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FLOOD-RUNOFF FORECASTING WITH HEC1F[1]

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ABSTRACT: HEC1F is a computer program for making short- to medium-term forecasts of uncontrolled flood runoff. The program employs unit hydrographs and hydrologic routing to simulate runoff from a subdivided basin. Estimates of future rainfall can be accommodated. Runoff parameters for gaged headwater subbasins can be estimated (optimized) in real time. Blending of calculated with observed hydrographs can be performed. HEC1F is a component of an on-line software system that includes capability for data acquisition and processing, precipitation analysis, streamflow forecasting, reservoir system analysis, and graphical display of data and simulation results. The conceptual framework for HEC1F is described, and application of the program is illustrated.
(KEY TERMS: flood forecasting; flood runoff.)

INTRODUCTION

HEC1F is a computer program for making forecasts of uncontrolled flood runoff for periods up to several days. It is an adaptation of computer program HEC-1, Flood Hydrograph Package (HEC, 1981) and is a component of an on-line software system that includes capability for data acquisition and processing, precipitation analysis, streamflow forecasting, reservoir system analysis, and graphical display of data and simulation results (Pabst and Peters, 1983). Capability is provided in HEC1F (HEC, 1983b) to model virtually any network of elementary basins. Automated parameter estimation can be performed on a real-time basis for elementary basins for which observed precipitation and streamflow data are available. Hydrologic routing methods can be used to route flow through a stream network, and blending can be performed at gaged locations prior to subsequent routing. Capability is provided for the user to specify loss rate and base flow parameters, and future precipitation, for zones which consist of aggregations of subbasins. Loss rate and base flow parameters must be established by the user on an iterative basis as there is no capability for continuous soil moisture accounting. This paper contains a description of the conceptual framework for HEC1F, and describes and illustrates its use for runoff forecasting.

ORIGIN AND ROLE OF HEC1F

The U.S. Army Corps of Engineers has responsibility for operating a large number of reservoirs and reservoir systems throughout the United States. In recent years there has been a concerted effort to improve project operations by employing state-of-the-art data collection and transmission equipment, by acquisition of minicomputers that are dedicated to water control activities and by developing software that will facilitate the making of water control decisions by the water control manager.

The Corps' Hydrologic Engineering Center (HEC) has been actively involved in developing and adapting software for real-time data acquisition and processing, runoff forecasting and reservoir system simulation. These software components are part of a comprehensive software system that includes a specially-designed data storage system, an interactive executive program, and a graphical display capability. The software system is presently being implemented on minicomputers at several Corps offices.

Considerations that influenced the decision to adapt HEC-1 for real-time forecasting are as follows:

a. HEC-1 is widely used throughout the United States. Runoff parameters have already been developed for many of the basins in which Corps projects are located as part of the planning and design studies for the projects.

b. A large number of Corps engineers are knowledgeable in use of the program.

c. Conceptually, HEC-1 is a relatively simple model that provides capability to model runoff from a subdivided basin and can accommodate estimates of future rainfall. It provides a reasonable compromise between more empirical techniques on the one hand and more complex and data intensive techniques on the other.

A forecast approach that makes use of explicit soil moisture accounting may provide more reliable forecasts for some basins. The software system has a modular structure so that alternative components can be added to the system. For runoff forecasting, provision is being made to enable use of the

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SSARR program (U.S. Army Corps of Engineers, 1975). Likewise, consideration is being given to inclusion of the moisture accounting methodology of the National Weather Service River Forecast System as developed from the Sacramento Hydrologic Model (Burnash, 1973). Inclusion of various components will enable comparative testing to establish the realm of applicability and the utility of alternative forecast procedures.

HEC1F FORECAST APPROACH

Application to HEC1F to forecast runoff in a subdivided watershed is generally a two-step process, requiring two separate applications of the program. The first step is to estimate parameters and calculate discharge hydrographs for gaged headwater subbasins. The second step is to calculate discharge hydrographs for remaining subbasins employing user-defined runoff parameters, and to route and combine hydrographs throughout the basin. In the second step, blending can be performed at each gaged location prior to subsequent routing. This enables use of observed data wherever it is available.

In the first step, automated parameter estimation (optimization) is used to refine initial estimates of user-designated runoff parameters (e.g., unit hydrograph, loss rate, and base flow) in real time. The estimated parameters are used to forecast runoff, with or without consideration of future precipitation. Real-time parameter estimation is generally limited to gaged headwater subbasins, although it may also be applied to a downstream subbasin for which incremental streamflows have been derived by subtracting routed streamflows (from an upstream gage) from the observed total streamflows at the downstream gage. However, streamflows obtained by subtraction are generally sensitive to routing errors and may not be suitable for parameter estimation. Besides providing forecast hydrographs for the gaged subbasins, the parameter estimation application of HEC1F provides parameter estimates which should be of value to the water control manager in establishing the magnitude of parameters to be used for all other subbasins.

For the second application of HEC1F, the user must specify values for base flow and loss rate variables. Because these variables are required for each subbasin, a large number of values can be involved. Input of these values, as well as input of future precipitation, is facilitated with a capability for zonal specification of the variables. A zone comprises a group of subbasins for which the given variables, for example, loss rates, have the same values. Each subbasin can be assigned to individual base flow, loss rate and future precipitation zones. The magnitudes for zonal variables can be set by the user through an interactive executive program and a preprocessor for HEC1F (HEC, 1983b).

PROCEDURE FOR PARAMETER ESTIMATION

Consider Figure 1, which illustrates the framework for parameter estimation. It is desired to forecast runoff at the outlet of the subbasin shown in part "a" of the figure. There is a stream gage at the outlet for which real time data are available. A unit hydrograph for the basin is shown in part "b." The unit hydrograph was determined by analysis of historical events and represents an initial estimate.

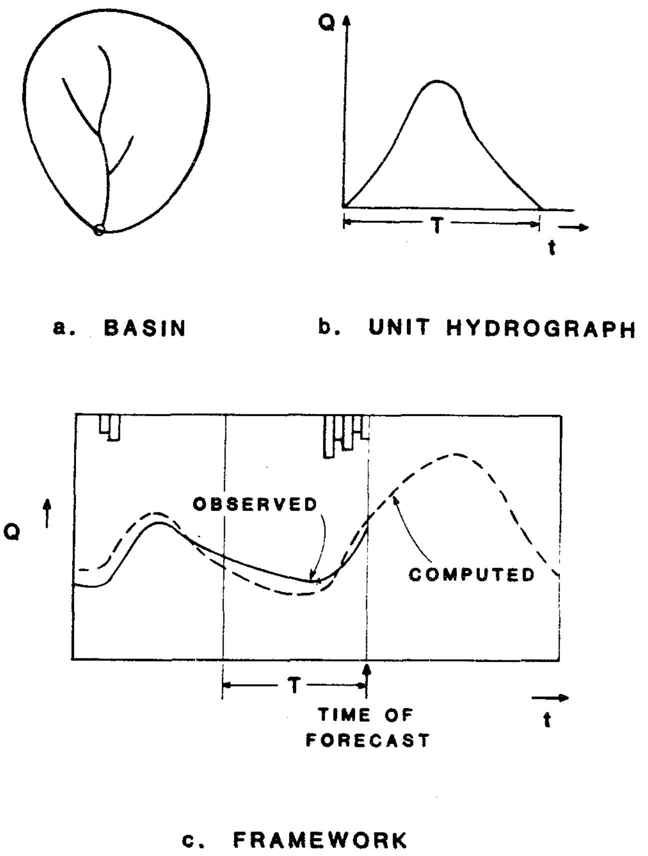

Figure 1. Framework for Parameter Estimation.

Part "c" of Figure 1 illustrates essential aspects of the forecast procedure. The time at which the forecast is being generated is labeled Time of Forecast. Observed streamflow and precipitation data are available up to this point in time. The time period labeled T is the period over which an objective function will be calculated for parameter estimation purposes. The program sets T equal to seven times the initial value for the standard lag associated with the Snyder synthetic unit hydrograph. This relationship was derived empirically to provide a time period approximately equal to the time base of the unit hydrograph. Precipitation occurring prior to the beginning of time period T will have little or no influence on direct runoff occurring after the time of forecast. Likewise, the length of time from the beginning of the simulation to the beginning of the time period T should be at least of comparable magnitude to T so that precipitation occurring prior to the beginning of the simulation will not have a significant impact on direct runoff that occurs during T.

HEC1F can estimate up to six parameters for a subbasin two unit hydrograph, two base flow, and two loss rate parameters. The user may freeze the magnitude of any variable and exclude it from the optimization process. During the optimization process, estimates for each variable are constrained to lie within a range of physically reasonable values.

A univariate search technique (Ford, *et al.,* 1980) is used for parameter estimation. The objective function that is minimized in the estimation process is

$$STDER = \sqrt{\frac{\sum_{i=1}^{N} (QOBS_i - QCOMP_i)^2 * WT_i}{N}} \qquad (1)$$

where:

$STDER$ = objective function,

$QOBS_i$ = ordinate i of the observed hydrograph,

$QCOMP_i$ = ordinate i of the computed hydrograph,

WT_i = weighting factor applied at ordinate i, and

N = total number of hydrograph ordinates encompassed by the objective function.

The objective function is evaluated over the time period labeled T in Figure 1. For forecasting purposes, it is generally desirable to give more weight to deviations that occur immediately prior to the time of forecast than to deviations that occur earlier in time. This will tend to produce close agreement between the observed and computed hydrographs as the time of forecast is approached. A weighting function for use in the above equation is defined as follows:

$$WT_i = \left(\frac{j}{N-1}\right)^2 \qquad (2)$$

where j = number of Δt intervals from the beginning of the time frame T for parameter estimation to the time of ordinate i. Thus, the weight given to squared deviations varies nonlinearly from a value of 0 at the beginning of the time period T (see Figure 1) to a value of 1 at the time of forecast.

The parameter estimation process is intended to operate under a wide range of precipitation-runoff conditions, including periods involving a sequence of storms as well as low flow periods. Also, the process is intended to accommodate missing data. In order to provide for this variety of situations, the following procedures are followed:

(1) Unit hydrograph and loss rate parameters are estimated (optimized) only if the precipitation during the time frame for parameter estimation, T, exceeds a user-specified threshold amount.

(2) If the time difference between the center of mass of precipitation in the period T and the time of forecast is less than the initial value of the Snyder lag for the subbasin, unit hydrograph and loss rate parameters are not optimized. The purpose of this restriction is to prevent estimation of unit hydrograph and loss rate parameters when there is an inadequate hydrograph rise upon which to base estimates.

(3) In application of the initial loss-constant loss rate approach to rainfall excess estimation, the initial loss is generally assumed to apply at the beginning of a period of simulation without provision for reinstating the initial loss if a dry period follows an initial period of precipitation. Capability is provided in HEC1F to reinstate the initial loss after a period of no precipitation, in accordance with a simple moisture deficit calculation based on mean monthly pan evaporation data.

(4) If more than 20 percent of the observed streamflow data is missing during the time frame for parameter estimation, parameter estimation is not performed.

BASIN-WIDE RUNOFF FORECASTING

As indicated previously, a second application of HEC1F is made following the parameter-estimation application. In the second application, forecasted hydrographs are calculated for all locations of interest. The standard capabilities from HEC-1 for runoff calculation, routing and combining are used for this purpose. However, blending can be performed at each gage prior to subsequent routing and combining operations.

The purpose of blending is to provide a smooth transition from the observed to the calculated hydrograph. The transition is made by linearly decreasing the difference between the calculated and observed hydrographs at the time of forecast over the six ordinates following the time of forecast. For example, assume that the computed discharge is 120 c.f.s. less than the observed discharge at the time of forecast. The five subsequent ordinates of the blended hydrograph would be obtained by adding 100, 80, 60, 40, and 20 c.f.s., respectively, to the computed-hydrograph ordinates. Subsequent ordinates of the blended hydrograph would equal the ordinates of the computed hydrograph.

The hypothetical basin shown in Figure 2 will be used to illustrate the forecast approach. The basin is subdivided into three subbasins. A reservoir is located at B. Stream gages are located at the reservoir outlet and at A and C. Locations B and C are control points for which runoff forecasts are required as a basis for making release decisions for the reservoir.

A first application of HEC1F is made to perform parameter estimation for subbasin 1 using observed discharge data for the gage at A. The optimized parameters should be useful information for use in establishing loss rate and base flow parameters for calculating runoff from subbasins 2 and 3. The calculated hydrograph for subbasin 1 is written to a special data base file (HEC, 1983a) to enable retrieval later.

A second application of HEC1F is made in which the following sequence of steps is performed:

(1) Retrieve the hydrograph that has been calculated for subbasin 1 as a result of parameter optimization.

(2) Blend the calculated hydrograph for subbasin 1 with the observed hydrograph at A.

(3) Route the blended hydrograph for subbasin 1 to location B.

(4) Calculate a discharge hydrograph for subbasin 2 using user-specified runoff parameters. Subbasin 2 represents the intervening drainage area between locations A and B.

(5) Combine the hydrographs from steps 3 and 4.

(6) Blend the hydrograph from step 5 with the "observed" reservoir inflow hydrograph. The observed hydrograph in this case may have been previously derived from observed outflow and change in reservoir storage. The blended hydrograph is the forecasted inflow hydrograph for the reservoir.

(7) Route the observed outflow hydrograph at B to location C.

(8) Calculate a discharge hydrograph for subbasin 3 using user-specified runoff parameters.

(9) Combine the hydrographs from steps 7 and 8.

(10) Blend the hydrograph from step 9 with the observed hydrograph at C. The blended hydrograph is the forecast for location C exclusive of future reservoir releases.

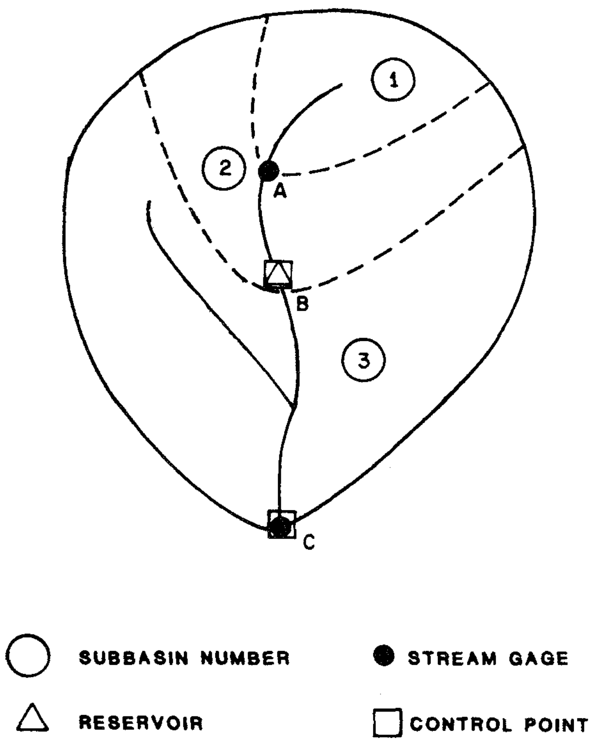

Figure 2. Hypothetical Basin.

OPERATIONAL CONSIDERATIONS

The hypothetical application of HEC1F just described would provide a forecast of inflow to the reservoir and a forecast of runoff at the downstream control point. These forecasted hydrographs could be used with a reservoir system simulation model such as HEC-5 (HEC, 1982) to determine optimal reservoir releases. The general approach can be applied to basins and reservoir systems of virtually any size and configuration.

Subbasin precipitation hyetographs for use in HEC1F can be generated with the program PRECIP (HEC, 1983b). The program is designed to develop spatial averages of rainfall depth from a gage network for which data can be missing at various times from various gages.

Observed data as well as intermediate and final simulation results can be plotted or tabulated with the program DSPLAY (HEC, 1983a). This capability greatly facilitates analysis of forecast results.

ILLUSTRATIVE APPLICATION

One of the basins to which HEC1F is being applied is the 12,300 square mile Kanawha Basin, which drains portions of North Carolina, Virginia, and West Virginia. The Kanawha River flows northward and joins the Ohio River at Pt. Pleasant, West Virginia, as shown in Figure 3. The basin is subdivided into 20 subbasins for purposes of runoff determination. There are four reservoirs in the Basin. Three are operated for flood control and other purposes by the Corps of Engineers: Bluestone, Summersville, and Sutton. The fourth, Claytor, is operated for hydropower by the Appalachian Power Company. HEC1F is being applied to provide forecasts of inflow to the three Corps reservoirs as well as forecasts of uncontrolled runoff at downstream control points. The water control management system includes an automated data collection network using satellite communications, the forecast methodology described herein, as well as an HEC-5 model to aid in making operational decisions for the reservoir system.

There are seven gaged headwater subbasins in the Kanawha Basin. HEC1F is used to estimate loss rate, base flow and unit hydrograph parameters in real time for these subbasins. Two of the subbasins are relatively small, about 50 square miles each, and are not in the subbasin network used in making basin-wide forecasts. However, the response times for index basins are relatively short, which enables estimation of loss rate parameters relatively early in a flood event. Parameter estimates for the seven headwater subbasins are used by the forecaster to set zonal values for loss rate and base flow parameters for the remaining subbasins.

A second application of HEC1F using the complete subbasin network produces forecasts at all locations of interest. The forecaster reviews forecast results to determine how well the calculated hydrographs reproduce the observed hydrographs up to the time of forecast. Additional adjustment of zonal parameters may be required to improve the forecast.

Figures 4-9 illustrate forecasts made with HEC1F at the end of a period of moderate rainfall in April 1983. The dashed vertical line in the figures represents the time of forecast. A time step size of three hours was used. The rainfall hyetograph in the upper portion of each figure pertains to the subbasin in which the forecast is being made and does not necessarily represent the entire drainage area upstream from the forecast location.

The forecast for Glen Lyn, Figure 4, was based on calculating runoff for each of the four upstream subbasins, and associated routing and combining operations. The two upstream stream gages were not connected to the real-time reporting network for this event, consequently neither parameter optimization nor blending was performed at these locations. Outflow was assumed to equal inflow for Claytor Reservoir.

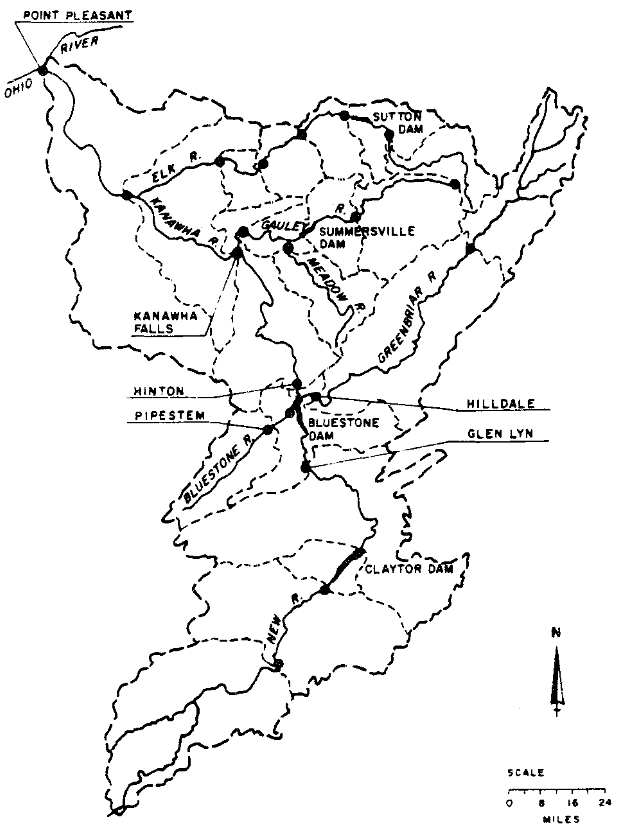

Figure 3. Kanawha River Basin.

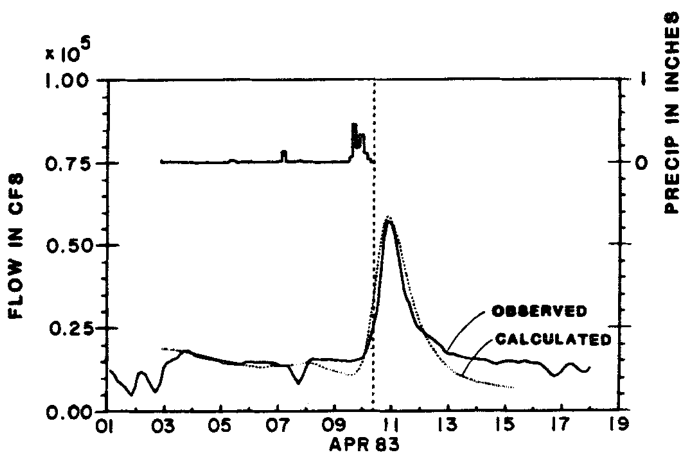

Figure 4. Observed and Forecasted Hydrographs at Glen Lyn – Time of Forecast is 0800 on April 10, 1983.

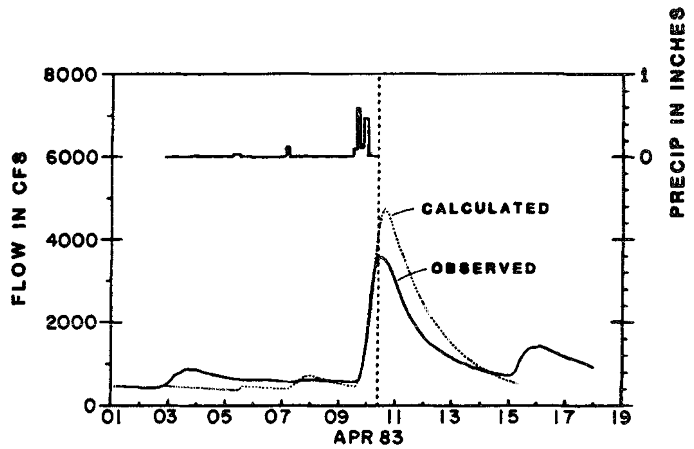

Figure 5. Observed and Forecasted Hydrographs at Pipestem – Time of Forecast is 0800 on April 10, 1983.

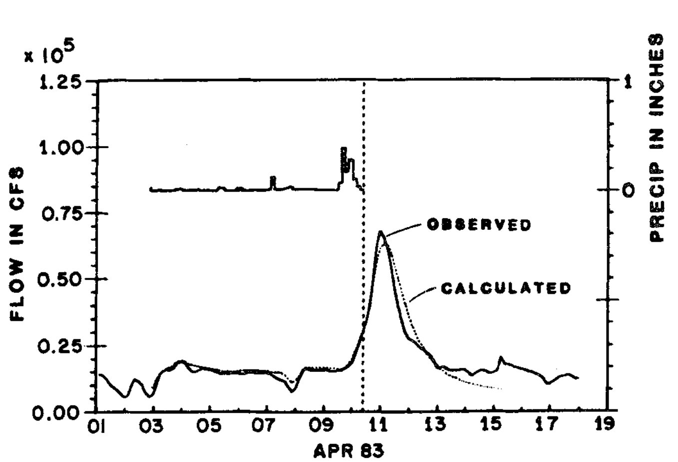

Figure 6. Observed and Forecasted Inflow Hydrographs to Bluestone Reservoir – Time of Forecase is 0800 on April 10, 1983.

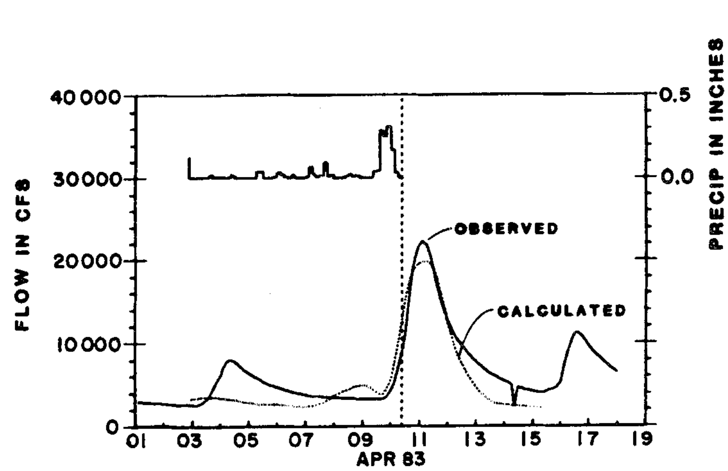

Figure 7. Observed and Forecasted Hydrographs at Hilldale – Time of Forecast is 0800 on April 10, 1983.

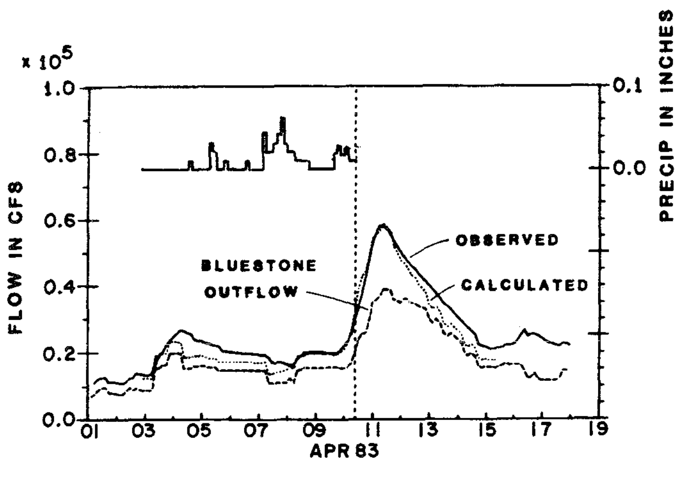

Figure 8. Observed Hydrographs at Hinton and Bluestone Dam; Forecasted Hydrograph at Hinton – Time of Forecast is 0800 on April 10, 1983.

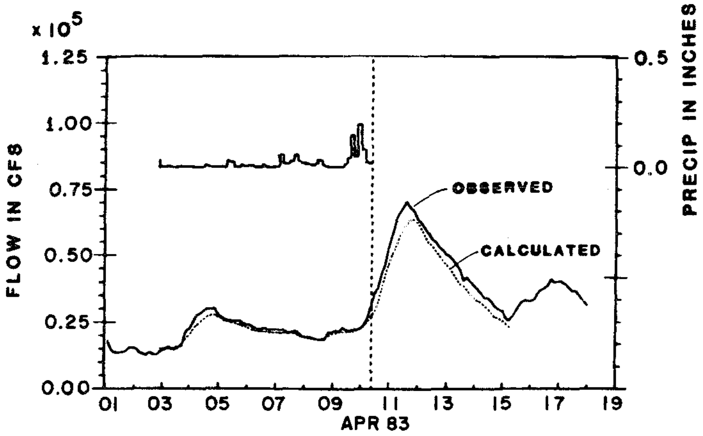

Figure 9. Observed and Forecasted Hydrographs at Kanawha Falls – Time of Forecast is 0800 on April 10, 1983.

The forecast for peak discharge at Pipestem is about 35 percent too high (Figure 5). This is a headwater subbasin and real-time streamflow data were available. However, unit hydrograph and loss rate parameters were not optimized because of an insufficient time span between the time corresponding to the center of mass of the rainfall and the time of forecast.

The forecast of inflow to Bluestone Reservoir (Figure 6) was based on combining blended hydrographs routed from Glen Lyn and Pipestem with a hydrograph for the 'local' area downstream from those two locations.

The forecast for Hilldale, Figure 7, was based on calculated runoff for the two upstream subbasins, and associated routing and combining operations. The upstream stream gage was not connected to the real-time reporting network for this event, consequently data were not available to enable parameter optimization or blending at the upstream gage.

The forecasts for Hinton and Kanawha Falls, Figures 8 and 9, include outflow from Bluestone Reservoir (Figure 8) to enable comparison of the forecasted hydrographs with the observed hydrographs. The forecast at Kanawha Falls is based on a blended hydrograph routed from Hinton, a blended hydrograph at Hilldale and a calculated hydrograph for the intervening subbasin.

SUMMARY

An approach for making short- to medium-term runoff forecasts from subdivided basins has been described and illustrated. Use of HEC1F in a real-time mode involves user selection of runoff parameters to best fit observed flow conditions up to the time of forecast. Capability exists for using parameter optimization for individual gaged subbasins.

Subbasin runoff is simulated using 'standard' unit hydrograph techniques as contained in the HEC-1 program. Loss rate and base flow parameters, and future precipitation, can be specified on a zonal basis. Blending of calculated hydrographs with observed hydrographs can be performed at each gaged location prior to subsequent routing and combining operations.

HEC1F is a component of a comprehensive system of water control software that includes the programs PRECIP, HEC-5, and DSPLAY.

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