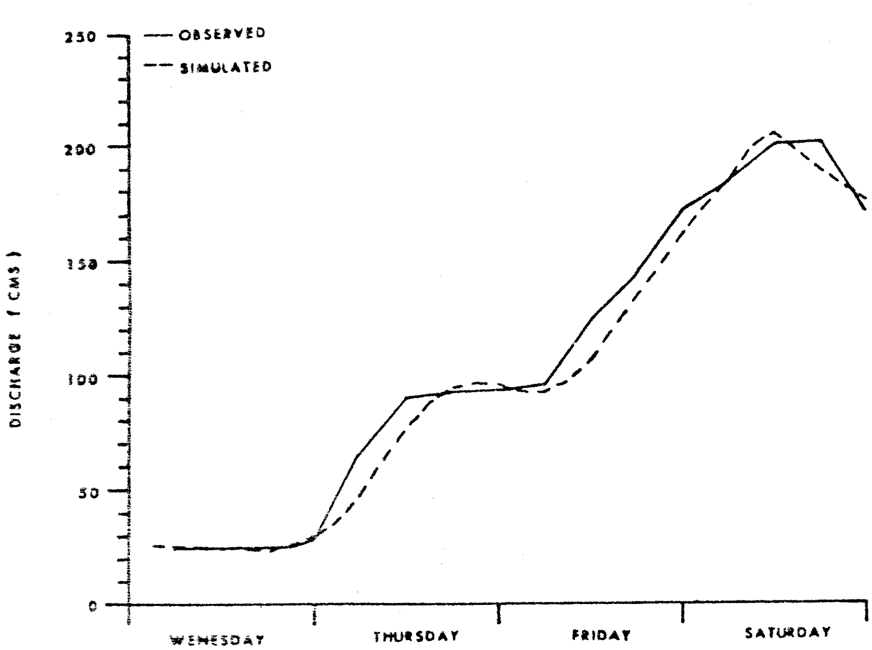

Figure 9. Observed and simulated hydrographs for Blantyre segment showing results of temporary modifications to input

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