STREAMFLOW ROUTING IN THE SCHOHARIE CREEK BASIN NEAR NORTH BLENHEIM, NEW YORK

By Stephen W. Wolcott

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert the inch-pound units of measurement in this report to the International System Units of (SI).

Multiply Inch-pound unit	by	To obtain SI unit
inch (in)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons (Mgal)	3785.0	cubic meters (m^3)

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ABSTRACT

A flow-routing model of the upper Schoharie Creek basin was developed and used to simulate high flows at the inlet of the Blenheim-Gilboa Reservoir. The flows from Schoharie Creek at Prattsville, the primary source of flow data in the basin, and tributary flows from the six minor basins downstream, were combined and routed along the 9.7-mile reach of the Schoharie Creek between Prattsville and the reservoir inlet. Data from five historic floods were used for model calibration and four for verification. The accuracy of the model, measured as the difference between simulated and observed total flow volumes in the model verification, is within 14 percent. Results indicate that inflows to the Blenheim-Gilboa Reservoir can be predicted approximately 2 hours in advance.

One of the historical floods was chosen for additional model testing to assess a hypothetical real-time model application. Total flow-volume errors ranged from 30.2 percent to -9.2 percent when the model was reinitiated every 3 hours.

Alternative methods of obtaining certain types of hydrologic data for model input are presented for use in the event that standard sources are unavailable.

INTRODUCTION

The Blenheim-Gilboa Reservoir is one of two large reservoirs on the Schoharie Creek near North Blenheim, in the northern Catskill Mountains (fig. 1). Since 1973, the Power Authority of the State of New York (PASNY) has operated the Blenheim-Gilboa Reservoir as part of a pumped-storage hydroelectric system. As stipulated in its license, PASNY is required to allow inflow from Schoharie Creek and Mine Kill to pass directly through the Blenheim-Gilboa Reservoir. The ability to forecast the reservoir's inflow is important to PASNY in management of the reservoir during periods of high flow.

Although five telemetered stream and reservoir gages above the Blenheim-Gilboa Reservoir are currently in operation, no reliable method has been developed to combine and route observed flow values to the Blenheim-Gilboa Reservoir. The U.S. Geological Survey, in cooperation with PASNY, has developed a hydrologic routing model that can be used to predict the inflows to the Blenheim-Gilboa Reservoir from available stream and reservoir data. The locations of the gages and major reservoirs, creeks, and tributaries are shown in figure 1.

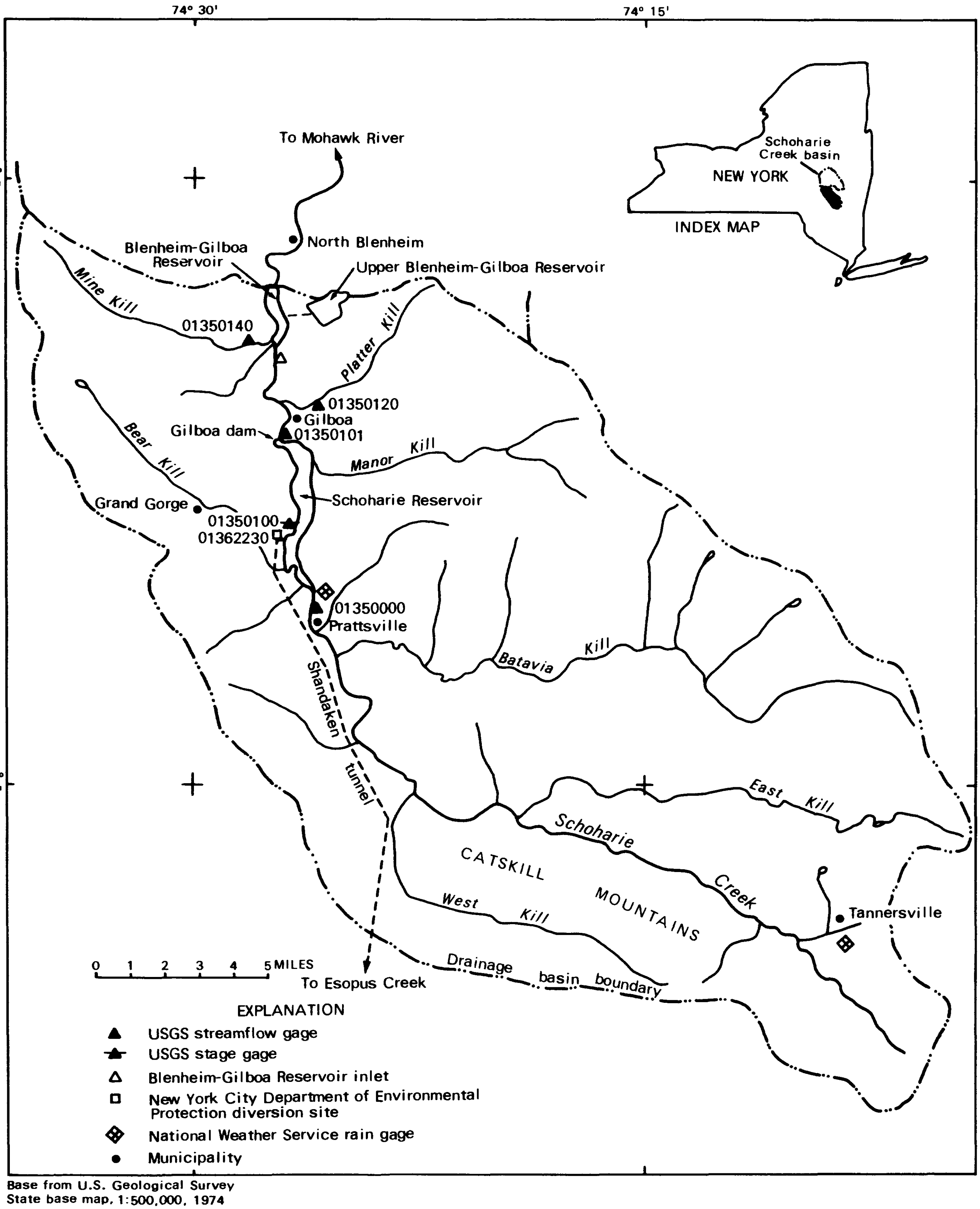

Figure 1.--Locations of Gages and major reservoirs, creeks, and tributaries in the upper Schoharie Creek basin.

Purpose and Scope

This report describes the development and testing of a routing model that relies on both the modified Puls and Muskingham routing techniques (Chow, 1964). The modified Puls routing technique was used to route flows through Schoharie Reservoir; the Muskingham method was used to route outflows from Schoharie Reservoir through the Schoharie Creek channel to the inlet of the Blenheim-Gilboa Reservoir. Five historic floods were chosen for model calibration, and four other floods were used for verification. One of the floods chosen for verification was also used to simulate a hypothetical real-time model application. Alternative methods of obtaining flow data necessary for model input, in the event that standard hydrologic data obtained from the gaging network are unavailable, also are described. These methods include the derivation of flows by the use of index stations and reverse-routing techniques.

Description of the Area

Schoharie Creek originates in the northern Catskill Mountains and flows 75 mi north into the Mohawk River. The upper Schoharie Creek basin, the study area, extends from the headwaters of Schoharie Creek to the outlet of the Blenheim-Gilboa Reservoir (fig. 1). It is mostly undeveloped and heavily forested.

Schoharie Creek passes through two major reservoirs--Schoharie Reservoir and Blenheim-Gilboa Reservoir. The Schoharie Reservoir (maximum capacity 21,551 Mgal), formed by Gilboa Dam, is part of the water-supply system for the City of New York. The entire flow of Schoharie Creek upstream from Gilboa Dam is diverted southward from the basin through the Shandaken Tunnel (fig. 1) into Esopus Creek except during periods of spill. Most commonly these periods of spill are in the late fall, early spring, or during large floods at other times of the year. The outflow is uncontrolled, and the only operation at the reservoir is the diversion to Shandaken Tunnel.

Downstream from Schoharie Reservoir is the pumped-storage Blenheim-Gilboa Reservoir (maximum capacity 5,328 Mgal), operated by PASNY. Its inlet is 3.6 mi downstream from Gilboa Dam. During evenings and weekends, water is pumped from this reservoir to the Upper Blenheim-Gilboa Reservoir, an elevated-storage reservoir, for subsequent release back into the lower reservoir to generate power during peak demand periods. The operating license granted in 1969 by the Federal Energy Regulatory Commission[1] (formerly the Federal Power Commission) requires that inflow from the Schoharie Creek and Mine Kill be passed directly out the Blenheim-Gilboa Reservoir without storing for future release.

Seven major tributaries enter Schoharie Creek upstream from the outlet of the Blenheim-Gilboa Reservoir (fig. 1). The combined flows from these tributaries during periods of flooding can contribute significantly to the total

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[1] Federal Energy Regulatory Commission, June 6, 1969, License no. 2685, Blenheim Gilboa power subject.

inflow to the Blenheim-Gilboa Reservoir. When the Schoharie Reservoir is not spilling, however, flows from tributaries upstream from Gilboa Dam are not observed downstream.

High streamflows in the upper Schoharie Creek basin are created by several types of meteorological phenomena. Storms whose primary supply of moisture is from the Gulf of Mexico or the North Atlantic often pass through the area. During spring, these storms, coupled with a melting snowpack, often produce the year's highest flows. Summer thunderstorms can also cause stream flooding, but the floods are usually confined to a few tributaries. Probably the most unpredictable and damaging type of storm that afflicts the area is the remnant of a hurricane. The Schoharie Creek basin is too rugged and too far inland to be buffeted by a full-strength hurricane, but the rainfall associated with the remnants can produce substantial runoff.

Precipitation is generally uniform throughout the year, with slightly higher amounts during spring and summer (National Oceanic and Atmospheric Administration, 1974). Yearly mean precipitation ranges from 39 in. in the northern part of the upper basin to about 48 in. in the southern, mountainous part (Zembrzuski and Dunn, 1979).

Data Network

The U.S. Geological Survey maintains four stream gages and one stage gage in the study area, all of which are telemetered. Locations are shown in figure 1.

The Schoharie Creek at Prattsville gage (station 01350000) 9.7 mi upstream from the inlet to the Blenheim-Gilboa Reservoir and 5.4 mi upstream from Gilboa Dam, is the oldest gage in the basin, established in 1902. It measures flow from the largest uncontrolled drainage area, 236 mi^2. Three major ungaged tributaries--East Kill, West Kill, and Batavia Kill--drain into the Schoharie Creek upstream from the Prattsville gage. The gage at Prattsville records flow from 75 percent of the area that is tributary to Schoharie Reservoir.

The Schoharie Creek at Gilboa gage (station 01350101) is 0.4 mi downstream from Gilboa Dam and measures the outflow of the Schoharie Reservoir. The drainage area at this gage is 314 mi^2. Two major ungaged tributaries--Bear Kill and Manor Kill--with drainage areas of 25.8 mi^2 and 34.5 mi^2, respectively, account for 19 percent of the drainage area to the Schoharie Reservoir and 77 percent of the drainage area between the Prattsville and Gilboa gages. When the reservoir is not spilling, the flow measured at the Gilboa gage is seepage.

The Platter Kill at Gilboa gage (station 01350120) receives flow from a drainage area of 11.1 mi^2. The mouth of the Platter Kill is approximately 1.3 miles downstream from Gilboa Dam. The Mine Kill near North Blenheim gage (station 01350140) receives flow from a slightly larger drainage area of 16.3 mi^2. The mouth of the Mine Kill is 4.1 mi below Gilboa Dam and flows directly the Blenheim-Gilboa Reservoir. The drainage areas at the Mine Kill and Platter Kill gages account for approximately 61 percent of the total drainage area between the Gilboa gage and the outlet of the Blenheim-Gilboa Reservoir. Flows from both the Platter Kill and Mine Kill contribute a significant proportion of the inflow to Blenheim-Gilboa Reservoir when Schoharie Reservoir is not spilling, but during periods of spill, their overall percentage of the inflow diminishes as the outflow from Schoharie Reservoir increases.

The water-surface elevation of the Schoharie Reservoir is monitored near Grand Gorge (station 01350100) near the entrance to the Shandaken Tunnel, 2.5 mi upstream from the Gilboa Dam. Flow diverted from the Schoharie Reservoir through the Shandaken Tunnel (station 01362230) is regulated by the New York City Department of Environmental Protection (NYCDEP) at the entrance to the tunnel. Reports of diverted flow rate are available hourly but can be obtained for smaller time intervals during rapidly changing diversion operations. Current information concerning diverted flows are obtainable by direct contact with the plant operations manager.

The flow of Schoharie Creek at the inlet of the Blenheim-Gilboa Reservoir is calculated by PASNY by adding the rate of change in storage of the reservoir to a known value of outflow. Inflows are usually determined every hour but can be calculated for intervals as small as 5 minutes if desired. (In this study, calculated flows at the inlet for time intervals less than 1 hour were not available and were therefore interpolated from the hourly values.)

The National Weather Service maintains two rain gages in the study area from which hourly precipitation data are available. One gage is in the northern Catskills at Tannersville; the other is downstream at Prattsville. The data network is summarized in table 1.

Table 1.--Data network in the upper Schoharie Creek basin, New York.
[Locations are shown in fig. 1.]

Station number	Station name	Drainage area (mi^2)	Remarks[1]
01350000	Schoharie Creek at Prattsville	236	USGS stream gage.
01350100	Schoharie Reservoir near Grand Gorge	314	USGS reservoir gage.
01350101	Schoharie Creek at Gilboa	314	USGS stream gage.
01350120	Platter Kill at Gilboa	11.1	Do.
01350140	Mine Kill near North Blenheim	16.3	Do.
--	Blenheim-Gilboa Reservoir inlet	330	PASNY flow calculation site
--	Blenheim-Gilboa Reservoir outlet	357	PASNY flow site.
01362230	Schoharie Reservoir diversion	--	NYCDEP diversion site.
--	Tannersville rain gage	--	NWS rain gage.
--	Prattsville rain gage	--	Do.

[1] USGS, U.S. Geological Survey;
PASNY, Power Authority of the State of New York;
NYCDEP, New York City Department of Environmental Protection; and
NWS, National Weather Service.

Preliminary Analysis

In a preliminary analysis, the HEC-1 flood hydrograph package developed by the U.S. Army Corps of Engineers (1973) was used to calibrate both a rainfall-runoff model and a flow-routing model of the upper Schoharie Creek basin. Results are outlined below.

Hydrographs generated by rainfall-runoff models representing the three unregulated gaged sites--Schoharie Creek at Prattsville, Platter Kill at Gilboa, and Mine Kill near North Blenheim--were initially used in the flow-routing model. The rainfall-runoff models were developed by optimizing loss-rate parameters and unit hydrographs for all three sites. The interpolated results from the optimization were applied to the ungaged sites, thereby supplying the flow-routing model for the remaining input hydrographs, which could then be appropriately combined and routed. Major emphasis was placed on rainfall-runoff model development for the upper Schoharie Creek basin at the Prattsville gage because flow passing this gage contributes most of the inflow to the Schoharie Reservoir.

Hourly streamflow and precipitation data were used. Three historic floods at the Prattsville gage were chosen for calibration and two others for verification. Winter conditions were omitted in all models to avoid flows affected by variable backwater from ice and the uncertainty in modeling snowmelt runoff.

Verification results of the rainfall-runoff models were poor. Major errors in both timing and magnitude were noted between simulated and observed flows at all sites. One cause of rainfall-runoff model failure was probably insufficient spatial distribution of precipitation data. The flows generated for the Prattsville gage were derived from rainfall values averaged between the two rain gages. Therefore, neither the amount nor the distribution of basin rainfall were accurate, especially because precipitation patterns in this area are highly variable. The rainfall-runoff relationships for both the Platter Kill and Mine Kill gages were based on data from the Prattsville rain gage, which is not in either basin. It was apparent from these results that the precipitation gages in smaller basins should be located either close to or within the watershed.

The basin above the Prattsville gage is a complex watershed with several tributaries and variable topography. It was hoped that a simple hydrologic model of the watershed would be adequate, but the observed and simulated flows differed significantly. These differences were attributed in part to oversimplification of independent variables in the model.

Another major contributor to failure of the rainfall-runoff models was inaccuracy of the initial loss-rate parameters. A lumped-sum approach for representing soil and vegetation conditions, which resulted in inaccurate antecedent conditions, hindered model development by inaccurately predicting initial flows at all three gaged sites. Erroneous initial flows often prevented the model from recovering to within acceptable limits during verification tests.

Because the verification results for the rainfall-runoff model were unsatisfactory, no additional efforts toward model development, including the study of historic floods during winter, were pursued. The flow-routing model, seemed promising, however, if it could be redeveloped with a smaller time interval during routing because the basin-response time seemed to be of the same magnitude as the 1-hour time interval. The hydrographs computed by the flow-routing model for Gilboa and, more important, the inlet to the Blenheim-Gilboa Reservoir, exhibited the correct shape and timing in relation to the observed hydrographs. It was also concluded that alternative methods of obtaining hydrologic data for model input should be developed to improve the model's reliability in the event that certain hydrologic records are missing.

Initial efforts in developing a flow-routing model for the upper basin used a 1-hour time interval for the input of all hydrograph data and also a 1-hour time interval for routing for both the modified Puls and Muskingham routing techniques. Results indicated that, given accurate input hydrograph data, the basin-response time of 1 to 2 hours could be modeled for flows routed from the Prattsville stream gage to the inlet of the Blenheim-Gilboa Reservoir.

DESCRIPTION OF THE FLOW-ROUTING MODEL

The Schoharie Creek basin upstream from the Gilboa stream gage was divided into four drainage basins from which either observed or calculated hydrographs could be used as input in the flow-routing model. Figure 2 is a schematic diagram of the flow-routing model. The initial procedure combines the observed hydrograph from the Schoharie Creek at Prattsville with the calculated hydrographs from the drainage basins of the Bear Kill, Manor Kill, and the remaining 17.7-mi^2 area upstream from the Gilboa Dam, identified as subbasin 1. These combined flows are used as the inflow hydrograph to the Schoharie Reservoir. If reservoir operations indicate that flows are being diverted through the Shandaken Tunnel, these diversions are subtracted.

The calculated hydrographs used in computing the total inflow to the Schoharie Reservoir were obtained by using the Mine Kill and Platter Kill gages as index stations. These stations were chosen because their hydrologic characteristics are generally similar to those of the ungaged areas. Streamflows from the ungaged basins were estimated in most instances by multiplying the gaged inflow from the index station by the ratio of ungaged to gaged drainage areas, or drainage-area ratio. The index station chosen for the Manor Kill was the Platter Kill, with a drainage-area ratio of 3.11. The index station for the Bear Kill was the Mine Kill, with a drainage-area ratio of 1.58. The remaining area (subbasin 1) also used the Mine Kill as an index station, but a value of 2.18, or twice the drainage-area ratio, was used to compute the estimated streamflow. This greater value was chosen because the infiltration losses of precipitation from the Schoharie Reservoir are minimal.

Once all hydrographs for basins upstream from the Gilboa stream gage have been combined, the streamflows are routed through the Schoharie Reservoir to the Gilboa stream gage by the modified Puls routing technique. This method gives satisfactory results for reservoirs because the variable slope occurring during the passage of a floodwave can be neglected. A constant storage-outflow relationship at the reservoir's outflow is also assumed (Chow, 1964).

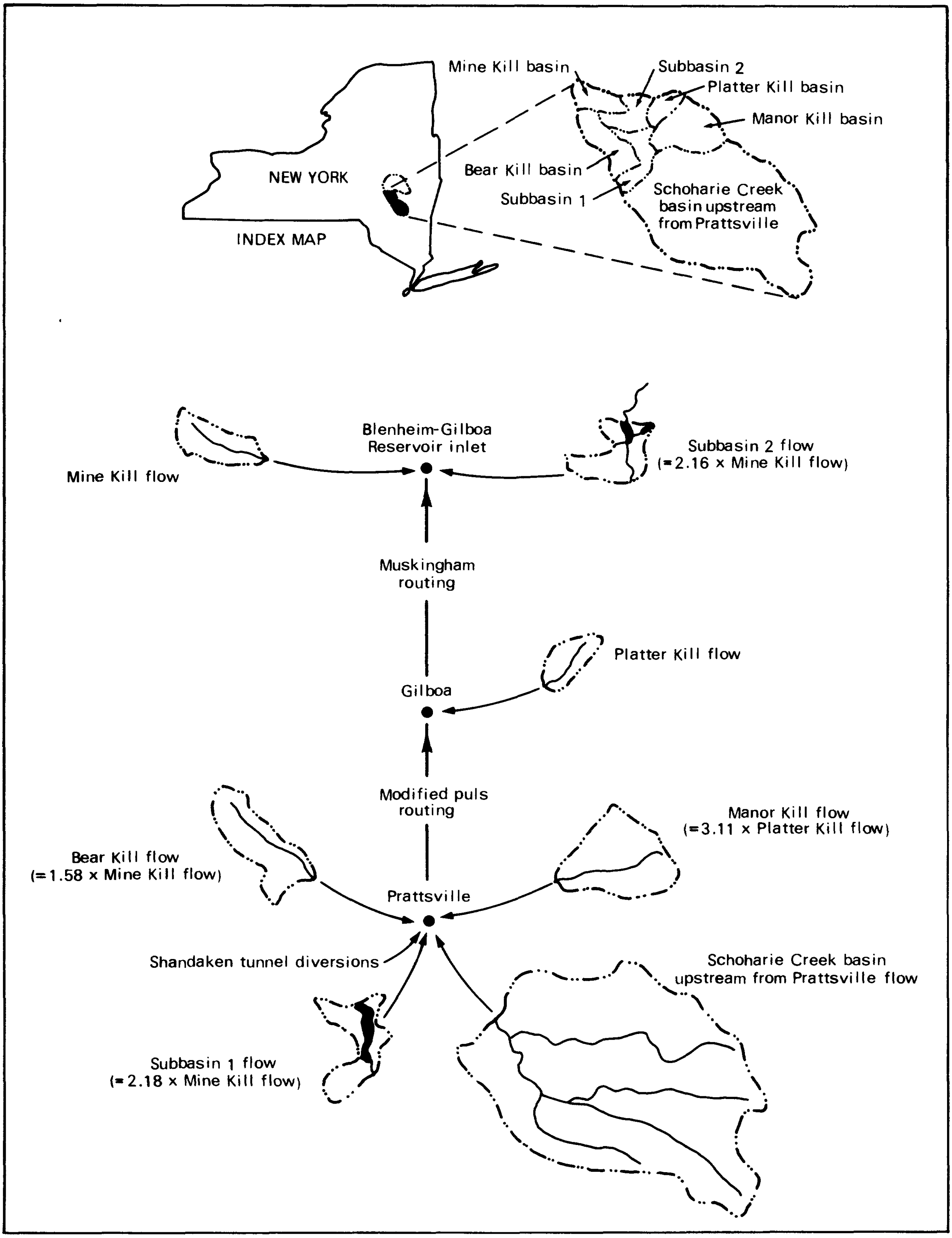

Figure 2.--Schematic diagram of flow-routing model of upper Schoharie Creek basin.

The modified Puls routing technique, expressed in finite-difference form, is:

$$S_{t+\Delta t} + \tfrac{1}{2}\,(O_{t+\Delta t})(\Delta t) = \tfrac{1}{2}\,(I_t + I_{t+\Delta t})(\Delta t) + (S_t) - \tfrac{1}{2}\,(O_t)(\Delta t) \qquad (1)$$

where: S, O, and I = instantaneous values of storage, outflow, and inflow,

t = time, and

Δt = time interval.

The storage-outflow relationship is used to determine the outflows at the start and end of the time interval--O_t and $O_{t+\Delta t}$, respectively.

The total inflow to the Schoharie Reservoir is approximated in the flow-routing model by combining all flows from the basins above the Gilboa stream gage at one location. This presents no serious modeling limitations for Bear Kill and Schoharie Creek at Prattsville because they are close to each other at the upper end of the reservoir, but combining the Manor Kill, which enters the reservoir further downstream, and subbasin 1, which includes the drainage area of the reservoir at one location, could cause errors in the simulated reservoir outflows. These errors would probably be minor, however, because flow from the Prattsville gage contributes substantially to the total inflow of the reservoir.

After the inflows are routed through the Schoharie Reservoir, the outflow hydrograph is combined with the observed flow from the Platter Kill basin. The combined hydrographs are then routed by the Muskingham method from the Gilboa gage through Schoharie Creek to the inlet of the Blenheim-Gilboa Reservoir. The Muskingham method, expressed in finite-difference form, is:

$$O_{t+\Delta t} = O_t + C_1\,(I_t - O_t) + C_2\,(I_{t+\Delta t} - I_t) \qquad (2)$$

where: I = combined instantaneous inflow from Platterkill and outflow from Schoharie Reservoir,

O = instantaneous outflow,

$$C_1 = \frac{\Delta t}{K(1-x) + 0.5\,\Delta t} \qquad (3)$$

$$C_2 = \frac{0.5\,\Delta t - Kx}{K(1-x) + 0.5\,\Delta t} \qquad (4)$$

where: x = coefficient, Muskingham's x,

K = coefficient, Muskingham's K.

The coefficients x and K are derived values that describe storage in the channel (Chow, 1964).

Once flows have been routed to the inlet of the Blenheim-Gilboa Reservoir, they are combined with the hydrographs from the Mine Kill and subbasin 2. Subbasin 2, which represents the area between the outlet of the Blenheim-Gilboa Reservoir and the Gilboa stream gage minus the drainage area of the Platter Kill and Mine Kill basins, is 17.6 mi^2. Flows from subbasin 2 are combined at the inlet for ease in modeling. The errors induced by this aproximation are insignificant in relation to the total flow at the inlet. The Mine Kill is used as the index station for subbasin 2, and, as with subbasin 1, a value of 2.16, twice the drainage-area ratio, was used because the runoff per mi^2 is assumed greater than in the surrounding basins.

MODEL CALIBRATION AND VERIFICATION

Nine historic floods from October 1976 through September 1980 that were unaffected by winter conditions were available for analysis. Five of these were chosen for model calibration; the remaining four were used for model verification.

The upper Schoharie Creek basin was separated into two areas to develop and calibrate two different routing models from the HEC-1 flood hydrograph package. The modified Puls method was used for the area upstream from the Gilboa stream gage, and the Muskingham method was used for the area downstream. Flow at the Gilboa stream gage was used extensively during calibration because observed hydrographs were required for the end of the modified Puls routing and for the beginning of the Muskingham routing. In both areas several arrangements for combining or calculating observed tributary flow were tried with a 15-minute time interval.

Calibrating the flow-routing model for the upstream area required verification of the storage-outflow relationship at the Gilboa Dam. This relationship is critical in determining outflows by the modified Puls routing technique. The storage-outflow relationship was developed from measured discharges at the Gilboa stream gage, and these discharges were compared with Schoharie Reservoir elevations during the period in which the measurements were made. The outflows were then correlated with storage from known storage-elevation relationships.

The optimization routine in the HEC-1 flood hydrograph package was used to obtain values for Muskingham's x and K coefficients for the reach downstream from the Gilboa gage. Once the coefficients were optimized for each flood, average values of 0.90 for x and 0.10 for K, respectively, were chosen for the final model. The model's sensitivity to different values of x and K was tested by applying the optimized values for a given flood to all other floods. The greatest change in total volume error was 1.5 percent, which was considered insignificant. The total volume error is found as follows:

$$\text{Total volume error (in percent)} = \frac{V_{sim} - V_{obs}}{V_{obs}} \times 100 \qquad (5)$$

where: V_{sim} = simulated flow volume, and

V_{obs} = observed flow volume.

Two different techniques for combining hydrographs were tried for the basin below the Gilboa gage. During the preliminary analysis discussed earlier, when the flow-routing model was orginally developed from hourly data, flows from the Mine Kill, Platter Kill, and subbasin 2 were combined with the outflow from the Schoharie Reservoir, then routed to the Blenheim-Gilboa Reservoir inlet. When the final flow-routing model, which uses a 15-minute time interval, was developed, only Platter Kill was combined with the outflow, and the remaining hydrographs were combined at the inlet to more closely depict the basin's hydrologic arrangement. The differences between the two methods seemed small, but comparisons were difficult to assess because the two time intervals differed.

After both model reaches were calibrated, the combined model was run, and flows at the inlet to the Blenheim-Gilboa Reservoir during four historic floods were simulated. The objective of the verification was to determine how well the model simulated inflows to the inlet using observed flows as data input for the duration of each flood. The use of observed flows would, of course, theoretically yield negligible total volume errors at the inlet if the basin were modeled correctly during calibration. Errors would result only from incorrect hydrologic approximations and finite differencing.

Before the flow-routing model could be verified, adjustments to certain model components were required for three of the floods. The flood record of October 17-18, 1977 lacked observed flows from the Mine Kill. To compensate, the Platter Kill was used as an index station for the Mine Kill and other basins that relied on it as an index station. The floods of March 21-22 and April 9-10, 1980 lacked observed flows at the Gilboa stream gage. To compensate, elevations from the Schoharie Reservoir gage were used to find the storage, and outflows were determined from the storage-outflow relationship. Unlike calibration tests, observed flows at the Gilboa gage were used during verification, both as a check on the initial values of storage and for comparison with simulated flows after routing through the reservoir. These and other methods of computing missing data are discussed later in the section "Compensating for Missing Hydrologic Data."

The accuracy of the model, measured as the total volume error at the Gilboa stream gage and inlet to the Blenheim-Gilboa Reservoir, was within 26 and 14 percent, respectively. The total volume errors are summarized in table 2. The timing and magnitude of the simulated versus observed peaks at

Table 2.--Total volume errors in model verification.

	Total volume error (in percent)	
Flood	Gilboa stream gage	Blenheim-Gilboa Reservoir inlet
Oct. 17-18, 1977	+3.9	-1.9
May 16-17, 1978	-4.2	-14.0
Mar. 21-22, 1980	-2.8	-1.7
Apr. 9-10, 1980	-26.8	-9.1

the inlet to the Blenheim-Gilboa Reservoir, judged qualitatively, seem acceptable. Observed hydrographs of significant magnitude, and the hydrographs for the inlet to the Blenheim-Gilboa Reservoir, are presented in figures 3A-3D. Each dot on the simulated curve represents a flow calculated for a 15-minute time interval.

Although the results match closely in general, certain errors require explanation. An unusually large total volume error of -26.8 percent at the Gilboa stream gage for the April 9-10, 1980, flood is evident in figure 3C. The error is attributed to questionable reservoir elevations used to compute the outflow of the Schoharie Reservoir. Also, the total volume error of -14.0 at the inlet to the Blenheim-Gilboa Reservoir for the May 16-17, 1978, flood (fig. 3B) is high. Several unnatural perturbations on the observed-flow hydrograph are the probable cause of some of this error.

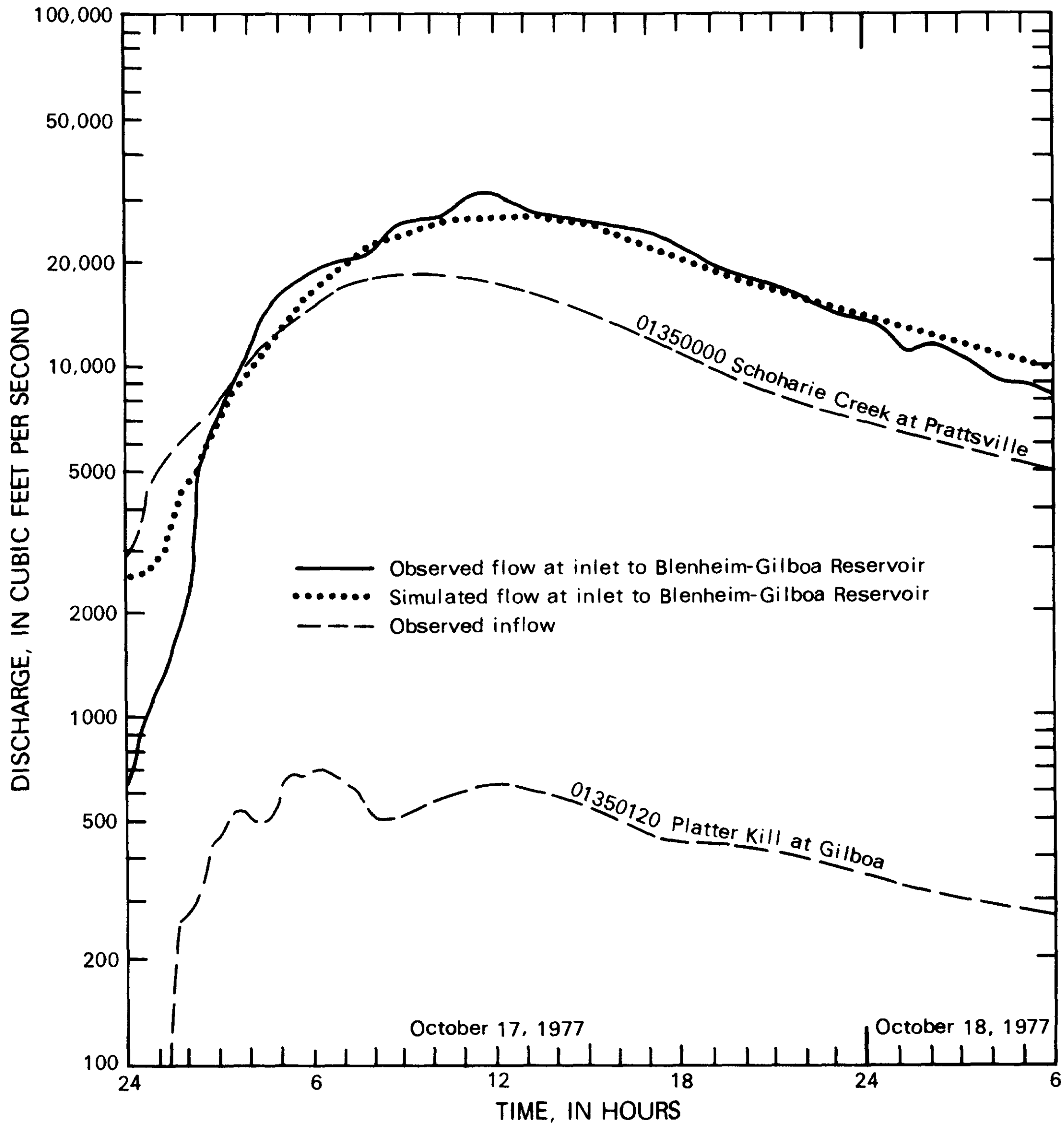

Figure 3A.--Model-verification results for flood of October 17-18, 1977.

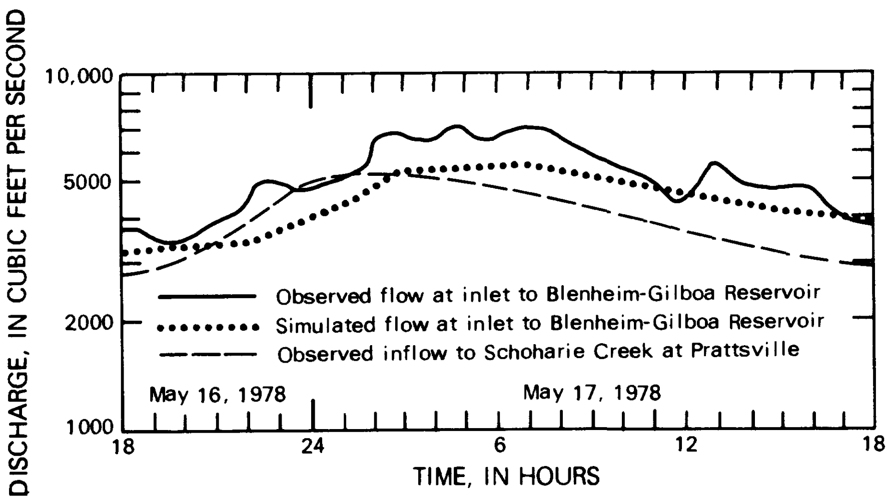

Figure 3B.--Model-verification results for flood of May 16-17, 1978.

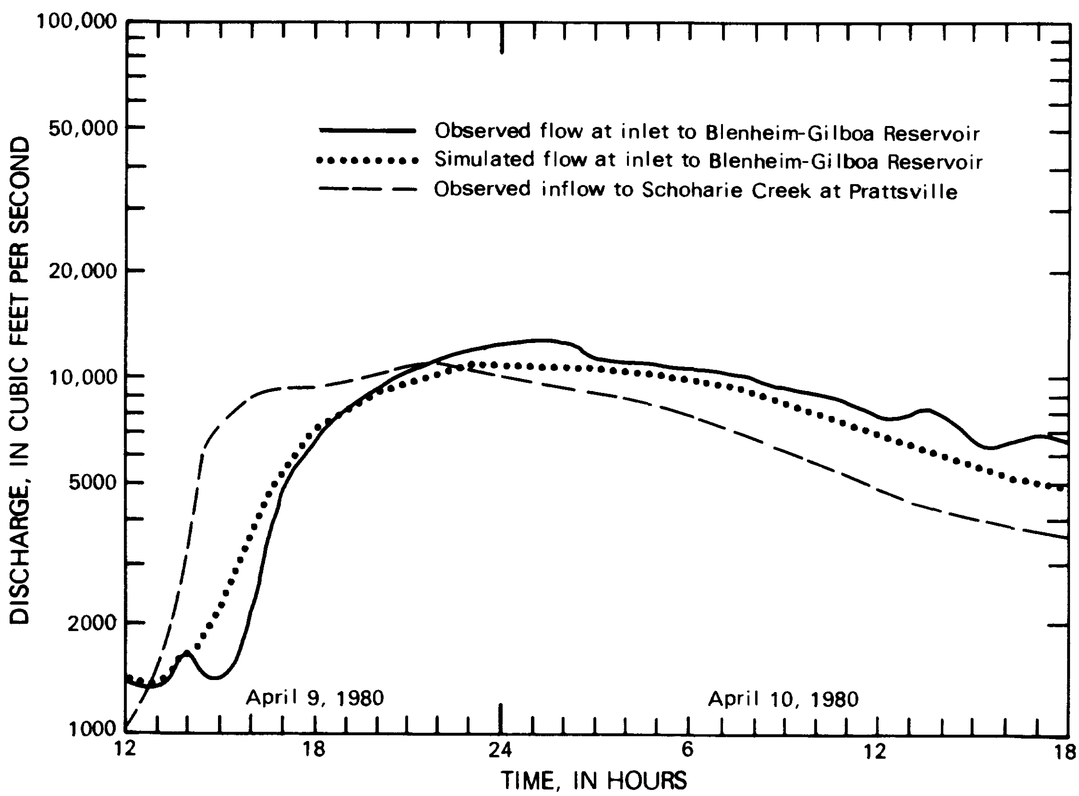

Figure 3C.--Model-verification results for flood of April 9-10, 1980.

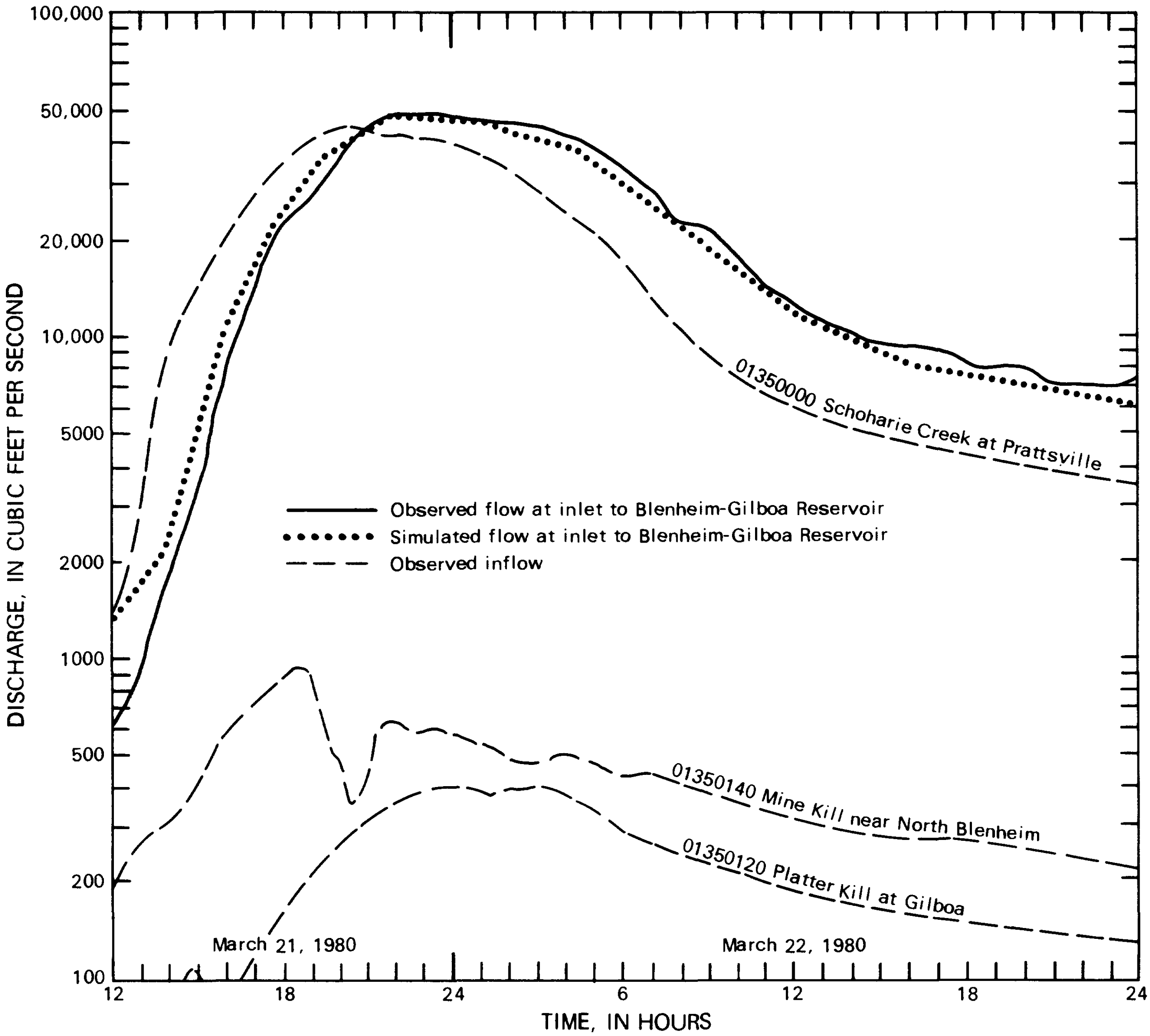

Figure 3D.--Model-verification results for flood of March 21-22, 1980.

Inherent in the HEC-1 flood hydrograph package are errors in the assumptions made at the beginning of both routing techniques. The actual total inflow to the Schoharie Reservoir at the model initialization time, I_{t_o}, is not required when the HEC-1 version of the modified Puls method is used. Instead, I_{t_o} is set equal to $I_{t_o+\Delta t}$, the inflow at the end of the initial time step. In the Muskingham method, neither I_{t_o} or O_{t_o} are used to determine $O_{t_o+\Delta t}$ for the reach between the Gilboa stream gage and the Blenheim-Gilboa Reservoir. In this situation, $O_{t_o+\Delta t}$ is set equal to $I_{t_o+\Delta t}$ for the initial time step only. Under unchanging conditions, the resultant errors from approximations used in both routing methods will be small, but can be expected under rapidly varying conditions. The simulated hydrographs during the initial and the immediately succeeding time steps in figures 3A, 3B, and 3D show errors resulting from these assumptions.

HYPOTHETICAL REAL-TIME MODEL APPLICATION

The historic flood of March 21-22, 1980 was chosen for demonstration of a hypothetical real-time application of the flow-routing model. This additional model testing in a real-time situation helped to reverify the approximate 2-hour basin-response time and the accuracy of flows at the Blenheim-Gilboa inlet as determined from previous model verifications and also served to test a procedure for computing flows at the inlet in real time.

Real-time model applications, unlike model verifications described in the preceding chapter, use estimated input data and require frequent model initializations. Observed input data are available only at the model initialization time in a real-time application, whereas estimated input data (except diversions) must be used to drive the model for the remainder of the simulation period. Simulated flows from a real-time application will equal simulated flows from a verification if estimated input data of the real-time application equal the observed input data of the verification. Frequent model initialization is also necessary in real-time model applications because the estimated input data begin to strongly influence the simulated flows if the simulation period is greater than the basin-response time. Real-time results should approximate verification results if the time between model initializations is equal to or less than the basin-response time.

Observed input data at the initialization times and estimated input data for the remainder of each simulation period were used to initialize the flow-routing model once every 3 hours for March 21, 1980, beginning at 1200 hours. A 15-minute time step was used.

A simple procedure was used for developing estimated input flows that would ensure reasonable results for at least the first time step. Estimated input flows for each simulation period used constant flows obtained by adding the change in observed flow before the initialization time to the observed flow at initialization time.

Before simulations could be run, the previously discussed assumptions used in the HEC-1 program during the initial time step for both routing techniques needed to be changed. All data necessary to compute the correct inflows and outflows for both methods at the end of the first time step were used to solve equations 1 and 2 directly. Unlike the flows used in calibration and verification, the actual values of inflow and outflow are required for real-time applications for both routing techniques at the initialization time. The flow at the Gilboa stream gage, which served only as a check during verification, must be included in real-time applications.

Results of the simulated flows generated by the hypothetical real-time model application are presented in figure 4, and the hourly volume errors at the inlet of the Blenheim-Gilboa Reservoir are summarized in table 3. Total volume errors ranged from 30.2 percent to -9.2 percent. The basin response is evident on the rising limb of the flood hydrograph where the estimated flows do not match the observed flows (fig. 4). The simulated flows begin to differ appreciably from the observed flows after approximately 2 hours. Simulation periods 4 through 6 indicate that flows can be predicted for a longer time when the estimated flows closely approximate the observed flows. Another feature of each simulation period is the convergence of the simulated hydrograph at specific flow values. This results from the almost constant value of the estimated flows supplied as input data. The flows generated during simulation periods 1 through 3 are show only slight departures from the observed values. As in the verification results, these discrepancies can be attributed partly to inaccuracy of data used in the calculations of the observed flows. It should also be noted that the observed hydrograph, although shown as continuous in figure 4, is based on hourly data. Thus it is possible that interpolated values in the observed hydrograph will not match the simulated hydrograph values.

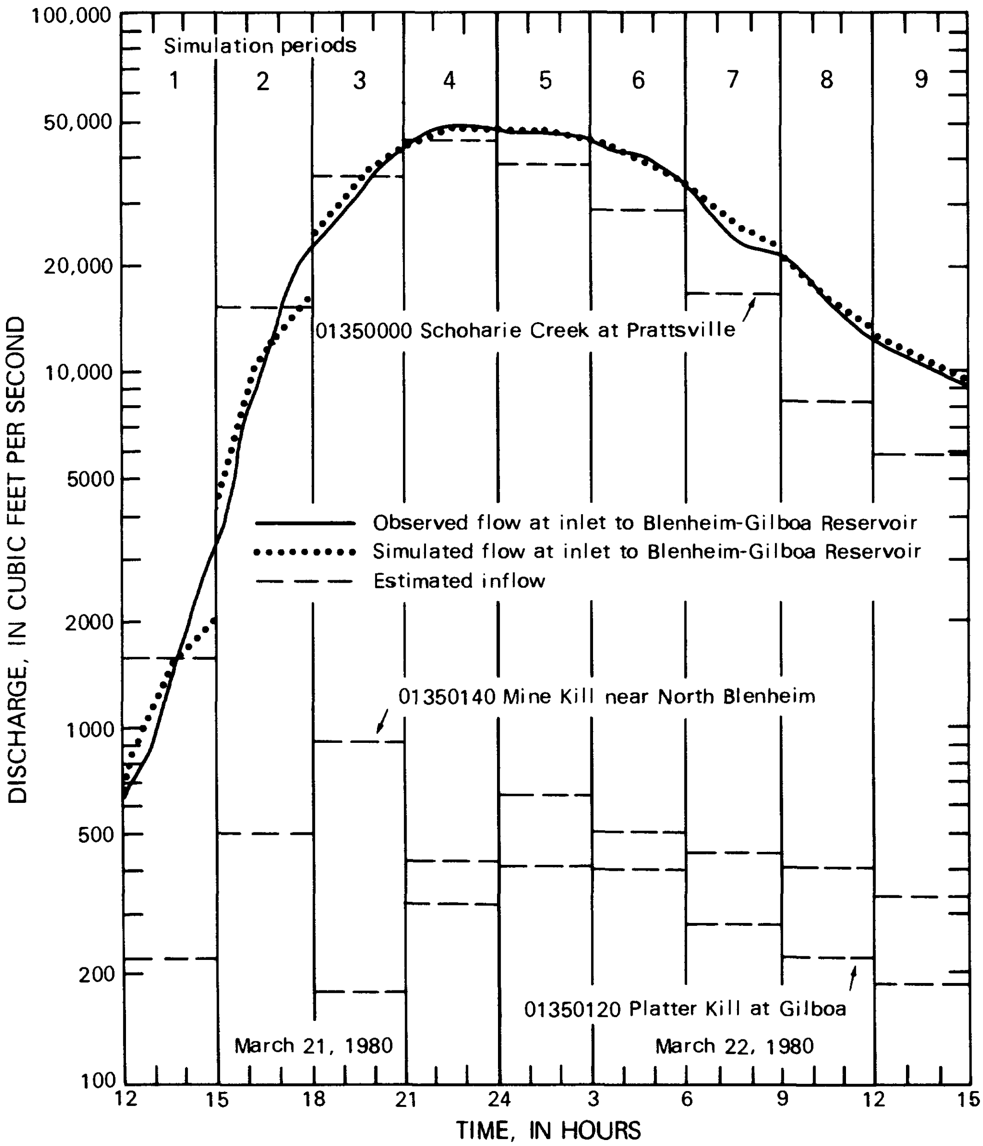

Figure 4.--Hypothetical real-time simulated flows generated from the flow-routing model reinitiated once every 3 hours for March 21-22, 1980.

The model was reinitiated every 3 hours through the duration of the flood simulation. In practice, however, it would be advisable to reinitiate the model at least every 2 hours (the basin-response time), especially during intervals of rapid change.

Table 3.--Total volume errors at inlet of Blenheim-Gilboa Reservoir for hypothetical real-time simulated flows generated from the flow-routing model reinitiated once every 3 hours for flood of March 21-22, 1980.

Simulation period	Total volume error (in percent) 1st hour	(time)	2d hour	(time)	3d hour	(time)
1	30.2	(1300)	11.7	(1400)	-9.2	(1500)
2	26.0	(1600)	13.7	(1700)	-3.2	(1800)
3	13.1	(1900)	10.8	(2000)	5.5	(2100)
4	-2.1	(2200)	-2.6	(2300)	-1.8	(0000)
5	0.8	(0100)	-0.4	(0200)	-0.9	(0300)
6	-1.1	(0400)	-3.0	(0500)	-2.1	(0600)
7	0.3	(0700)	3.9	(0800)	4.9	(0900)
8	-1.6	(1000)	-0.2	(1100)	2.3	(1200)
9	-0.2	(1300)	-0.2	(1400)	1.1	(1500)

COMPENSATING FOR MISSING HYDROLOGIC DATA

The versatility of the flow-routing model can be greatly enhanced through the use of alternative data sources to replace hydrologic data that are missing as a result of power failure, equipment malfunction, the loss of telephone communications, etc. Alternative methods also serve as a check on questionable data. The many types of hydrologic data available, and the different methods of computation, allow several means of computing and routing missing flows. The following paragraphs describe how hydrologic data missing from seven different model components can be computed by indirect methods.

Flow of Schoharie Creek at Prattsville.--Flows at the Prattsville gage are not essential to the flow-routing model but can be found by adding the diversions and subtracting the flows of the Bear Kill, Manor Kill, and subbasin 1 from the calculated Schoharie Reservoir inflow. Calculating flow at the Prattsville stream gage serves only as a check on the validity of the data when indirect methods have been used to determine the total inflow to Schoharie Reservoir.

Inflow to Schoharie Reservoir.--Missing inflows to the Schoharie Reservoir can be calculated by reverse routing the observed outflows of the reservoir by equation 1. Equation 1, rearranged to calculate the average inflow for the time interval, is

$$\frac{I_{t_o-\Delta t} + I_{t_o}}{2} = \frac{S_{t_o-\Delta t} - S_{t_o}}{\Delta t} + \frac{O_{t_o-\Delta t} + O_{t_o}}{2} \tag{5}$$

where: t_o = model initialization time.

The values of storage and outflow are computed from either the Schoharie Reservoir elevations or the flows at the Gilboa stream gage when the reservoir is spilling. When the reservoir is not spilling, the outflows are zero, and storage can be computed only from the reservoir elevations. The average inflows for the two time periods preceding the model-initialization time are computed in the same manner and used to make a linear approximation of the inflow, I_{t_o}. Through the reverse routing technique described above, flows at the inlet to the Blenheim-Gilboa Reservoir can still be predicted approximately 2 hours in advance of their arrival.

Diversions from Schoharie Reservoir.--Diversions during a given time interval can be calculated by indirect methods, although this is not recommended because they can be severely altered during the simulation period. The diversions, can, however, be omitted during significant floods, when their overall effect is minimal. In such instances, the accuracy of the computed outflows will decrease as the inflows decrease.

Schoharie Reservoir storage.--The reservoir elevation can be used to compute both the outflow when the reservoir is spilling and the storage. If the elevations are unavailable, the storage can be found from flows at the Gilboa gage by the storage-outflow relationship. This procedure was applied in the model verification of the March 21-22, 1980 and April 9-10, 1980 floods. The procedure can be applied only when the reservoir is spilling; otherwise the storage cannot be directly determined unless the elevations are known.

Flow of Schoharie Creek at Gilboa.--Flow at the Gilboa stream gage can be calculated by two methods. The first uses the elevation of the Schoharie Reservoir. When the elevation is below the crest of the spillway, flow is zero; conversely, when the reservoir is spilling, the storage for a given elevation is used to determine the flow from the storage-outflow relationship.

The second method is to reverse-route flows from the inlet at the Blenheim-Gilboa Reservoir. The flows from the Mine Kill and subbasin 1 are subtracted from the observed flows at the inlet and applied to the outflows of a rearranged form of the Muskingham equation. The equation, which uses a 15-minute time step and the derived values for Muskingham's x and k, is

$$6.143\ I_{t_o-\Delta t} + I_{t_o} = 26.717\ O_{t_o} - 19.573\ O_{t_o-\Delta t} \tag{6}$$

where: I = combined flows from the Platter Kill and Gilboa gages,

O = observed flow at the inlet minus the flows from the Mine Kill stream gage and subbasin 2.

I_{t_o} is determined by first assuming that I_{t_o} equals $I_{t_o-\Delta t}$ and solving for $I_{t_o-\Delta t}$. This value is then substituted into equation 6, adjusted for the previous time period, for which an almost exact solution to $I_{t_o-2\Delta t}$ can be found. The difference between the calculated inflows at the beginning of each time period is then added to $I_{t_o-\Delta t}$ to yield an approximate value for I_{t_o}. The flow at Gilboa is finally obtained by subtracting the Platter Kill flow from I_{t_o}.

Flow of Platter Kill at Gilboa.--Flow data from the Platter Kill gage are estimated by index ratios of 0.68 or 0.05 from either the Mine Kill or Prattsville index gaging stations, respectively. The Mine Kill flows are preferable because this basin is close to the Platter Kill basin and similar in size. The Prattsville gage is a second choice because as an index station the timing of the peaks can differ substantially from those of the Mine Kill and Platter Kill, and a greater runoff per mi^2 is often observed.

Flow of Mine Kill near North Blenheim.--Like the Platter Kill gage, the Prattsville gage can be used as an index station with an index ratio of 0.07, although it, too, is a second alternative. The index ratio of 1.47 determined from the Platter Kill index station is the primary choice for estimating missing flow at the Mine Kill. This procedure was used in the model verification of the flood of October 17-18, 1977.

The procedures described above were developed primarily to predict flows in real-time model applications only at the model-initialization time, although for certain methods the missing flows are easily calculated for the entire period during model verification. Many of the proposed methods can also be used concurrently. For instance, both methods of determining missing flows at the Prattsville and Platter Kill stream gages can be applied simultaneously. However, a decrease in the overall accuracy of the predicted flows at the inlet to the Blenheim-Gilboa Reservoir may be expected.

SUMMARY

A streamflow-routing model of the upper Schoharie Creek has been developed to predict high flows at the inlet of the Blenheim-Gilboa Reservoir. The ability to forecast the reservoir's inflow is important to PASNY in management of the pumped-storage facility during periods of high flow. Flows from the primary source of flow data in the basin, the hydrograph of the Schoharie Creek at Prattsville, are routed through the Schoharie Reservoir by the modified Puls method. The outflow is then routed through the remaining channel by the Muskingham method to the inlet of the Blenheim-Gilboa Reservoir. Tributary flow from the six small basins between the two sites are combined at appropriate locations.

The overall accuracy of the model, measured as the difference between simulated and observed total flow volume, was within 14 percent, and the timing and magnitude of the peaks appeared acceptable. Discrepancies may be attributed to inaccuracies in the observed data and the HEC-1 assumptions used during the initial periods in both routing techniques.

A hypothetical real-time application of the model was demonstrated in which observed flows at the model-initialization times and estimated flows for the remainder of the simulation periods were used as data input for the March 21-22, 1980 flood. Total flow volume errors ranged from 30.2 percent to -9.2 percent.

The flow-routing model is operable even if certain required hydrologic data are unavailable. Although other methods of deriving several types of hydrologic data are available, a decrease in the overall model accuracy might be expected when more than one alternative method is used for a given flood.

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