A FLOOD MODEL FOR THE TUG FORK BASIN, KENTUCKY, VIRGINIA, AND WEST VIRGINIA

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METRIC CONVERSIONS

Inch-pound units in this report may be converted to International System of Units (SI) of measurements by the following conversion factors:

Multiply Inch-pound units	By	To obtain SI units
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.6093	kilometer (km)
acre	0.4047	hectare (ha)
square foot (ft^2)	0.0929	square meter (m^2)
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)
ton, short	0.9072	megagram (Mg) or metric ton (t)
degree Fahrenheit (°F)	°C = 5/9 (°F-32)	degree Celsius (°C)
langleys per day	41840	joules per square meter per day

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ABSTRACT

Surface mining of coal in the United States increased from 406 million tons to almost 800 millions tons from 1978 to 1979. In the coal-rich 1,560-square-mile Tug Fork basin located in Kentucky, Virginia, and West Virginia, there has been a 2,500 percent increase since 1950 in areas affected by surface-mining activities.

This study used a rainfall-runoff model to determine if land-use changes associated with surface mining in the Tug Fork basin have affected basin streamflow characteristics. The model was calibrated and verified for two periods, one representing 1980 land-use and one representing 1950 land-use. Two 29-year synthetic daily streamflow time series representing the two land-use conditions were generated. Statistical tests performed on the two time series at 15 points in the basin showed no difference at the 0.01 percent confidence level at any of the locations.

In addition, analyses were made to determine if future increases in surface-mining activities might affect basin streamflow. One analysis showed that increasing mining in an upland watershed by as much as 200 percent had little effect on streamflow in the intermediate area and no effect on streamflow at downstream locations along the Tug Fork. Even for a scenario where all areas disturbed by mining were assumed totally impervious, the modeling process demonstrated that the increase in mean-annual 1-day high flows (for recurrence intervals of 2, 5, 10, 25, 50, 100, and 200 years) was less than 4 percent at the basin outlet.

INTRODUCTION

The Tug Fork basin, a 1,560-square-mile mountainous area of Kentucky, Virginia, and West Virginia (fig. 1), is underlain by extensive coal deposits comprising a significant part of the nation's coal reserves. The low-sulfur characteristics of the coal deposits in the basin make it an important product that is used in the iron and steel industries in the United States and in European markets. The coal-mining industry provides the main livelihood of those living in the area. Mining is prevalent throughout the basin.

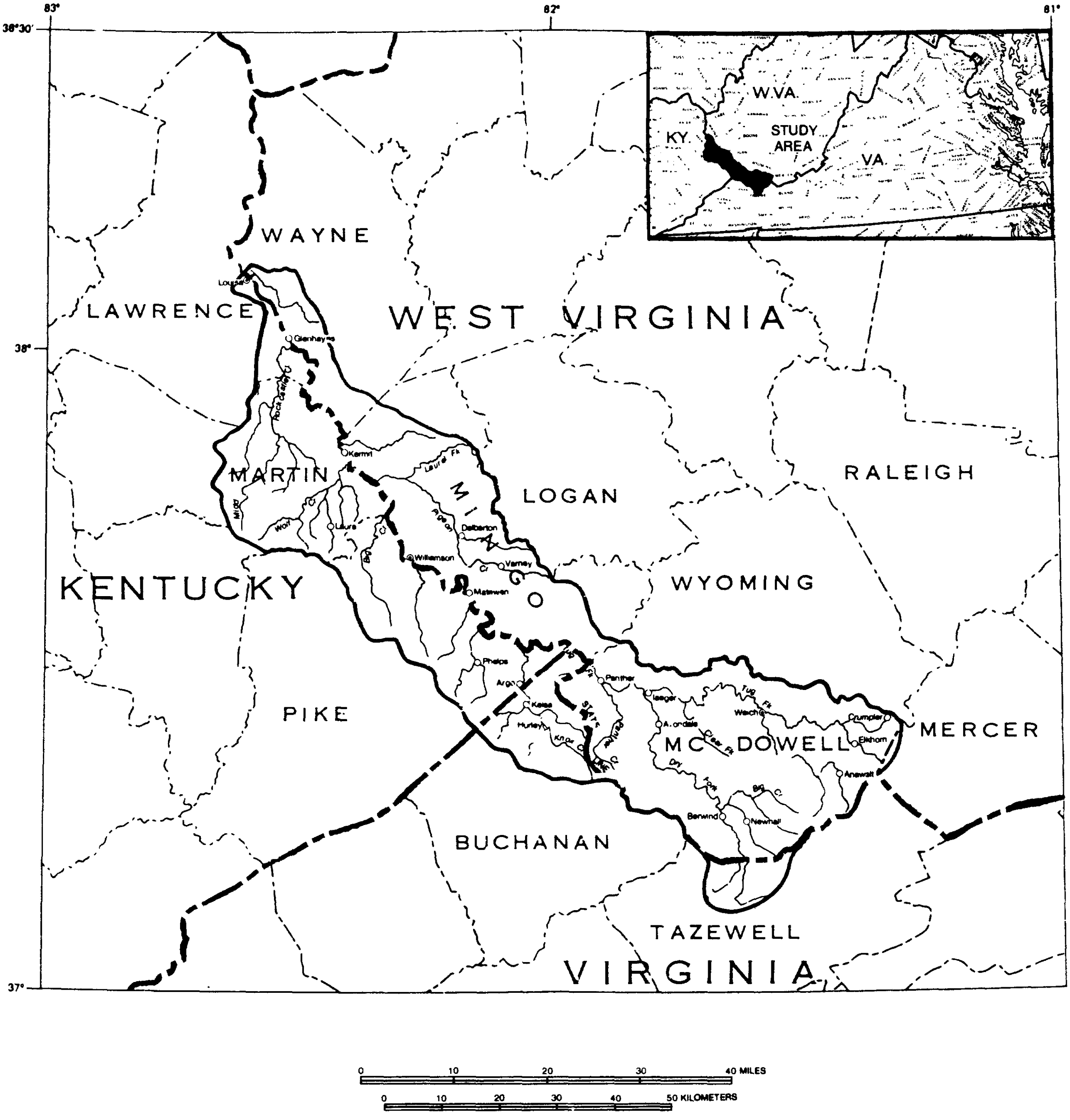

Figure 1.--Location of the Tug Fork basin.

There is much concern that surface-mining activities may have affected the characteristics and patterns of storm runoff in the basin since 1950. Periodic flooding on many watersheds in the region such as the major flood in April 1977 (Runner, 1979; Runner and Chin, 1980) is speculated to be the result of surface-mining operations in the area. With 166 billion tons of coal in reserve, there is certain to be land-use changes in the future that may affect flooding in the basin. A calibrated and verified precipitation-runoff model that can simulate streamflow for different conditions is needed to analyze the effects of past, present and future land-use scenarios.

The U.S. Geological Survey, in cooperation with the U.S. Bureau of Mines and the Office of Surface Mining Reclamation and Enforcement, began a study in early 1980 in the Tug Fork basin (Scott, 1980). The objectives of the study were (1) to identify relative effects of the various land-use changes on flood characteristics, (2) to assess the effectiveness of present mine-reclamation practices for controlling undesirable aspects of storm runoff, and (3) to observe and analyze cumulative impacts of typical land-use changes on sediment and flood characteristics at downstream points in the Tug Fork basin.

The approach outlined in the study plan for achieving the first objective consisted of statistical analyses on existing data and a precipitation-runoff modeling effort that would continuously simulate streamflow for both the entire basin and on each of 10 small watershed sites implemented for the study. The model for the entire basin also could be used to analyze cumulative impacts of typical land-use changes.

The results of statistical analyses (Hirsch and others, 1982), based on selected long-term discharge records alone, indicated that annual flood peak characteristics in the Tug Fork basin exhibit an increasing trend. However, the report stated that this trend even persisted in undisturbed and relatively unmined parts of the basin. One conclusion was that there is no direct evidence that the increase in annual flood peaks is related to surface mining or that the increase was too small to detect with the existing data and trend analysis techniques. Although these statistical analyses showed that flood peaks in the basin have slightly increased, they could not conclusively identify the causative factors that affected these changes. The changes could have been the result of climate, channel modifications, surface mining, other environmental factors or a combination of these factors.

A later report (Scott and Hirsch, 1982) summarized results of a statistical analysis made of historical partial-duration peak-flow data and sequential land-use data from 1950 through 1980 for the Tug Fork basin. This subsequent analysis indicated an increasing trend in the magnitude of smaller flood peaks at a stream gaging site in the upper part of the Tug Fork basin at the same time that land disturbance related to surface mining also increased. As before, no increase in the magnitude of larger floods was evident. For a gage in the lower part of the Tug Fork basin no statistically significant (at a 10 percent level of confidence) evidence of change was found. The difference in results for the two gages may reflect the greater concentration of land disturbance near the upstream Tug Fork gage and the location of the surface mining within the Tug Fork basin.

Objectives of Study

The next approach to detect the impact of surface-mining activities on the flooding in the Tug Fork basin is to use a precipitation-runoff model. This technique eliminates climatic changes as a cause for increased flooding. If climate is not the cause and channel modifications have been shown not to occur (Hirsch and others, 1982), one concludes that surface-mining activities must be the cause as no other major changes can be identified. The precipitation-runoff modeling effort encompassed the following tasks:

1. Calibrate and verify a mathematical watershed model for the Tug Fork basin with streamflow records for both 1950 and 1980 land-use conditions.

2. Use long-term (1951-1980) rainfall data with each modeled condition to provide two simulated streamflow records at 15 principal points of interest in the basin.

3. Statistically analyze the simulated streamflow records produced for 1950 and 1980 land-use conditions to detect any change.

4. Compare simulated streamflow difference resulting from land-use changes with possible discrepancies in the modeling process that may be overshadowing any computed differences.

5. Apply the model with a range of assumptions and future hypothetical land-use changes to illustrate possible hydrologic consequences.

Acknowledgements

A major part of the study involved compiling and analyzing historic data. The authors are indebted to those who supplied the required information. In particular, we acknowledge the assistance of Survey personnel in Kentucky, Virginia, and West Virginia who provided streamflow data; Ken Harmon, Chief, Hydraulics and Hydrology Branch, and Kenneth Halstead, Hydraulic Design Section, Huntington District, U.S. Army Corps of Engineers, Huntington, W. Va., for river cross-sectional and hydraulic data; Soil Conservation Service Soil Scientists in the above three states for soils data; and the National Weather Service Center in Asheville, N.C., for climatological data.

BASIN CHARACTERISTICS

The Tug Fork basin (fig.1) has a drainage area of nearly 1,560 mi^2 and extends from the headwaters near the Virginia-West Virginia state line, northwest until its waters join the Levisa Fork at Louisa, Ky. The basin is characterized by narrow river valleys bordered by steeply rising mountains. The major river in the basin is the Tug Fork which winds through the basin for about 150 mi. For much of this length, the Tug Fork serves as the political boundary between Kentucky and West Virginia. Scott (1980) characterized in detail basin physiography, topography, and geology.

Climate in the area is characterized by moderately severe winters with frequent alternations of fair and stormy weather and hot, showery summers. Temperatures range from a mean minimum of 28°F in January to a mean maximum of 88°F in July. Mean annual precipitation is about 44 inches which includes snowfall in the colder months. Intense rainfall occurs periodically and is a common source of flooding. Runoff in the basin is generally highest during February and March and lowest during September and October. The maximum observed discharge in the basin was 104,000 ft^3/s which occurred on the Tug Fork River at Kermit, W. Va., during April 1977.

MODELING APPROACH

The Precipitation-Runoff Modeling System (PRMS) (G. H., Leavesley, written commun., 1982) developed by the Geological Survey was chosen to be applied to the Tug Fork basin. The liabilities of inadequate rainfall data and the large size of watershed segments for hydrologic-processes definition were recognized as possible limitations of a fully successful watershed modeling application. The modeling approach, however, was assumed valid based on earlier studies in the basin (Lumb, 1982). PRMS was developed to evaluate the impacts of various combinations of precipitation, climate, and land-use on surface-water runoff, sediment yields, and general basin hydrology. The modeling system has the capability of computing soil-moisture deficits based upon inputs to and losses from the watershed. Rainfall and snowmelt not added to surface or soil moisture storages can be routed overland and through comprehensive channel networks.

Although PRMS can simulate streamflow in the daily mode or shorter time interval (5-minute, 15-minute, 1-hour, and so forth) unit mode, it was decided that only the daily mode would be used and the mean daily streamflow analyzed instead of instantaneous streamflow. Also, the size of the basin would make it very difficult to represent surface-mined disturbed areas as overland flow planes as required in the unit mode.

Fifteen points (table 1) were selected in the Tug Fork basin at which streamflow data were desired. The basin was subdivided into individual watersheds with the 15 points of interest each being an outlet of a subwatershed. Eleven of the 15 points have observed streamflow data while four are ungaged sites. The ungaged sites along the Tug Fork River are near tributary confluences that represent a significant change in contributing drainage area. The most downstream gaging station considered was Tug Fork at Glenhayes, W. Va., although the study area is shown to extend to Louisa, Ky., (fig. 1) to provide continuity with other reports of the area. Backwater from the Levisa Fork affects flow and invalidates model flow computations downstream from this station.

PRMS was calibrated and verified for two periods during 1950-1980, the earlier pre-mined period in 1950 and the later period in 1980 reflecting the increase in surface-mining activities. The 1980 period was modeled first because streamflow data at 11 gaging stations were available to compare with model-generated streamflow.

The approach involved applying the model to both periods with each of the 15 subwatersheds having disturbed areas designated as mined and reclaimed. These disturbed areas were assigned flatter slopes reflecting the effect of mining. Cover densities, soil covers, precipitation interception storage of vegetation, amount of solar radiation received, and other variables were also varied for the mined and reclaimed areas.

Using this approach, the model was calibrated and verified in the daily mode for both 1980 and 1950 periods. In the 1950 period, mined and reclaimed areas were identified and the model was checked at the three active stream gages. Continuous daily rainfall data from 1951 to 1980 were used with both calibrated models and simulated mean-daily streamflow time series were generated at all 15 points of interest. Annual maximum daily frequency analyses were performed on the 1950 and 1980 simulated streamflow series. Using several nonparametric statistical tests, a determination was made as to whether or not land-use changes have caused statistically significant hydrologic changes in streamflow patterns and characteristics.

Table 1.--Fifteen reference points in Tug Fork basin selected for model output generation

Reference point[1/]	Station identification	Station name or location	Drainage area (mi^2)	Period of record	River mile location along Tug Fork (mi)
A	03212700	Elkhorn Creek at Maitland, W. Va.	73.3	1979-1980	[2/]134.85
B	03212600	Tug Fork at Welch, W. Va.	85.8	1979-1981	135.80
C	---	On Tug Fork below confluence of Elkhorn Creek and Tug Fork downstream from city limits of Welch, W. Va.	162	Ungaged	134.45
D	---	On Tug Fork at Iaeger, W. Va., 1 mi upstream of confluence of Dry Fork and Tug Fork	268	Ungaged	110.70
E	03212985	Dry Fork at Avondale, W. Va.	225	1979-1981	109.70*
F	03213000	Tug Fork at Litwar, W. Va.	505	1930-present	107.00
G	03213500	Panther Creek near Panther, W. Va.	31.0	1946-present	103.10*
H	---	On Tug Fork below confluence of Panther Creek and Tug Fork	562	Ungaged	102.60
I	---	On Tug Fork at Matewan, W. Va., 14.8 mi downstream of confluence of Knox Creek and Tug Fork	874	Ungaged	70.50
I2	03213590	Knox Creek near Kelsa, Va.	84.3	1980-1981	85.30*
J	03213700	Tug Fork at Williamson, W. Va.	936	1967-present	57.40
K	03213800	Pigeon Creek near Lenore, W. Va.	93.9	1979-1981	41.60*
L	03214000	Tug Fork near Kermit, W. Va.	1,188	1934-present	38.40
M	03214700	Rockcastle Creek near Inez, Ky.	63.1	1980-1981	10.20*
N	03214900	Tug Fork at Glenhayes, W. Va.	1,507	1976-present	9.50

[1/]See figure 7 for location of reference point.

[2/]Tributary to Tug Fork River and river mile location refers to point where tributary confluences with Tug Fork.

The investigation also demonstrated that additional consideration should be given to identifying "modeling noise" that might be responsible for producing a detected statistical difference between the 1950 and 1980 simulations. Modeling noise includes input-data errors, streamflow-measurement errors, discrepancies between the model processes and real watershed processes, and errors in parameter calibration. Therefore, a comprehensive analysis was performed on the smallest, least-disturbed watershed, Panther Creek near Panther, W. Va. This 31-square-mile basin has experienced very little surface mining during the last 30 years and any difference in estimating observed discharges can be attributed to "modeling noise."

Additionally, an analysis was made with the calibrated 1980 model for a hypothetical future land-use scenario representing a significant increase in mining activity. This kind of application can show what would happen to the streamflow characteristics if surface mining continues to increase in the basin. Also, a worst-case scenario for the 1980 condition was modeled to determine a maximum-possible alteration to streamflow.

DESCRIPTION OF PRMS

PRMS was developed by the Geological Survey to evaluate the hydrologic impacts of land-use changes. Table 2 lists some of the major hydrologic processes and characteristics of PRMS. Both rainfall and snowmelt events can be simulated on a watershed to evaluate changes in the hydrologic balance due to activities such as surface mining. PRMS will simulate mean daily flows (daily mode) and shorter time interval storm hydrographs (unit mode).

It is a distributed-parameter model with two levels of partitioning available to the user. In the first level, the user subdivides the watershed into hydrologic response units (HRUs) on the basis of characteristics such as land use, vegetation type, soil type, and precipitation distribution. Each resulting HRU is assumed to produce a unique and homogeneous hydrologic response. A water balance and energy balance are computed daily for each HRU. The sum of the responses of all HRUs weighted on a unit-area basis produces the daily system response and streamflow from a basin. PRMS will accommodate a maximum of 50 HRUs.

A second level of partitioning is available for delineating overland flow plane and channel segments for the purpose of routing surface runoff and channel flow in the unit mode. An HRU can be considered the equivalent of a flow plane or it can be subdivided into a number of flow planes. PRMS will handle a combined total of 100 overland flow plane and channel segments.

Table 2.--Major hydrologic processes and characteristics of Precipitation-Runoff Modeling System

HYDROLOGIC PROCESSES	
Interception	Assigned maximum storage, computed as a function of cover density and depth of storage available.
Infiltration	Green-Ampt equation for unit storm computation.
Surface runoff	Contributing area concept for daily computation; kinematic wave hydraulic routing of rainfall excess for unit storm computation.
Evapotranspiration	Actual rate limited by moisture storage; three computational procedures are available to compute potential -- (1) direct use of evaporation pan data, (2) function of daily mean air temperature and possible hours of sunshine, and (3) function of daily mean air temperature and solar radiation.
Soil moisture storage	Two-layer soil-moisture storage; field capacity specified to each layer; water balance between rainfall and snowmelt infiltration, evapotranspiration, and recharge to subsurface and ground-water storage reservoirs.
Percolation	Takes place in excess of soil-moisture field capacity and user-specified recharge rate.
Subsurface flow	Nonlinear function of available storage volume and user-specified routing coefficients.
Ground-water flow	Linear function of available storage volume and user-specified routing coefficients.
Channel flow routing	Solution of continuity equation and Manning formula assuming uniform flow condition for unit storm computations; none for daily computations.

Table 2.--Continued

HYDROLOGIC PROCESSES--Continued	
Reservoir routing	Two computational procedures available: (1) solution of continuity equation and linear storage function; or (2) modified-Puls.
Snow accumulation and melt	Based on theoretical accumulation and melt equations; snowpack is maintained and modified both on a water-equivalent basis and as a dynamic-heat reservoir.
OTHER CHARACTERISTICS	
Rainfall input	Multiple rain gages (as many as three) may be used as input.
Basin configuration	Distributed segment.
Parameter representation	Distributed.
Calibration	Automatic parameter optimization with sensitivity analyses.

The watershed system is conceptualized as a series of linear or nonlinear cascading storage elements. The model has three of these storage elements: (1) upper soil-zone reservoir, (2) subsurface reservoir, and (3) ground-water reservoir. The upper soil-zone is treated as a two-layered system. Subsurface flow is considered to support the recession of storm-flow hydrographs and can be defined as either a linear or nonlinear reservoir. The ground-water reservoir is a linear reservoir and is the source of all base flow. Total streamflow is the sum of the output of each reservoir. For daily flow simulations, no channel routing is performed. Therefore, in the daily mode, PRMS simulates hydrologic processes as daily averages or total values. Streamflow is computed as a mean daily flow.

The model is structured into four general components with regard to the hydrologic cycle. These are the climatic, land phase, snow, and sediment components. The climatic component accepts input time-series data from one climatic station and adjusts these data to define the climate over the watershed on a daily basis. The land phase component simulates the processes of interception, infiltration, evapotranspiration, soil-water accounting, surface runoff, and subsurface and ground water flow. Surface runoff in the daily mode is computed using a contributing-area concept. In the unit mode, surface runoff is computed using a variation of the Green-Ampt point infiltration equation (Green and Ampt, 1911; Mein and Larson, 1973). Point infiltration is converted to an areal value for each HRU using a linear relationship between point infiltration and rainfall supply rate. This rainfall excess is subsequently routed overland and through channels using a finite difference approximation of the solution of the one-dimensional equations of continuity and momentum with the kinematic wave simplification.

The snow component simulates the initiation, accumulations, and depletion of a snowpack on each HRU. A snowpack is maintained and modified on both a water-equivalent basis and as a dynamic heat reservoir. A snowpack balance is computed daily and an energy balance is computed twice each day for two 12-hour periods.

Optimization and sensitivity components included in PRMS aid in adjusting model parameters. The user can potentially optimize 42 model parameters to obtain better agreement between computed and observed runoff. There are three objective functions in the optimization routine: (1) absolute difference between observed and predicted discharge, (2) square of the differences, and (3) square of the differences of the logarithmic values. When sensitivity analysis is coupled with optimization, the user also can assess the magnitude of parameter standard errors and parameter intercorrelations.

PRMS is designed to operate with data retrieved from the WATSTORE (Showen, 1978) data storage and retrieval system of the Geological Survey. However, for data not stored on the WATSTORE system, programs are available to read and convert these data into a model compatible format.

MODIFICATIONS TO PRMS FOR TUG FORK APPLICATION

PRMS was modified before it was calibrated in the daily mode. Surface, subsurface, and groundwater discharge contributions are computed daily for each HRU. The model combines these discharges from all HRUs to produce a total streamflow at the basin outlet. There is no daily streamflow routing performed by PRMS. Total traveltime in the Tug Fork Basin from the headwaters to the outlet at Glenhayes, W. Va. was determined to be approximately three days for most flow regimes. It was estimated that it takes about one day traveltime between the following locations in the basin:

1. From headwaters on the West Virginia-Virginia border to Litwar, W. Va.;

2. From Litwar, W. Va., to Williamson, W. Va.; and

3. From Williamson, W. Va., to Glenhayes, W. Va.

The model was modified to account for this traveltime. Discharges from HRUs in the upper part of the basin were lagged two days, from HRUs in the middle part of the basin one day, and then added to discharge from the lower HRUs to produce total streamflow at 14 other locations in the basin taking into account the appropriate lag times where necessary. Simulated streamflow from all 15 points of interest (table 1) were stored in data files for later analyses.

Flow attenuation was not directly considered in this modification of PRMS. Flow attenuation results from overbank and channel storage. The narrow river valleys and adjacent steeply rising mountains promote little attenuation of streamflow as it moves through the basin. Also, it has been shown repeatedly in channel-routing applications, that the kinematic wave approximation used in PRMS in the unit mode always predicts a steeper wave with less dispersion and attenuation than may actually occur.

MODEL INPUT DATA

Basically, two types of data are required to run PRMS in the daily-flow mode: (1) time-series; and (2) physical descriptors. Necessary daily time-series data included rainfall, streamflow (used for comparison purposes), maximum and minimum air temperature, and solar radiation.

Physical descriptors describing the drainage area, slope, aspect, elevation, and so forth; soil characteristics; and vegetal cover were obtained from (1) topographic maps at a scale of 1:250,000, (2) general statewide soil maps, or (3) by judgment and previous experience. Land-use data were obtained from maps at a scale of 1:50,000 and will be discussed in a later section of the report.

Rainfall

Rainfall data is by far the single most important time-series in any watershed modeling study. Numerous investigations, for example, Dawdy and Bergmann (1969), Troutman (1981), and Johanson (1971) bear out this fact. Therefore, a careful analysis was made of all available rainfall data located in or near the Tug Fork basin. Consideration of areal coverage, orographic effects, model limitations, and completeness of record all influence the choice of which station to use for modeling purposes.

Fifteen long-term rain gages were identified for possible use in the study (table 3 and fig. 2). Because only three precipitation records can be used in this model, the following three stations were selected to provide the best spatial coverage and most complete records: (1) 3353 Gary at Gary, W. Va.; (2) 9610 Williamson 2 at Williamson, W. Va.; and (3) 4946 Louisa at Louisa, Ky.

Streamflow

The Geological Survey operates 11 gaging stations that provided continuous records of streamflow in the Tug Fork basin for this study. Table 1 lists these sites along with station number, name, drainage area, period of record, and river-mile location along the Tug Fork. The locations of these sites are shown in figure 3. Only 3 of the 11 gages have continuous records since 1950 or earlier: 03213000 Tug Fork at Litwar, W. Va.; 03213500 Panther Creek near Panther, W. Va.; and 03214000 Tug Fork near Kermit, W. Va. All streamflow data were retrieved from the WATSTORE system of the Geological Survey.

Temperature

A preliminary analysis of the data from 11 National Weather Service (NWS) air-temperature stations, located in or near the Tug Fork basin, was made to determine which gage, if any, had adequate record needed for the study. The analysis identified two stations with a sufficient length of concurrent maximum and minimum air temperature records: 3350 Gary, W. Va., and 9605 Williamson, W. Va. Further study of the records at these two stations revealed that the Gary gage had the least number of days with missing record and was therefore chosen for model input.

Periods of missing records were reconstructed from the data from both stations so the records would be complete. The procedure used can be illustrated with reference to figure 4. Historic data were used to relate air temperatures recorded at Williamson to those at Gary. A relation was derived for each month for both maximum and minimum daily air temperatures using linear least-squares theory. Missing records at Gary were computed from these relationships and data available at the Williamson station.

Table 3.--Recording National Weather Service precipitation stations in or near the Tug Fork basin

Name	Station No.	Location		Period of record[1/]
		Latitude	Longitude	
TUG FORK BASIN				
Davella, Ky.	2053	37°48'	82°35'	1940-present.
Freeburn, Ky.	3046	37°33'	82°10'	1951-present.
Hurley, Va.	4180	37°25'	82°01'	1964-present.
Kermit, W. Va.	4816	37°50'	82°24'	1942-present.
Williamson, W. Va.	9605	37°40'	82°17'	1940-present.
Williamson 2 NNW, W. Va.	9610	37°42'	82°17'	1951-present.
Iaeger, W. Va.	4408	37°28'	81°49'	1942-present.
Gary, W. Va.	3353	37°22'	81°33'	1941-present.
ADJACENT BASINS				
Kentucky				
Burdine 2 NE	1120	37°13'	82°35'	1951-present.
Louisa 2 SW	4946	38°07'	82°38'	1941-present.
Pikeville 2	6355	37°29'	82°32'	1934-present.
Meta 4 SE	5370	37°32'	82°23'	1958-present.
Virginia				
Davenport 2 NE	2269	37°07'	82°06'	1940-present.
West Virginia				
Flat Top	3072	37°35'	81°06'	1940-present.
Logan	5353	37°51'	82°00'	1941-present.

1/May include short periods of missing records.

Figure 2.--Recording precipitation stations, **National Weather Service**, in or near the Tug Fork Basin.

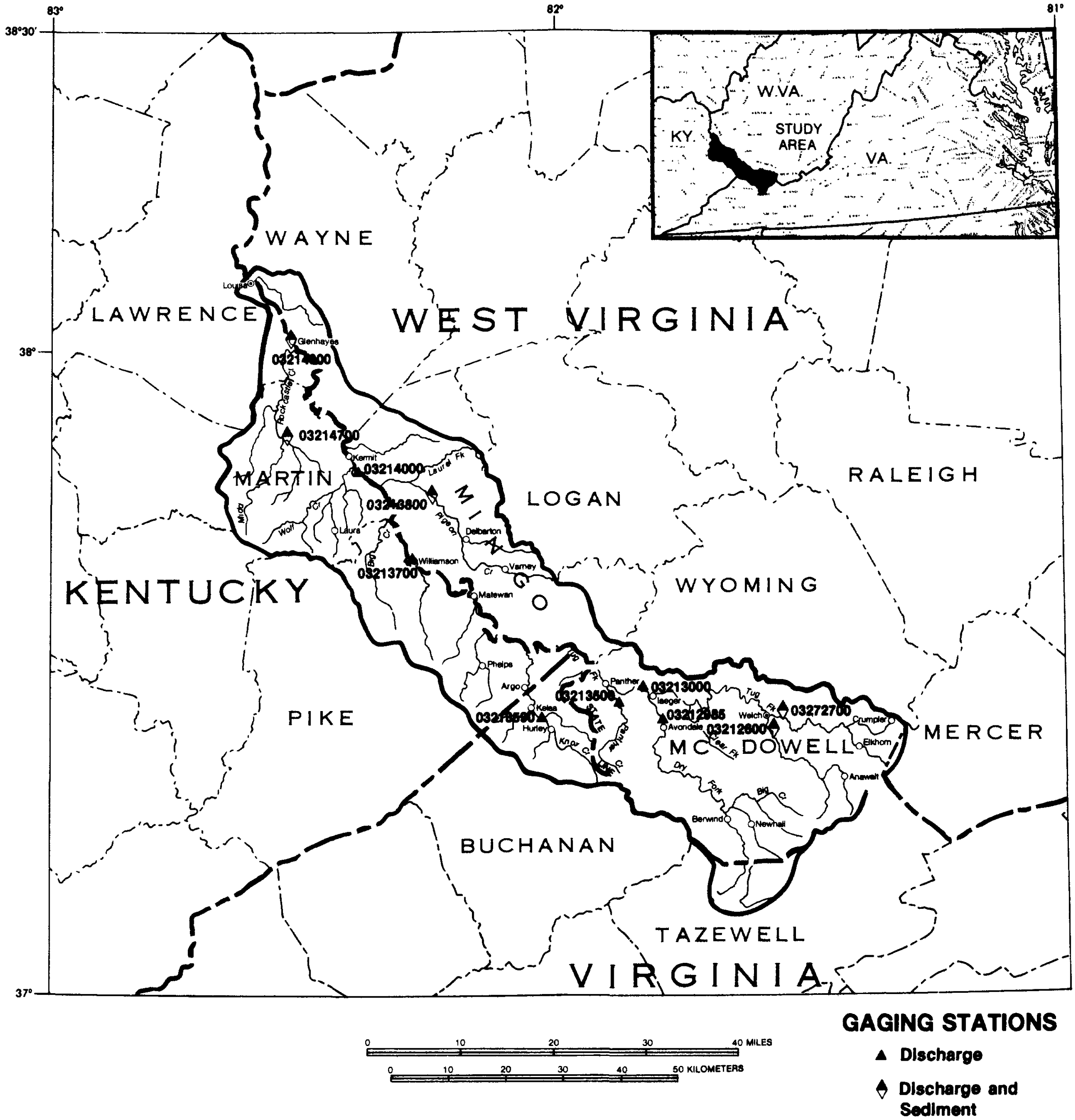

Figure 3.--Continuous-record streamflow-gaging stations in the Tug Fork basin.

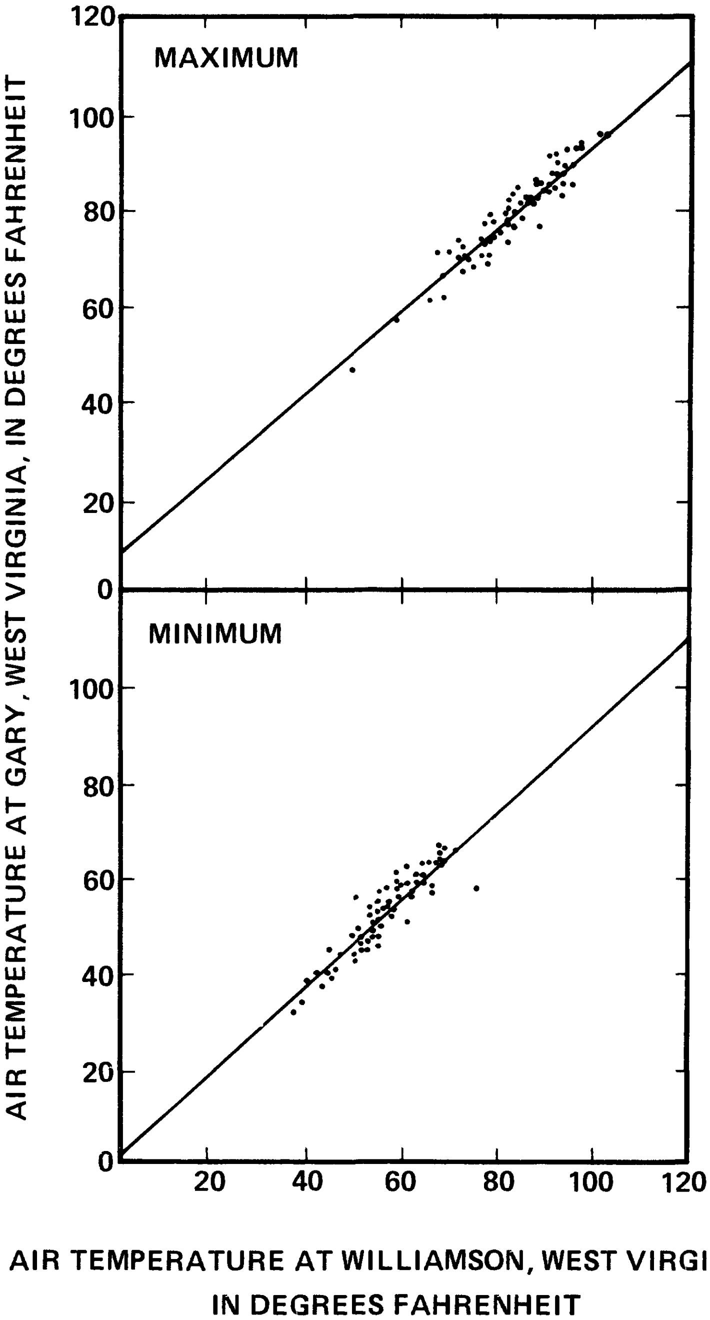

Figure 4.--Linear relationship of maximum and minimum daily air temperatures for the month of September. (Data points plotted for the 1st, 15th, and 30th days of month for illustrative purposes only)

Solar Radiation

The nearest long-term station was used to provide the solar radiation data for modeling purposes. The data were recorded by the University of Kentucky, Agricultural Engineering Department, in Lexington, Ky. Lexington is approximately 160 mi west of the centroid of the Tug Fork basin. Data has been collected at this site since 1967. However, considerable missing record existed in the data. The missing records were reconstructed by fitting a Fourier series with least squares theory to the available data. For wet days the solar radiation time-series was approximated as

$$S_W(t) = 220.18 + \left[- 138.68 \cos\left(\frac{2\pi t}{365}\right) + 31.31 \sin\left(\frac{2\pi t}{365}\right)\right]$$

where

t = julian day (1 - 365), and
$S_W(t)$ = solar radiation on day t when it rains.

For dry days the solar radiation time-series was approximated as

$$S_D(t) = 362.55 + \left[- 172.78 \cos\left(\frac{2\pi t}{365}\right) + 43.40 \sin\left(\frac{2\pi t}{365}\right)\right]$$

where

t = julian day (1 - 365), and
$S_D(t)$ = solar radiation on day t when it does not rain.

These relations are shown superimposed on plots of mean daily solar radiation for 1975-79 in figure 5.

Soils

Soil surveys have not been completed by the Soil Conservation Service for all counties in the Tug Fork basin. Instead, data compiled from statewide general soil maps (U.S. Dept. of Agriculture, 1975, 1979a, and 1979b) and soil interpretation records were used to determine the physical descriptors of the soils for modeling purposes.

The general soil map for the Tug Fork basin is shown in figure 6. This map shows the distribution of different soil associations in the basin. The soil associations were named for the two or three major soil series that occur in the area and are listed in table 4. Since the general soil map does not show the spatial extent of individual soil series, it was assumed that each series was uniformly distributed and occurred in equal proportion within a soil association.

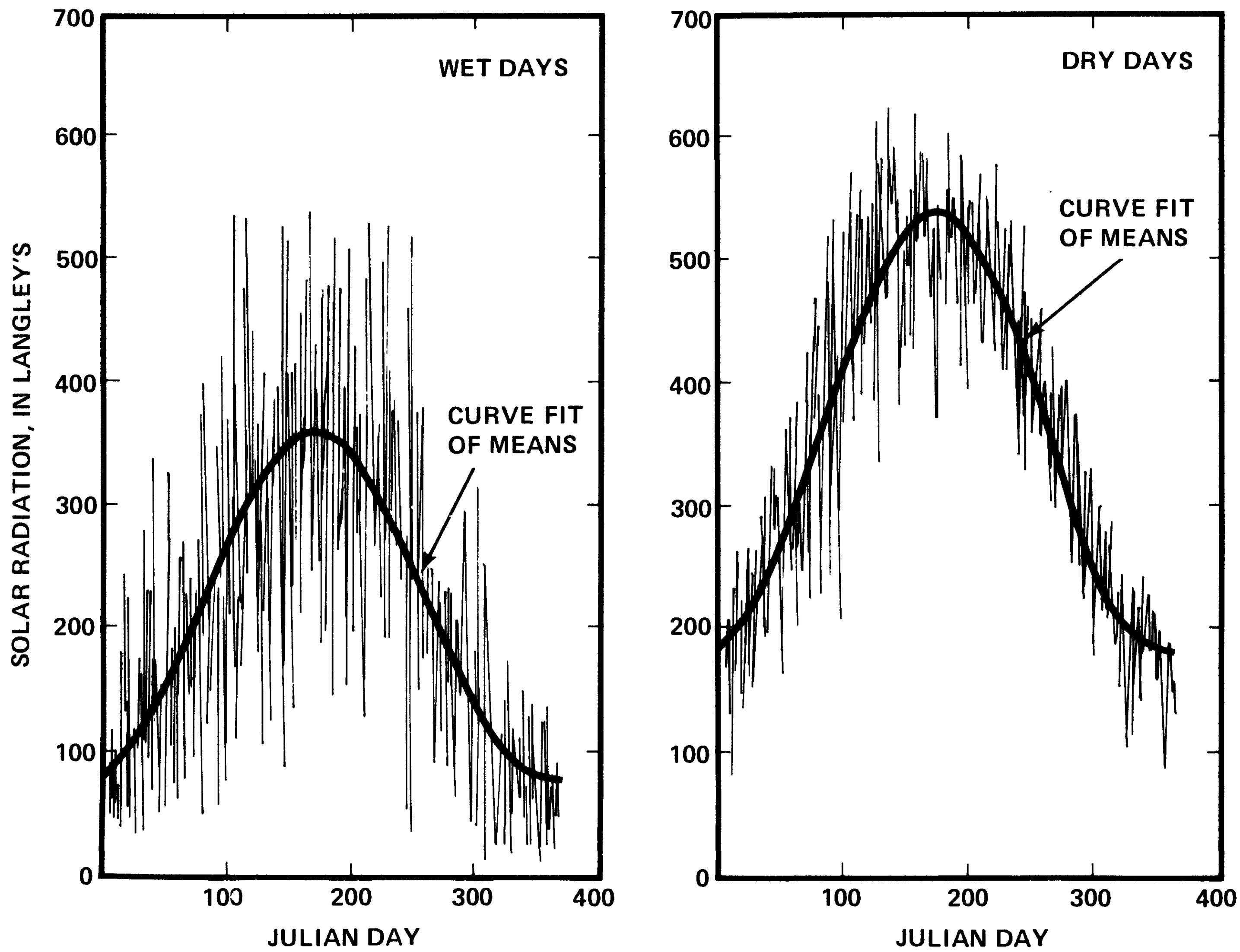

Figure 5.--Mean daily solar radiation and Fourier series fit for wet and dry days.

Soil Associations

A1 **DeKalb-Berks-Weikert**
B1 **Clymer-DeKalb-Jefferson**
B2 **Clymer-Gilpin**
C1 **Jefferson-Shelocta**

Figure 6.--General soil map of Tug Fork basin.

Table 4.--Soil series of the Tug Fork River basin

Soil Association	Series
A1	DeKalb Berks Weikert
B1	Clymer DeKalb Jefferson
B2	Clymer Gilpin
C1	Jefferson Shelocta

The physical descriptors of the soils in the basin are listed in table 5. The soils are classified as loams and silty loams according to the U.S. Department of Agriculture textural classification system. The maximum water-holding capacities varied between 0.06 and 0.14 in./in. The depth of the hydrologically active part of the soil mantle was taken as either the depth to the water table or depth to bedrock, whichever was shallowest. This depth ranged from 20 to 65 in.

Land Use

The Tug Fork basin was subdivided into 30 subwatersheds as shown in figure 7. The 15 selected points (table 1) where streamflow data are required are outlets at some of the subareas and are shown by letters A-N. The remaining subareas were selected so that a better representation of the basin could be made for modeling purposes.

Land-use maps of the Tug Fork basin for the years 1950, 1960, 1976, and 1980 (scale 1:50,000) were prepared by the Geological Survey. The following land-use categories were used:

1. Urban.--Relatively dense concentration of residential, commercial, or industrial buildings in a single area. All areas were mapped that were a minimum of 10 acres and were over 300 feet wide.

2. Active mining.--Areas of current surface mining. The surface is freshly disturbed with no visible signs of regrading, reconstruction, or revegetating. No minimum size.

3. Inactive mining.--Areas of recent surface mining, probably within the past 1 or 2 years, but no sign of current activity. No backfilling, reconstruction, or revegetation has occurred. No minimum size.

4. Reclaimed.--Areas previously disturbed by surface mining and that have been reclaimed naturally or by reconstruction including areas where natural revegetation has occurred and areas where regrading has taken place but revegetation has not occurred. No minimum size.

5. Associated mining.--These surface areas include all coal tipples, coal-processing areas, coal-storage areas, waste piles, and other industrial areas directly associated with coal mining. All areas exceeding 10 acres and over 300 feet in width were mapped.

6. Logged areas.--Areas that have been either selectively cut or clear cut for timber. All areas exceeding 40 acres were mapped.

7. Agriculture.--Crop and pasture areas. All areas exceeding 10 acres were mapped.

Table 5.--Physical descriptors of soils in the Tug Fork basin

Soil		Textural class	Available water-holding capacity (in./in.)	Depth of soil profile (in.)
Association	Series			
A1	DeKalb	Silt loam	0.09	40
	Berks	Loam	.07	40
	Weikert	Loam	.06	20
B1	Clymer	Silt loam	.09	60
	DeKalb	Silt loam	.09	40
	Jefferson	Silt loam	.12	65
B2	Clymer	Silt loam	.09	60
	Gilpin	Silt loam	.12	40
C1	Jefferson	Silt loam	.12	65
	Shelocta	Silt loam	.14	50

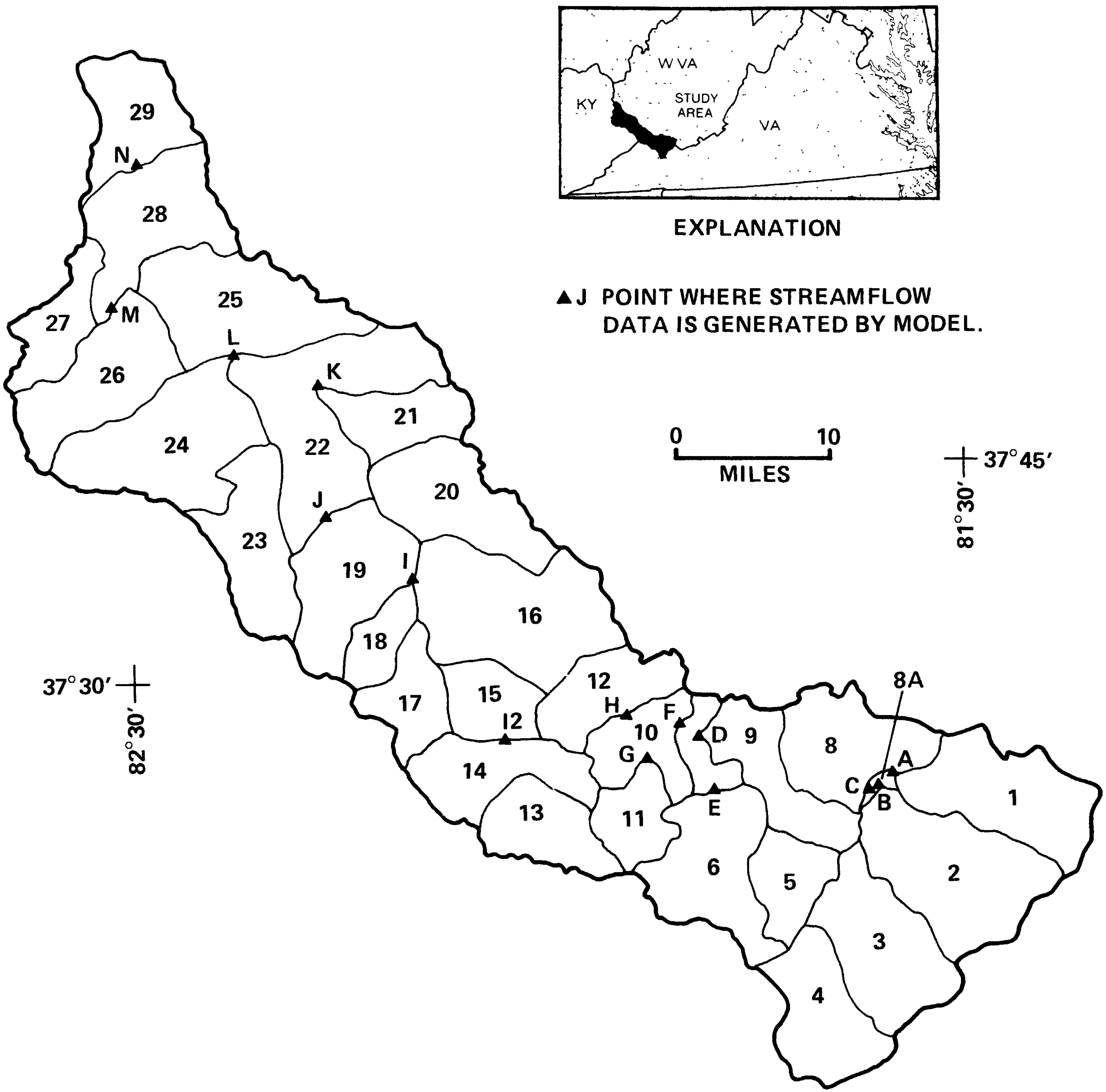

Figure 7.--Tug Fork basin subdivided into 30 subareas for determining land-use information.

8. Improved roads.--Paved roads defined as heavy duty, medium duty, or light duty. Lengths of roads were determined for all areas of basin (including urban) and an assumed width of 24 feet was used to compute areas.

9. Undeveloped roads.--All unimproved dirt roads for which an assumed width of 24 feet was used to compute areas.

10. Ponds.--All ponds and lakes exceeding 5 acres were mapped.

Table 6 lists land-use areas (in acres) by subarea for each category for 1950, 1960, 1976, and 1980. In addition, the total surface area disturbed by mining activities (sum of land-use categories 2-5 above) also is listed in table 6. Table 7 lists summary information for each of the four years and by category. These data were used to define cover densities, disturbed areas, and to provide other information required by the model. Subarea 29 (fig. 7) which is below Tug Fork at Glenhayes, W. Va., was not included in tables 6 and 7 tabulations.

As seen in table 7, mining activities increased significantly between 1950 and 1980. It can also be seen that agriculture in the same period decreased 78 percent. This information substantiates how important mining is in the Tug Fork basin, and with the large coal reserves, how it will continue to remain important. Overall, since 1950 there has been a decrease of just over 4 percent (97.17 to 93.07) in the undisturbed part of the basin. These areas are mostly forested, consisting primarily of deciduous hardwoods with some scattered conifers.

Watershed Subdivision

One of the first steps in watershed modeling is subdivision of the watershed into smaller homogeneous HRU subareas. These HRUs are assumed to produce a unique hydrologic response for a given combination of climate, topography, land-use, and soil condition. No totally objective criteria exist on how to subdivide the watershed and this is currently a topic of research. Watershed modelers must therefore employ subjective criteria to accomplish this step.

Study needs dictated that streamflow be simulated at 15 locations in the Tug Fork basin. These sites are shown in figure 8 (letters A-N) and identified in table 1. Nine sites are on the main stem of the Tug Fork (4 of which are ungaged) and the remaining six sites are on tributaries to the Tug Fork. Each drainage area associated with these sites was then subdivided on the basis of land use. Three land-use types were considered: mined, reclaimed, and "other." Mined areas included the active, inactive, and associated mined areas described earlier. The "other" land-use type consisted primarily of deciduous forest with a small percentage of urban and agriculture areas also included. With these considerations, the entire Tug Fork basin was subdivided into 44 model segments or HRUs. The subarea whose outlet was at reference point F was the only one without a land-use type "reclaimed" in either 1950 or 1980.

Table 6.--Summary of land-use information for Tug Fork basin during 1950-1980

Sub-area No.	Acreage of Subarea	Percent of total area	Acreage of land-use category			
			1950	1960	1976	1980
			1. Urban			
1	46912	4.86	153.1	164.0	259.7	259.7
2	54912	5.69	206.2	247.6	231.2	243.3
3	44172	4.58	11.1	44.6	36.6	36.6
4	39062	4.05	63.2	83.3	85.0	85.0
5	18560	1.92	74.2	162.2	158.8	158.8
6	42206	4.38	31.1	31.1	95.1	95.1
7	29084	3.02	17.3	17.3	12.6	12.6
8	38766	4.02	111.1	111.1	145.0	172.0
8a	1916	.20	91.4	91.4	137.3	137.3
9	7610	.79	9.3	9.3	24.6	24.6
10	16361	1.70	0.0	0.0	0.0	0.0
11	19840	2.06	0.0	0.0	0.0	0.0
12	29612	3.07	0.0	0.0	0.0	0.0
13	25750	2.67	0.0	0.0	0.0	0.0
14	28202	2.92	0.0	0.0	0.0	0.0
15	17587	1.82	0.0	0.0	0.0	0.0
16	65075	6.75	189.5	186.5	187.4	183.4
17	21120	2.19	32.0	32.0	59.5	59.5
18	12452	1.29	0.0	0.0	0.0	0.0
19	39841	4.13	260.7	260.7	285.4	279.8
20	36898	3.83	17.6	46.9	47.6	47.6
21	23198	2.41	0.0	0.0	0.0	0.0
22	63454	6.58	337.0	267.4	327.9	327.9
23	37730	3.91	0.0	0.0	0.0	0.0
24	53933	5.59	0.0	0.0	7.2	7.2
25	57003	5.91	115.9	115.9	133.8	174.3
26	40384	4.19	35.4	40.9	64.1	119.3
27	18371	1.90	0.0	0.0	0.0	0.0
28	34469	3.57	0.0	0.0	0.0	0.0
Total	964480	100.00	1756.1	1912.2	2298.8	2424.0

Table 6.--Continued

2. Active mining

1	46912	4.86	47.7	645.0	1586.3	593.7
2	54912	5.69	73.9	137.5	939.3	323.0
3	44172	4.58	0.0	589.0	401.5	385.0
4	39062	4.05	54.3	195.0	182.1	0.0
5	18560	1.92	13.0	13.0	45.0	33.3
6	42206	4.38	8.8	8.8	17.0	29.4
7	29084	3.02	0.0	39.6	14.7	18.7
8	38766	4.02	40.1	205.8	113.6	79.6
8a	1916	.20	0.0	0.0	42.7	29.7
9	7610	.79	0.0	0.0	0.0	0.0
10	16361	1.70	0.0	12.6	5.0	0.0
11	19840	2.06	0.0	21.1	21.1	0.0
12	29612	3.07	216.3	368.7	638.1	372.0
13	25750	2.67	20.4	117.8	294.0	113.9
14	28202	2.92	0.0	33.1	306.5	165.1
15	17587	1.82	66.9	185.5	506.6	448.3
16	65075	6.75	1154.2	1312.8	1222.0	784.9
17	21120	2.19	7.6	7.9	467.6	304.0
18	12452	1.29	20.3	20.3	0.0	2.2
19	39841	4.13	185.5	527.0	224.1	137.9
20	36898	3.83	0.0	132.1	39.5	77.2
21	23198	2.41	0.0	0.0	53.8	35.4
22	63454	6.58	72.9	108.3	220.5	374.1
23	37730	3.91	14.7	41.9	512.0	335.5
24	53933	5.59	7.0	9.7	1656.1	2146.7
25	57003	5.91	0.0	0.0	39.8	94.2
26	40384	4.19	0.0	0.0	1259.4	1487.8
27	18371	1.90	9.6	30.7	574.8	205.1
28	34469	3.57	0.0	0.0	489.7	290.1
Total	964480	100.00	2013.2	4763.7	11872.8	8866.8

Table 6.--Continued

3. Inactive mining						
1	46912	4.86	0.0	0.0	1248.5	307.6
2	54912	5.69	0.0	0.0	1443.4	355.5
3	44172	4.58	0.0	26.4	407.6	244.4
4	39062	4.05	0.0	0.0	116.3	113.4
5	18560	1.92	0.0	0.0	116.7	116.7
6	42206	4.38	0.0	0.0	333.2	115.1
7	29084	3.02	0.0	0.0	20.8	20.8
8	38766	4.02	0.0	0.0	144.6	128.7
8a	1916	.20	0.0	0.0	58.0	3.8
9	7610	.79	0.0	0.0	4.4	4.4
10	16361	1.70	0.0	0.0	45.1	5.0
11	19840	2.06	0.0	0.0	86.3	0.0
12	29612	3.07	0.0	0.0	289.2	477.3
13	25750	2.67	0.0	0.0	1065.5	730.1
14	28202	2.92	0.0	0.0	739.6	465.2
15	17587	1.82	0.0	0.0	1119.3	1431.2
16	65075	6.75	0.0	127.0	1842.8	1576.2
17	21120	2.19	0.0	0.0	279.9	596.7
18	12452	1.29	0.0	0.0	521.5	470.7
19	39841	4.13	0.0	0.0	0.0	366.6
20	36898	3.83	0.0	0.0	406.7	67.9
21	23198	2.41	0.0	0.0	56.9	62.6
22	63454	6.58	0.0	13.7	172.5	210.1
23	37730	3.91	0.0	0.0	698.1	1001.3
24	53933	5.59	0.0	0.0	626.8	322.2
25	57003	5.91	0.0	0.0	28.0	37.4
26	40384	4.19	0.0	0.0	662.8	518.3
27	18371	1.90	0.0	0.0	135.2	117.6
28	34469	3.57	0.0	0.0	356.0	262.6
Total	964480	100.00	0.0	167.1	13025.7	10129.4

Table 6.--Continued

			4. Reclaimed			
1	46912	4.86	0.0	0.0	2380.1	4653.6
2	54912	5.69	0.0	0.0	2897.4	5043.1
3	44172	4.58	0.0	0.0	3052.2	3663.5
4	39062	4.05	0.0	0.0	571.0	791.2
5	18560	1.92	0.0	0.0	175.4	190.2
6	42206	4.38	0.0	0.0	661.1	899.3
7	29084	3.02	0.0	0.0	230.6	276.3
8	38766	4.02	0.0	0.0	879.3	1004.5
8a	1916	.20	0.0	0.0	0.0	117.2
9	7610	.79	0.0	0.0	0.0	0.0
10	16361	1.70	0.0	0.0	162.6	207.7
11	19840	2.06	0.0	0.0	19.6	127.0
12	29612	3.07	0.0	0.0	600.3	766.9
13	25750	2.67	0.0	0.0	211.4	709.1
14	28202	2.92	0.0	0.0	334.7	655.9
15	17587	1.82	0.0	0.0	118.6	118.6
16	65075	6.75	0.0	0.0	1908.4	3096.6
17	21120	2.19	0.0	0.0	170.3	259.6
18	12452	1.29	0.0	0.0	53.7	237.1
19	39841	4.13	5.4	5.4	725.3	789.7
20	36898	3.83	0.0	0.0	222.7	826.7
21	23198	2.41	0.0	0.0	332.5	385.3
22	63454	6.58	0.0	0.0	677.9	648.5
23	37730	3.91	0.0	0.0	474.5	547.5
24	53933	5.59	0.0	0.0	670.9	2393.6
25	57003	5.91	0.0	0.0	23.4	86.1
26	40384	4.19	0.0	0.0	800.5	2365.1
27	18371	1.90	0.0	0.0	932.1	1548.7
28	34469	3.57	0.0	0.0	0.0	587.3
Total	964480	100.00	5.4	5.4	19286.5	32995.9

Table 6.--Continued

5. Associated mining						
1	46912	4.86	33.2	47.6	222.8	229.1
2	54912	5.69	0.0	25.8	193.8	193.0
3	44172	4.58	0.0	0.0	76.9	102.1
4	39062	4.05	8.5	8.5	17.8	18.0
5	18560	1.92	0.0	0.0	63.1	63.1
6	42206	4.38	0.0	0.0	28.4	28.4
7	29084	3.02	0.0	0.0	7.4	18.8
8	38766	4.02	0.0	0.0	29.4	69.1
8a	1916	.20	0.0	0.0	0.0	0.0
9	7610	.79	0.0	0.0	0.0	0.0
10	16361	1.70	0.0	0.0	0.0	0.0
11	19840	2.06	0.0	0.0	0.0	0.0
12	29612	3.07	0.0	0.0	0.0	0.0
13	25750	2.67	0.0	0.0	13.8	13.8
14	28202	2.92	0.0	0.0	0.0	0.0
15	17587	1.82	0.0	0.0	0.0	0.0
16	65075	6.75	0.0	0.0	0.0	0.0
17	21120	2.19	0.0	0.0	0.0	0.0
18	12452	1.29	0.0	0.0	132.6	0.0
19	39841	4.13	25.6	15.2	87.9	105.0
20	36898	3.83	0.0	0.0	0.0	0.0
21	23198	2.41	5.4	5.4	10.7	10.7
22	63454	6.58	0.0	0.0	15.1	15.1
23	37730	3.91	0.0	0.0	39.7	58.0
24	53933	5.59	0.0	0.0	51.4	36.7
25	57003	5.91	0.0	0.0	0.0	0.0
26	40384	4.19	0.0	0.0	0.0	0.0
27	18371	1.90	0.0	0.0	0.0	29.7
28	34469	3.57	0.0	0.0	0.0	0.0
Total	964480	100.00	72.7	102.5	990.8	990.6

Table 6.--Continued

6. Total surface area disturbed by mining (categories 2 + 3 + 4 + 5)

1	46912	4.86	80.9	692.6	5437.7	5784.0
2	54912	5.69	73.9	163.3	5473.9	5914.6
3	44172	4.58	0.0	615.4	3938.2	4395.0
4	39062	4.05	62.8	203.5	887.2	922.6
5	18560	1.92	13.0	13.0	400.2	403.3
6	42206	4.38	8.8	8.8	1039.7	1072.2
7	29084	3.02	0.0	39.6	273.5	334.6
8	38766	4.02	40.1	205.8	1166.9	1281.9
8a	1916	.20	0.0	0.0	100.7	150.7
9	7610	.79	0.0	0.0	4.4	4.4
10	16361	1.70	0.0	12.6	212.7	212.7
11	19840	2.06	0.0	21.1	127.0	127.0
12	29612	3.07	216.3	368.7	1527.6	1616.2
13	25750	2.67	20.4	117.8	1584.7	1566.9
14	28202	2.92	0.0	33.1	1380.8	1286.2
15	17587	1.82	66.9	185.5	1744.5	1998.1
16	65075	6.75	1154.2	1439.8	4973.2	5457.7
17	21120	2.19	7.6	7.9	917.8	1160.3
18	12452	1.29	20.3	20.3	707.8	710.0
19	39841	4.13	216.5	547.6	1037.3	1399.2
20	36898	3.83	0.0	132.1	668.9	971.8
21	23198	2.41	5.4	5.4	453.9	494.0
22	63454	6.58	72.9	122.0	1086.0	1247.8
23	37730	3.91	14.7	41.9	1724.3	1942.3
24	53933	5.59	7.0	9.7	3005.2	4899.2
25	57003	5.91	0.0	0.0	91.2	217.7
26	40384	4.19	0.0	0.0	2722.7	4371.2
27	18371	1.90	9.6	30.7	1642.1	1901.1
28	34469	3.57	0.0	0.0	845.7	1140.0
Total	964480	100.00	2091.3	5038.2	45175.8	52982.7

Table 6.--Continued

			7. Logged areas			
1	46912	4.86	0.0	0.0	0.0	0.0
2	54912	5.69	0.0	0.0	0.0	0.0
3	44172	4.58	0.0	0.0	0.0	0.0
4	39062	4.05	0.0	0.0	0.0	0.0
5	18560	1.92	0.0	0.0	0.0	0.0
6	42206	4.38	0.0	0.0	0.0	0.0
7	29084	3.02	0.0	0.0	0.0	0.0
8	38766	4.02	0.0	0.0	0.0	0.0
8a	1916	.20	0.0	0.0	0.0	0.0
9	7610	.79	0.0	0.0	0.0	0.0
10	16361	1.70	0.0	0.0	0.0	0.0
11	19840	2.06	0.0	0.0	0.0	0.0
12	29612	3.07	0.0	0.0	0.0	0.0
13	25750	2.67	0.0	0.0	0.0	0.0
14	28202	2.92	0.0	0.0	0.0	0.0
15	17587	1.82	0.0	0.0	0.0	0.0
16	65075	6.75	0.0	0.0	0.0	0.0
17	21120	2.19	0.0	0.0	0.0	0.0
18	12452	1.29	0.0	0.0	0.0	0.0
19	39841	4.13	0.0	0.0	0.0	0.0
20	36898	3.83	0.0	0.0	0.0	0.0
21	23198	2.41	0.0	0.0	0.0	0.0
22	63454	6.58	0.0	0.0	0.0	0.0
23	37730	3.91	0.0	0.0	0.0	0.0
24	53933	5.59	0.0	0.0	0.0	0.0
25	57003	5.91	0.0	0.0	0.0	0.0
26	40384	4.19	0.0	0.0	0.0	0.0
27	18371	1.90	0.0	0.0	0.0	0.0
28	34469	3.57	0.0	0.0	0.0	0.0
Total	964480	100.00	0.0	0.0	0.0	0.0

Table 6.--Continued

			8. Agriculture			
1	46912	4.86	858.9	825.7	384.6	396.2
2	54912	5.69	360.9	329.9	82.9	83.5
3	44172	4.58	1852.3	1882.3	430.2	395.6
4	39062	4.05	1228.2	1862.0	810.4	833.3
5	18560	1.92	56.4	56.4	0.0	0.0
6	42206	4.38	576.4	576.4	81.3	81.3
7	29084	3.02	119.6	107.3	0.0	0.0
8	38766	4.02	103.7	119.9	21.3	21.3
8a	1916	.20	14.8	14.8	14.0	0.0
9	7610	.79	170.0	164.4	0.0	0.0
10	16361	1.70	247.9	247.9	11.6	11.6
11	19840	2.06	442.8	357.4	114.2	114.2
12	29612	3.07	205.5	158.9	10.1	10.1
13	25750	2.67	380.7	371.0	27.8	27.8
14	28202	2.92	750.1	750.1	0.0	0.0
15	17587	1.82	117.4	95.7	0.0	0.0
16	65075	6.75	299.9	313.8	0.0	0.0
17	21120	2.19	168.5	168.5	36.0	36.0
18	12452	1.29	191.5	191.5	12.0	12.0
19	39841	4.13	779.5	749.1	17.2	17.2
20	36898	3.83	348.2	357.4	0.0	0.0
21	23198	2.41	479.8	436.4	0.0	0.0
22	63454	6.58	616.3	461.1	7.9	70.6
23	37730	3.91	1203.9	1279.1	257.7	258.7
24	53933	5.59	1190.9	937.5	137.5	136.4
25	57003	5.91	967.7	835.1	214.9	207.0
26	40384	4.19	1140.8	1207.0	0.0	308.1
27	18371	1.90	485.0	479.7	138.3	136.9
28	34469	3.57	402.4	389.8	337.7	337.7
Total	964480	100.00	15760.0	15726.1	3147.6	3495.5

Table 6.--Continued

9. Improved roads						
1	46912	4.86	292.0	292.0	292.0	305.7
2	54912	5.69	265.4	265.4	265.4	265.4
3	44172	4.58	225.6	225.6	225.6	225.6
4	39062	4.05	219.1	219.1	219.1	219.1
5	18560	1.92	86.0	86.0	86.0	86.0
6	42206	4.38	129.3	129.3	129.3	129.3
7	29084	3.02	66.6	66.6	66.6	66.6
8	38766	4.02	139.7	139.7	139.7	139.7
8a	1916	.20	6.9	6.9	6.9	6.9
9	7610	.79	47.0	47.0	47.0	47.0
10	16361	1.70	70.0	70.0	70.0	70.0
11	19840	2.06	60.1	60.1	60.1	60.1
12	29612	3.07	96.3	96.3	96.3	96.3
13	25750	2.67	93.4	93.4	93.4	93.4
14	28202	2.92	98.4	98.4	98.4	100.5
15	17587	1.82	47.1	47.1	47.1	47.1
16	65075	6.75	194.9	194.9	194.9	194.9
17	21120	2.19	110.3	110.3	110.3	110.3
18	12452	1.29	45.2	45.2	45.2	45.2
19	39841	4.13	248.7	248.7	248.7	249.8
20	36898	3.83	141.1	141.1	140.0	140.0
21	23198	2.41	61.4	61.4	82.0	85.9
22	63454	6.58	269.2	269.2	275.8	283.8
23	37730	3.91	129.9	129.9	129.9	129.9
24	53933	5.59	69.6	69.6	69.6	69.6
25	57003	5.91	243.8	243.8	245.9	245.9
26	40384	4.19	101.6	101.6	101.6	101.6
27	18371	1.90	51.9	51.9	51.9	51.9
28	34469	3.57	131.8	131.8	135.8	135.8
Total	964480	100.00	3742.3	3742.3	3774.5	3803.3

Table 6.--Continued

		10. Undeveloped roads				
1	46912	4.86	238.4	238.4	238.4	238.4
2	54912	5.69	197.8	197.8	197.8	197.8
3	44172	4.58	118.9	118.9	118.9	118.9
4	39062	4.05	99.2	99.2	99.2	99.2
5	18560	1.92	100.7	100.7	100.7	100.7
6	42206	4.38	288.8	288.8	288.8	288.8
7	29084	3.02	213.0	213.0	213.0	213.0
8	38766	4.02	185.9	185.9	185.9	185.9
8a	1916	.20	9.2	9.2	9.2	9.2
9	7610	.79	34.9	34.9	34.9	34.9
10	16361	1.70	76.3	76.3	76.3	76.3
11	19840	2.06	112.0	112.0	112.0	112.0
12	29612	3.07	61.6	61.6	61.6	61.6
13	25750	2.67	100.9	100.9	100.9	100.9
14	28202	2.92	52.2	52.2	52.2	52.2
15	17587	1.82	47.1	47.1	47.1	47.1
16	65075	6.75	196.9	196.9	196.9	196.9
17	21120	2.19	73.0	73.0	73.0	73.0
18	12452	1.29	64.3	64.3	64.3	64.3
19	39841	4.13	180.3	180.3	180.3	180.3
20	36898	3.83	88.6	88.6	92.4	92.4
21	23198	2.41	56.8	56.8	56.8	59.0
22	63454	6.58	171.1	171.1	171.1	172.2
23	37730	3.91	116.9	116.9	116.9	116.9
24	53933	5.59	228.1	228.1	225.5	225.5
25	57003	5.91	195.6	195.6	195.6	195.6
26	40384	4.19	173.5	173.5	173.5	173.5
27	18371	1.90	100.2	100.2	100.2	100.2
28	34469	3.57	167.2	167.2	167.2	168.3
Total	964480	100.00	3749.4	3749.4	3750.6	3755.0

Table 6.--Continued

11. Ponds						
1	46912	4.86	9.5	9.5	23.5	17.9
2	54912	5.69	10.6	10.6	75.8	165.6
3	44172	4.58	6.4	6.4	40.8	42.1
4	39062	4.05	16.6	16.6	16.6	16.6
5	18560	1.92	1.0	1.0	4.3	1.0
6	42206	4.38	1.9	1.9	1.8	1.9
7	29084	3.02	5.7	5.7	5.7	5.7
8	38766	4.02	1.9	1.9	9.8	9.8
8a	1916	.20	0.1	0.1	0.5	0.5
9	7610	.79	0.0	0.0	0.0	0.0
10	16361	1.70	0.0	0.0	0.0	0.0
11	19840	2.06	1.2	1.2	1.2	1.2
12	29612	3.07	3.8	2.7	3.8	3.8
13	25750	2.67	1.2	1.2	1.2	1.2
14	28202	2.92	1.7	1.7	1.7	1.7
15	17587	1.82	2.4	2.4	2.4	2.4
16	65075	6.75	6.1	6.1	9.0	6.1
17	21120	2.19	18.6	18.6	18.6	18.6
18	12452	1.29	0.9	0.9	0.9	0.9
19	39841	4.13	4.5	4.9	16.7	16.7
20	36898	3.83	6.4	6.4	6.4	6.4
21	23198	2.41	0.0	0.0	0.0	0.0
22	63454	6.58	24.8	24.8	24.8	24.8
23	37730	3.91	6.3	6.3	6.3	6.3
24	53933	5.59	7.6	7.6	20.6	27.2
25	57003	5.91	1.5	1.5	1.5	1.5
26	40384	4.19	12.6	12.6	37.2	110.4
27	18371	1.90	0.0	6.6	6.6	9.8
28	34469	3.57	5.1	5.1	5.1	5.1
Total	964480	100.00	158.4	164.3	342.8	505.2

Table 6.--Concluded

12. Undisturbed						
1	46912	4.86	45279.2	44689.8	40276.1	39910.1
2	54912	5.69	53797.2	53697.4	48585.0	48041.8
3	44172	4.58	41957.7	41278.8	39381.7	38958.2
4	39062	4.05	37372.9	36577.8	36944.5	36886.2
5	18560	1.92	18228.7	18140.7	17810.0	17810.2
6	42206	4.38	41169.7	41169.7	40570.0	40537.4
7	29084	3.02	28661.8	28634.5	28512.6	28451.5
8	38766	4.02	38183.6	38001.7	37097.4	36955.4
8a	1916	.20	1793.6	1793.6	1647.4	1611.4
9	7610	.79	7348.8	7354.4	7499.1	7499.1
10	16361	1.70	15966.8	15954.2	15990.4	15990.4
11	19840	2.06	19223.9	19288.2	19425.5	19425.5
12	29612	3.07	29028.5	28923.8	27912.6	27824.0
13	25750	2.67	25153.4	25065.7	23942.0	23959.8
14	28202	2.92	27299.6	27266.5	26668.9	26761.4
15	17587	1.82	17306.1	17209.2	15745.9	15492.3
16	65075	6.75	63033.5	62737.0	59513.6	59036.0
17	21120	2.19	20710.0	20709.7	19904.8	19662.3
18	12452	1.29	12129.8	12129.8	11621.8	11619.6
19	39841	4.13	38150.8	37849.7	38055.4	37698.0
20	36898	3.83	36296.1	36125.5	35942.7	35639.8
21	23198	2.41	22594.6	22638.0	22605.3	22559.1
22	63454	6.58	61962.7	62138.4	61550.5	61326.9
23	37730	3.91	36258.3	36155.9	35494.9	35275.9
24	53933	5.59	52429.8	52680.5	50467.4	48567.9
25	57003	5.91	55478.5	55611.1	56120.1	55961.0
26	40384	4.19	38920.1	38848.4	37284.9	35199.9
27	18371	1.90	17724.3	17701.9	16431.9	16171.1
28	34469	3.57	33762.5	33775.1	32977.5	32682.1
Total	964480	100.00	937222.5	934147.0	905989.9	897514.3

Table 7.--Summary of land use in the Tug Fork basin for 1950, 1960, 1976, and 1980

Land-use category	1950 area (acres)	Percent	1960 area (acres)	Percent	1976 area (acres)	Percent	1980 area (acres)	Percent
1. Urban	1756.1	0.18	1912.2	0.20	2298.8	0.24	2424.0	0.25
2. Active mining	2013.2	.21	4763.7	.49	11872.8	1.23	8866.8	.92
3. Inactive mining	0	0	167.1	.01	13025.7	1.35	10129.4	1.05
4. Reclaimed	5.4	0	5.4	0	19286.5	2.00	32995.9	3.42
5. Associated mining	72.7	.01	102.5	.01	990.8	.10	990.6	.10
6. Total surface area disturbed by mining (categories 2 + 3 + 4 + 5)	2091.3	.22	5038.7	.51	45178.8	4.68	52982.7	5.49
7. Logged areas	0	0	0	0	0	0	0	0
8. Agriculture	15760.0	1.63	15726.1	1.63	3147.6	.33	3495.5	.36
9. Improved roads	3742.3	.39	3742.3	.39	3774.5	.39	3803.3	.39
10. Underdeveloped roads	3749.4	.39	3749.4	.39	3750.6	.39	3755.0	.39
11. Ponds	158.4	.02	164.3	.01	342.8	.04	505.2	.05
12. Undisturbed	937222.5	97.17	934147.0	96.85	905989.9	93.93	897514.3	93.07
Total	964480.0	100.00	964480.0	100.00	964480.0	100.00	964480.0	100.00

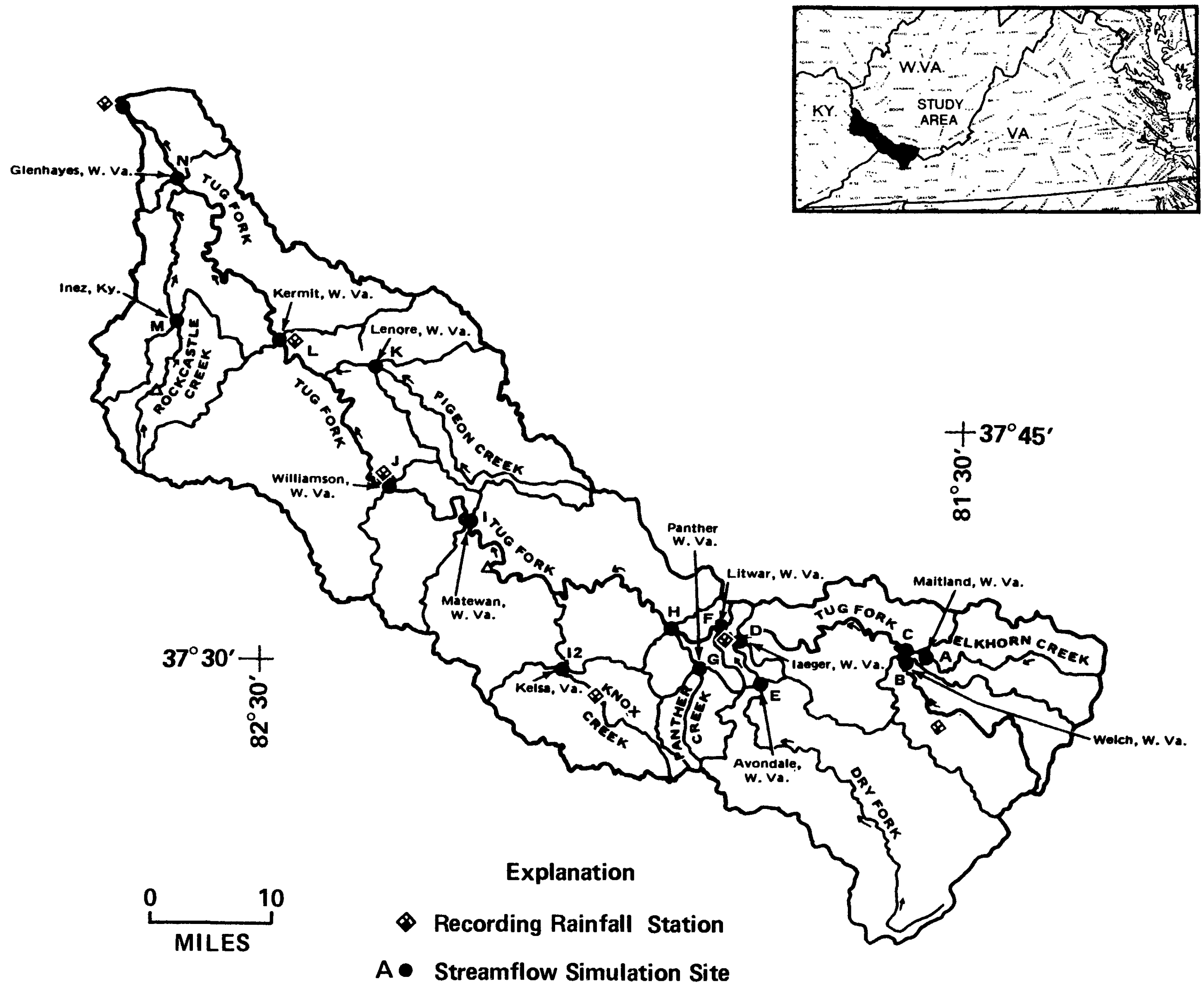

Figure 8.--Locations of subbasins where model information needed.

MODEL CALIBRATION AND VERIFICATION

Initial values of model parameters chosen for calibration were based upon knowledge of the watershed surface and soil characteristics, land use, and results of similar PRMS applications in other watersheds. Calibration involves changing selected model parameters to obtain a "best-fit" of the model output to observed data.

For this study, the "best-fit" was based primarily on minimization of a least squares objective function that is inherently biased towards high streamflow

$$OF = \sum_{i=1}^{n} (O_i - S_i)^2$$

where

O_i = observed discharge, in cubic foot per second;
S_i = simulated discharge, in cubic foot per second; and
n = number of days.

Since the purpose of this study was to evaluate the effects of surface mining on flood peaks, visual inspection was also used to compare observed and computed peak annual flows. In addition an attempt was made to establish good agreement between annual runoff volumes.

The entire basin model was calibrated for both land-use conditions (1980 and 1950) by starting at the most upstream site where streamflow data were available and proceeding downstream. The derived model parameters for the upstream catchments were not adjusted any further as the calibration proceeded downstream. That is, only those model parameters assigned to intervening contributing areas were adjusted to calibrate the model at downstream sites. Tributary sites with measured streamflow data were calibrated independently and incorporated in the entire basin model at their confluence with the Tug Fork.

Good fits obtained during model calibration do not necessarily guarantee good prediction ability. Parameters may have been adjusted to produce accurate simulations only for the time series used in the calibration process. Effective testing of the calibrated model using additional observed time-series data will serve to verify the model for accuracy. For proper calibration and verification, an extensive period of observed data that covers wet, dry, and average periods under static land-use conditions is required. Perhaps 5 to 8 years for both calibration and verification purposes would be a sufficient sample to reduce the effect of errors in observed rainfall and runoff data on the adjusted model parameter values. Detailed model-verification analyses were only possible at three stations where long-term records were available. Limited model verification at the other gaging stations were performed when data were available.

1980 Land-Use Condition

Calibration and verification of PRMS for 1980 land-use conditions was done using observed daily streamflow data from water years 1977 through 1980. The model was initialized with 1977 water year data, calibrated with 1978 and 1979 data, and verified with 1980 data. Eleven gaging stations were used to some degree in these analyses. Five stations were in operation during the entire period (1977 to 1980): 03213000 Tug Fork at Litwar, W. Va.; 03213500 Panther Creek near Panther, W. Va.; 03213700 Tug Fork at Williamson, W. Va.; 03214000 Tug Fork near Kermit, W. Va.; and 03214900 Tug Fork at Glenhayes, W. Va. Four additional stations were in operation during the last 2 water years 1979 and 1980: 03212700 Elkhorn Creek at Maitland, W. Va.; 03212600 Tug Fork at Welch, W. Va.; 03212985 Dry Fork at Avondale, W. Va.; and 03213800 Pigeon Creek near Lenore, W. Va. The two remaining gages, 03213590 Knox Creek near Kelsa, Va., and 03214700 Rockcastle Creek near Inez, Ky., were only in operation during the 1980 water year for approximately 6 and 10 months, respectively.

Land-use change is a dynamic process. Land disturbed by surface mining may be sporadic or steady in time. To better model the effects of surface-mining activities on flood hydrology, detailed data should be collected to define the time-series of land-use changes. These data may be available from a schedule of the mining activities or by field observation. In this study these data were not available on a year by year basis. Therefore, land-use changes were assumed to be static during the 4-year period. Definition of the land use in the model was taken as the average of the 1976 and 1980 conditions shown in table 6.

Model parameters fall into one of two categories. Those that have physical significance and can be readily measured such as slope, elevation and drainage area, and those that do not have physical interpretations and whose values are more difficult to determine. Usually, those parameters for which little information may be available are the ones that are adjusted during calibration. The guidance for adjusting these parameters is influenced by previous experience and available literature information on the parameters. In addition, sensitivity analyses can be performed during model calibration to determine the more sensitive parameters.

Sensitivity analyses were performed on nine model parameters in this study. Results from these analyses were used for three purposes. First, the results showed which parameters were the most sensitive to adjustment. The most sensitive parameters were subsequently adjusted during calibration. Second, the sensitivity analyses showed which parameters are highly correlated with each other and therefore should not be adjusted together. Last, the results of the sensitivity analyses showed which days or periods of record would strongly influence the automatic optimization of those parameters. Detailed investigation was made of the identified periods to assure proper model computations and to further assure realistic input data, especially rainfall. Because of the obvious non-representative rainfall patterns that were identified at times, automatic optimization was used cautiously.

There were three categories of model parameters. Some model parameters such as potential shortwave radiation were assigned equivalent values throughout the basin. Other parameters were assigned values dependent upon which subwatershed was being modeled, while some parameters were related to individual HRUs. Appendix A lists model parameter information for each category. Included are the model parameter names, their definitions, and values used during model calibration. Table 8 lists selected measured and assigned basin characteristics that were used to differentiate between parts of the basin disturbed by mining and those that have not been disturbed. The flatter slopes and bare cover assigned to mined areas represent those that have been most disturbed. Reclaimed areas were defined as having a cover of grasses that influences precipitation interception storage, infiltration, and resulting surface runoff. Last, the areas classified as other were assigned a vegetation cover and surface slope most closely related to actual basin conditions. These same concepts were used to describe landuse declared as mined, reclaimed, and other for the earlier 1950 period. The only difference, however, were the areas, in acres, actually disturbed by surface mining in 1950 and 1980.

There were seven model parameters that were adjusted during calibration for the 1980 land-use condition. The final values (listed in Table 8) for these parameters were arrived at through a combination of manual adjustment and limited automated optimization. Parameters that were adjusted in the model were those that influenced surface runoff (empirical coefficients SCN and SC1), available moisture storage in the soil (SMAX), percolation of subsurface water (SEP), and coefficients that control the timing and amount of subsurface and ground-water contributions to streamflow (RCF, RCP, and RCB). Data were not available to assign values for the seven model parameters by individual HRU and, therefore, for this study, each parameter was assigned the same value within a subwatershed, regardless of designated land use. Additional data are currently being collected by the Geological Survey to better determine values for SCN, SC1, SMAX, RCF, RCP, RCB, and SEP for surface-mined and reclaimed areas.

Figure 9 shows an example of the fit obtained between observed and model computed discharge hydrographs for the Tug Fork at Litwar, W. Va., for water years 1979 and 1980. Appendix B shows model-computed discharge hydrographs for all 4 water years at each of the 11 gaging stations in the basin. Observed data (when available) are also plotted.

1950 Land-Use Condition

Calibration and verification of PRMS for 1950 land-use conditions were attempted using data available from water years 1951 through 1954. Only three gaging stations were in operation during this period: 03213000 Tug Fork at Litwar, W. Va.; 03213500 Panther Creek near Panther, W. Va.; and 03214000 Tug Fork near Kermit, W. Va. Again, as with the 1980 application, the first year of observed data was used to initialize the model, the second and third years for calibration, and the last for verification.

Table 8.--Selected measured and assigned basin characteristics for the 1980 land-use condition

Reference point (see table 1)	Hydrologic Response Unit	Area (acres)	Land use	Mean elevation (ft)	Average overland slope (ft/ft)	Cover
A	1	2091	Mined	2380	0.0010	Bare
	2	3517	Reclaimed	2380	.0010	Grasses
	3	41860	Other	2380	.1647	Trees
B	4	1723	Mined	2100	.0010	Bare
	5	3970	Reclaimed	2100	.0010	Grasses
	6	50062	Other	2100	.1859	Trees
C	7	67	Mined	1700	.0010	Bare
	8	59	Reclaimed	1700	.0010	Grasses
	9	1871	Other	1700	.3035	Trees
D	10	334	Mined	1600	.0010	Bare
	11	1195	Reclaimed	1600	.0010	Grasses
	12	67193	Other	1600	.1627	Trees
E	13	1527	Mined	2000	.0010	Bare
	14	5002	Reclaimed	2000	.0010	Grasses
	15	139453	Other	2000	.1704	Trees
F	16	4	Mined	1525	.0010	Bare
	17	7659	Other	1525	.1181	Trees
G	18	54	Mined	1550	.0010	Bare
	19	73	Reclaimed	1550	.0010	Grasses
	20	19887	Other	1550	.1331	Trees
H	21	27	Mined	1500	.0010	Bare
	22	185	Reclaimed	1500	.0010	Grasses
	23	16463	Other	1500	.1394	Trees
I2	24	1954	Mined	1500	.0010	Bare
	25	955	Reclaimed	1500	.0010	Grasses
	26	51753	Other	1500	.1674	Trees
I	27	6741	Mined	1500	.0010	Bare
	28	3665	Reclaimed	1500	.0010	Grasses
	29	136780	Other	1500	.1410	Trees
J	30	460	Mined	1200	.0010	Bare
	31	758	Reclaimed	1200	.0010	Grasses
	32	39282	Other	1200	.1855	Trees
K	33	411	Mined	1350	.0010	Bare
	34	884	Reclaimed	1350	.0010	Grasses
	35	59622	Other	1350	.1677	Trees
L	36	1826	Mined	1050	.0010	Bare
	37	1174	Reclaimed	1050	.0010	Grasses
	38	99843	Other	1050	.1846	Trees
M	39	1965	Mined	950	.0010	Bare
	40	1583	Reclaimed	950	.0010	Grasses
	41	37196	Other	950	.1401	Trees
N	42	3699	Mined	850	.0010	Bare
	43	3121	Reclaimed	850	.0010	Grasses
	44	158340	Other	850	.1331	Trees

Table 8 -- Continued

Reference point (see table 1)	HRUs added	Empirical coefficients		SMAX (in.)	Subsurface coefficients		SEP (in./d)	Ground-water coefficient
		SCN	SC1		RCF	RCP		RCB
A	1	0.0011	0.3428	3.970	0.1000	0.2000	0.450	0.0372
	2	.0011	.3428	3.970	.1000	.2000	.450	.0372
	3	.0011	.3428	3.970	.1000	.2000	.450	.0372
B	4	.0009	.4000	4.916	.1500	.2000	.129	.0178
	5	.0009	.4000	4.916	.1500	.2000	.129	.0178
	6	.0009	.4000	4.916	.1500	.2000	.129	.0178
C	7	.0009	.4000	4.795	.1566	.2000	.125	.0099
	8	.0009	.4000	4.795	.1566	.2000	.125	.0099
	9	.0009	.4000	4.795	.1566	.2000	.125	.0099
D	10	.0009	.4000	4.795	.1566	.2000	.125	.0067
	11	.0009	.4000	4.795	.1566	.2000	.125	.0067
	12	.0009	.4000	4.795	.1566	.2000	.125	.0067
E	13	.0009	.4000	4.716	.1651	.2000	.125	.0099
	14	.0009	.4000	4.716	.1651	.2000	.125	.0099
	15	.0009	.4000	4.716	.1651	.2000	.125	.0099
F	16	.0009	.4000	4.795	.1566	.2000	.125	.0067
	17	.0009	.4000	4.795	.1566	.2000	.125	.0067
G	18	.0009	.4000	5.006	.3400	.3000	.125	.0149
	19	.0009	.4000	5.006	.3400	.3000	.125	.0149
	20	.0009	.4000	5.006	.3400	.3000	.125	.0149
H	21	.0009	.4000	4.928	.2300	.2000	.120	.0300
	22	.0009	.4000	4.928	.2300	.2000	.120	.0300
	23	.0009	.4000	4.928	.2300	.2000	.120	.0300
I2	24	.0009	.5000	3.874	.4200	.2000	.050	.0020
	25	.0009	.5000	3.874	.4200	.2000	.050	.0020
	26	.0009	.5000	3.874	.4200	.2000	.050	.0020
I	27	.0009	.4000	4.928	.2300	.2000	.120	.0300
	28	.0009	.4000	4.928	.2300	.2000	.120	.0300
	29	.0009	.4000	4.928	.2300	.2000	.120	.0300
J	30	.0009	.4000	4.928	.2300	.2000	.120	.0300
	31	.0009	.4000	4.928	.2300	.2000	.120	.0300
	32	.0009	.4000	4.928	.2300	.2000	.120	.0300
K	33	.0009	.4000	5.006	.2700	.2000	.150	.0100
	34	.0009	.4000	5.006	.2700	.2000	.150	.0100
	35	.0009	.4000	5.006	.2700	.2000	.150	.0100
L	36	.0009	.4000	6.884	.5466	.2000	.125	.0094
	37	.0009	.4000	6.884	.5466	.2000	.125	.0094
	38	.0009	.4000	6.884	.5466	.2000	.125	.0094
M	39	.0009	.3524	5.006	.3111	.2000	.255	.0200
	40	.0009	.3524	5.006	.3111	.2000	.255	.0200
	41	.0009	.3524	5.006	.3111	.2000	.255	.0200
N	42	.0009	.4000	5.006	.3111	.2000	.100	.0065
	43	.0009	.4000	5.006	.3111	.2000	.100	.0065
	44	.0009	.4000	5.006	.3111	.2000	.100	.0065

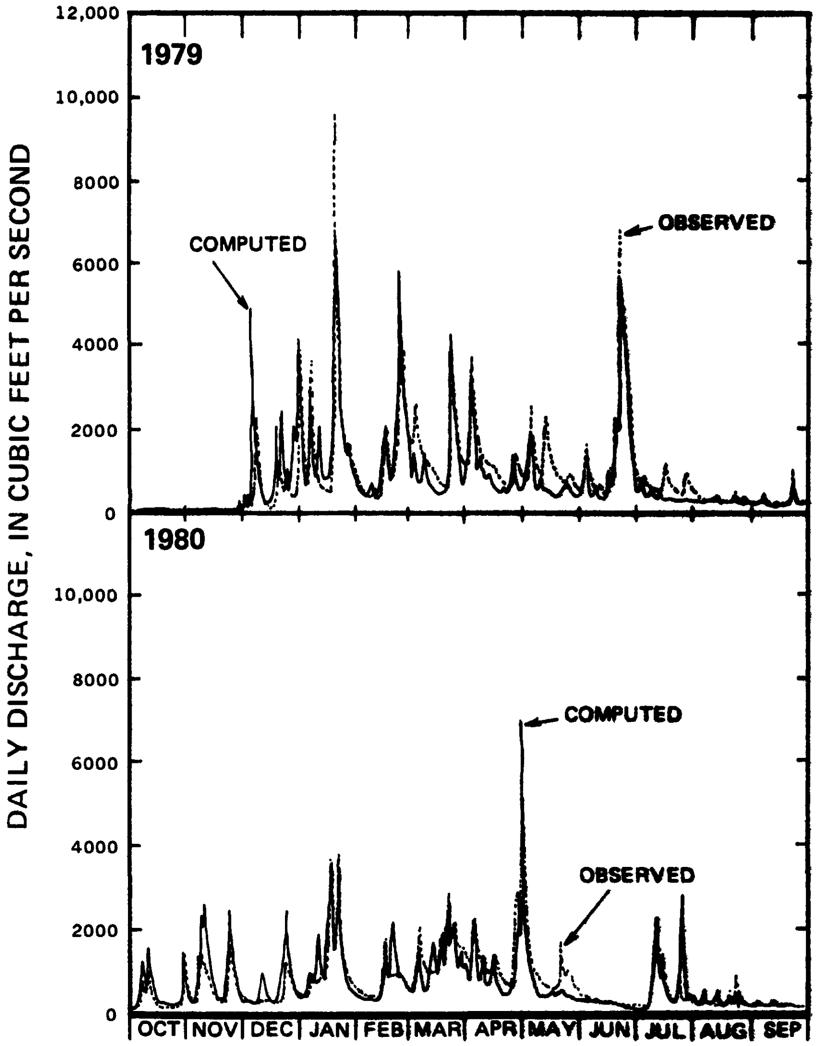

Figure 9.--Observed and computed mean daily discharge hydrographs for Tug Fork at Litwar, W. Va., for water years 1979 and 1980.

Since there was little change from 1950 to 1960 in the drainage areas that were disturbed by surface mining, the 1950 and 1960 land-use data were averaged to define mined and reclaimed areas in the basin. Each of the 44 HRU's were subsequently redefined with drainage areas corresponding to the earlier period land-use definition. The parameters optimized and adjusted in the 1980 calibration--SCN, SC1, SMAX, SEP, RCF, RCP, and RCB--were again analyzed during the 1950 calibration. Several optimization and calibration runs were made with these parameters being assigned initial values equal to the final 1980 calibration results. The model simulations did not improve significantly when the parameters were changed from the initial values. It must be emphasized that with only three available streamflow gaging stations during the earlier period, the information needed for spatial definition of these parameters is limited. However, it is reasonable to expect that these parameters should not differ appreciably from 1980 values since overall physical characteristics of the basin have changed very little since 1950. Therefore, the only change in the earlier period model was the size of areas defined as mined, reclaimed, and other. Table 9 lists the drainage areas in acres for the 44 HRUs. Other information about each HRU remained the same as presented in table 8. Figure 10 shows observed and computed discharge hydrographs for the Tug Fork at Litwar, W. Va., for water years 1952 and 1953.

SIMULATION AND FREQUENCY ANALYSIS OF LONG-TERM STREAMFLOW TIME SERIES

Long-term daily rainfall data (1951-1980) measured at three basin gages (Gary W. Va., Williamson, W. Va., and Louisa, Ky.) were used in the model for both calibrated conditions, and daily-mean streamflow representing 1950 and 1980 land-use conditions were simulated. Model output was generated at the 15 sites shown in table 1. Tables 10, 11, and 12 list both observed and computed highest and second highest annual discharges for selected years at the three long-term gaging stations, Tug Fork at Litwar, W. Va., Panther Creek near Panther, W. Va., and Tug Fork near Kermit, W. Va. The computed errors for the streamflow time series representing 1950 land-use conditions were based on 1952-1960 data at Tug Fork at Litwar, W. Va., and Tug Fork near Kermit, W. Va. Errors for the 1980 streamflow time series were based on 1976-1980 data at these same two stations. Since little mining occurred in the Panther Creek near Panther, W. Va., basin from 1950 to 1980, errors were computed for the entire period (1952-1980) for only the 1980 discharge time series. Average errors for the highest and second highest annual predicted discharges were: Tug Fork at Litwar, W. Va., 3.5 and -9.7 percent, respectively, and Tug Fork near Kermit, W. Va., -20.6 and -10.9 percent. The same two average errors for Panther Creek near Panther, W. Va., were -24.7 and -23.7 percent. Since the 1980 calibrated model was used entirely for the Panther Creek analysis, the closeness of the average error indicates the model is consistent for reproducing higher flows at the Panther Creek outlet. In addition, tables 10, 11, and 12 list the number

Table 9.--Drainage areas corresponding to the early period (1950) land-use conditions for each hydrologic response unit

Reference point (see table 1)	Hydrologic Response Unit	Area (acres)	Land use
A	1	387	Mined
	2	0	Reclaimed
	3	47152	Other
B	4	119	Mined
	5	0	Reclaimed
	6	55732	Other
C	7	0	Mined
	8	0	Reclaimed
	9	2002	Other
D	10	143	Mined
	11	0	Reclaimed
	12	68597	Other
E	13	463	Mined
	14	0	Reclaimed
	15	145606	Other
F	16	0	Mined
	17	7663	Other
G	18	11	Mined
	19	0	Reclaimed
	20	20004	Other
H	21	6	Mined
	22	0	Reclaimed
	23	16513	Other
I2	24	86	Mined
	25	0	Reclaimed
	26	54616	Other
I	27	1743	Mined
	28	0	Reclaimed
	29	145528	Other
J	30	377	Mined
	31	5	Reclaimed
	32	40132	Other
K	33	71	Mined
	34	0	Reclaimed
	35	60863	Other
L	36	126	Mined
	37	0	Reclaimed
	38	102765	Other
M	39	0	Mined
	40	0	Reclaimed
	41	40778	Other
N	42	28	Mined
	43	0	Reclaimed
	44	166051	Other

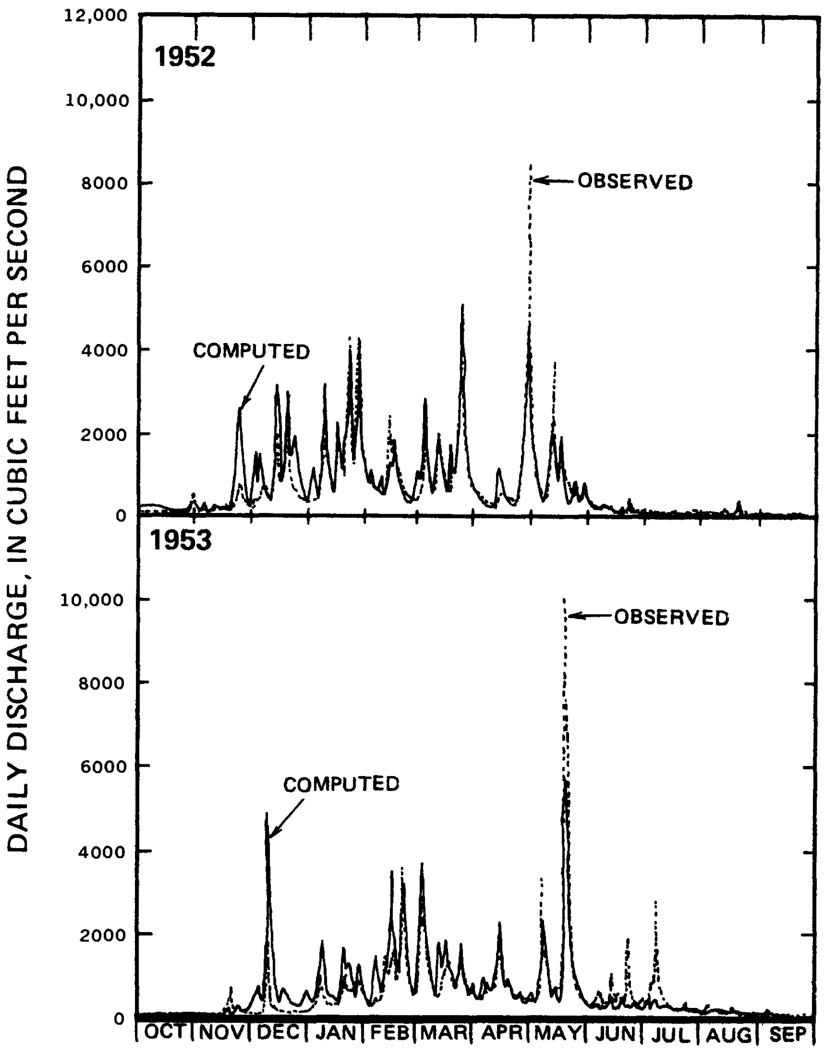

Figure 10.--Observed and computed mean daily discharge hydrographs for Tug Fork at Litwar, W. Va., for water years 1952 and 1953.

Table 10.--Difference between observed and computed streamflow at station 03213000, Tug Fork at Litwar, W. Va.

	Highest annual discharge* in cubic feet per second			Second highest annual discharge* in cubic feet per second		
Year	Observed	Predicted	Percentage Error*	Observed	Predicted	Percentage Error*
			Results using 1950 calibrated model			
1952	8,440	4,522	-46	5,190	4,073	-22
1953	10,100	5,486	-46.	3,650	3,326	-9.
1954	7,770	25,716	231.	4,980	2,349	-53.
1955	15,000	11,211	-25.	5,400	3,681	-32.
1956	9,700	7,694	-21.	4,810	4,216	-12.
1957	19,000	12,245	-36.	4,240	5,672	34.
1958	9,700	7,604	-22.	8,760	6,314	-28.
1959	4,810	3,997	-17.	3,720	2,491	-33.
1960	3,130	5,461	74.	2,550	2,147	-16.
			Results using 1980 calibrated model			
1976	3,640	5,084	40.	2,650	2,557	-4.
1977	22,000	24,130	10.	4,370	7,135	63.
1978	15,500	3,224	-79.	6,990	6,471	-7.
1979	9,620	7,162	-26.	6,920	5,627	-19.
1980	6,311	7,063	12.	3,820	3,880	2.
Average	10,337	9,328	3.5	4,861	4,281	-9.7
Number of + errors			5			3
Number of - errors			9			11
Percent of + errors			35.7			21.4
Percent of - errors			64.3			78.6

*Based on observed discharge.

Table 11.--Difference between observed and computed streamflow at station 03213500, Panther Creek near Panther, W. Va.

Year	Highest annual discharge* in cubic feet per second			Second highest annual discharge* in cubic feet per second		
	Observed	Predicted	Percentage Error*	Observed	Predicted	Percentage Error*
Results using 1980 calibrated model						
1952	804	372	-54.	764	329	-57.
1953	731	444	-39.	514	265	-48.
1954	301	211	-30.	281	305	9.
1955	1430	810	-43.	1160	805	-31.
1956	825	600	-27.	618	429	-31.
1957	2250	919	-59.	398	467	17.
1958	730	598	-18.	539	534	-1.
1959	909	201	-78.	493	316	-36.
1960	439	426	-3.	305	187	-39.
1961	760	139	-82.	575	407	-29.
1962	690	425	-38.	401	247	-38.
1963	2090	1059	-49.	1020	676	-34.
1964	389	226	-42.	386	433	12.
1965	799	446	-44.	767	934	22.
1966	585	664	14.	522	519	0.
1967	1290	630	-51.	499	201	-60.
1968	492	385	-22.	300	145	-52.
1969	176	236	34.	139	33	-76.
1970	795	373	-53.	598	263	-56.
1971	671	855	27.	409	304	-26.
1972	855	703	-18.	847	346	-59.
1973	890	752	-15.	682	682	0.
1974	1060	642	-39.	606	507	-16.
1975	910	904	-1.	706	467	-34.
1976	247	436	77.	229	210	-8.
1977	2300	1830	-20.	658	608	-8.
1978	1100	285	-74.	488	530	9.
1979	955	577	-40.	756	429	-43.
1980	332	566	71.	242	304	26.
Average	890	576	-24.7	548	402	-23.7
Number of + errors			5			6
Number of - errors			24			22
Percent of + errors			17.2			21.4
Percent of - errors			82.8			78.6

*Based on observed discharge.

Table 12.--Difference between observed and computed streamflow at station 03214000, Tug Fork near Kermit, W. Va.

	Highest annual discharge* in cubic feet per second			Second highest annual discharge* in cubic feet per second		
Year	Observed	Predicted	Percentage Error*	Observed	Predicted	Percentage Error*
			Results using 1950 calibrated model			
1952	25,200	13,826	-45.	15,600	5,800	-63.
1953	16,400	6,774	-59.	10,300	6,349	-38.
1954	12,800	28,448	122.	5,770	13,431	133.
1955	41,300	25,777	-38.	12,000	8,227	-31.
1956	28,100	16,160	-42.	16,900	16,637	-2.
1957	52,900	21,150	-60.	17,200	12,646	-26.
1958	39,200	21,755	-45.	10,900	7,881	-28.
1959	12,000	7,211	-40.	8,740	8,125	-7.
1960	6,430	11,804	84.	6,360	6,388	0.
			Results using 1980 calibrated model			
1976	9,640	10,500	9.	7,570	11,858	57.
1977	78,000	31,764	-59.	22,000	11,708	-47.
1978	38,080	3,627	-90.	21,900	13,523	-38.
1979	33,200	27,841	-16.	30,300	14,039	-54.
1980	8,780	7,935	-10.	7,000	6,358	-9.
Average	28,716	16,755	-20.6	13,752	10,212	-10.9
Number of + errors			3			3
Number of - errors			11			11
Percent of + errors			21.4			21.4
Percent of - errors			78.6			78.6

*Based on observed discharge.

and percent of positive (+) and negative (-) errors which indicate that the model underestimates peak flows. It is interesting to note that the percent of negative and positive errors for the second highest discharge were, respectively, 78.6 and 21.4 percent at all three locations.

A statistical frequency analysis was performed on each long-term streamflow time series generated by the model for the 1950 and 1980 calibrated conditions. A Geological Survey streamflow statistics computer program A969 (Meeks, 1975) was used to produce flow-duration tables, low-flow and high-flow sequence summaries, and fit the low-flow and high-flow data to a log-Pearson Type III frequency distribution. Annual peak discharges are considered a succession of random events which can be described by the log-Pearson Type III distribution with the parameters mean, standard deviation, and skew coefficient (Water Resources Council, 1981). For this analysis, the skew coefficient was not weighted with an assigned regional value.

Table 13 lists frequency-analysis results for all 15 points of interest for both the 1950 and 1980 model simulations. No trend is evident from these data. The greatest difference is less than 1 percent.

DETECTION OF HYDROLOGIC CHANGE

Annual 1-day high flows were selected from both long-term streamflow time series. These data were analyzed with several statistical tests to determine if there is a significant difference between them. Two standard nonparametric statistical tests -- (1) the Sign Test (Dixon and Massey, 1957), and (2) the Mann-Whitney Test (Shiau and Condie, 1980) -- were used to test the two time series for homogeneity. In addition, a linear-regression analysis was performed on the data to study the relationships between the two series at each of the 15 locations.

Statistical Tests for Differences

The following steps were used in performing the two nonparametric statistical tests:

(a) The null hypothesis, H_0, stated that there was no difference between the two time series.

(b) Significance levels, $\alpha = 0.05$ and $\alpha = 0.01$ were selected.

(c) The test statistic for each test was computed.

(d) A region of rejection was defined for the chosen significance level.

(e) If the computed test statistic lies in the region of rejection, then the null hypothesis is rejected.

Table 13.--Frequency analysis results for Tug Fork stations for 1950 and 1980 basin conditions, annual 1-day high streamflow in cubic feet per second

Reference point (See Table 1)	Name	Calibration used	Recurrence interval						
			2 year	5 year	10 year	25 year	50 year	100 year	200 year
A	Elkhorn Cr. at	1950	806	1227	1581	2128	2618	3187	3849
	Maitland, W. Va.	1980	806	1226	1580	2127	2618	3189	3853
B	Tug Fork at	1950	1360	2085	2713	3707	4617	5694	6969
	Welch, W. Va.	1980	1357	2082	2711	3711	4628	5715	7006
C	Tug Fork below	1950	2216	3385	4387	5959	7387	9066	11042
	Welch, W. Va.	1980	2213	3382	4385	5962	7395	9083	11070
D	Tug Fork at	1950	3837	5863	7594	10306	12762	15645	19030
	Iaeger, W. Va.	1980	3832	5859	7597	10325	12802	15715	19143
E	Dry Fork Cr. at	1950	3480	5297	6847	9269	11461	14028	17041
	Avondale, W. Va.	1980	3475	5291	6840	9265	11460	14033	17055
F	Tug Fork at	1950	7489	11421	14782	20046	24816	30413	36989
	Litwar, W. Va.	1980	7488	11423	14785	20052	24825	30425	37005
G	Panther Cr. near	1950	613	908	1152	1523	1849	2224	2655
	Panther, W. Va.	1980	613	908	1152	1523	1849	2224	2655
H	Tug Fork below	1950	8166	12359	15912	21435	26406	32208	38987
	Panther, W. Va.	1980	8168	12362	15916	21442	26415	32219	39001
I	Tug Fork at	1950	12879	18365	22033	26687	30163	33644	37152
	Matewan, W. Va.	1980	12884	18384	22071	26759	30267	33784	37335
I2	Knox Cr. near	1950	2075	3002	3611	4370	4926	5473	6017
	Kelsa, Va.	1980	2077	3004	3610	4363	4913	5454	5989
J	Tug Fork at	1950	13914	19818	23678	28481	32000	35470	38915
	Williamson, W. Va.	1980	13920	19838	23716	28547	32092	35592	39071
K	Pigeon Cr. near	1950	1985	2919	3529	4286	4838	5378	5910
	Lenore, W. Va.	1980	1985	2918	3529	4285	4836	5375	5907
L	Tug Fork near	1950	16243	22824	26930	31833	35292	38599	41784
	Kermit, W. Va.	1980	16235	22811	26915	31820	35282	38592	41784
M	Rockcastle Cr.	1950	1055	1558	1953	2529	3017	3561	4167
	near Inez, Ky.	1980	1055	1556	1950	2525	3012	3554	4158
N	Tug Fork at	1950	19843	27730	32552	38209	42134	45835	49355
	Glenhayes, W. Va.	1980	19823	27716	32551	38233	42183	45912	49464

It was determined that for these two tests, there is no statistically significant difference between the two time series at any of the 15 locations in the basin. Table 14 lists computed values for the Mann-Whitney test statistic Z. As seen, all values are well within the region for accepting the null hypothesis.

In addition, a linear-regression analysis, relating corresponding 1950 and 1980 simulated flood flows, was performed on the data to study the relationships between the two series at each location. At the 98 percent confidence level for a two-tail test, it was determined that the slopes of each relation were not different from unity indicating no difference between the two time series at any of the locations.

Discrepancies in the Modeling Process

At the outset of the study it was reasoned that a comparison of the long-term streamflow time series generated for 1950 and 1980 land-use conditions may or may not show statistical differences depending on the degree of impact and the model capability to detect impact. Thus, it is important to identify possible discrepancies in the modeling process or "model noise" that may be responsible for overshadowing the difference, if any.

Panther Creek near Panther, W. Va., the smallest (31.0 mi^2) and least-disturbed (less than 1 percent) subwatershed in the basin was selected for an analysis to determine "model noise." Discharge data are available from 1946 to present and were used to compute an observed frequency distribution of annual one-day high streamflows. Model calibrations were performed with data for the entire 1950-1980 period and for three separate shorter 1-year periods representing land-use conditions in 1950, 1960, and 1980. The four calibrated models were used to simulate separate long-term streamflow time series using long-term rainfall. Frequency distributions for simulated annual 1-day high streamflows were then computed for each time series. These results are presented in table 15 and it can be seen that all computed annual 1-day high streamflows, except the 2-year 1960 computed value, are less than the corresponding observed streamflow for the same recurrence interval with errors ranging from +1.0 to -24.7 percent. Thus, errors can occur from the years selected for calibration, in this case by as much as 20 percent. Also presented in the table are computed errors for the shorter calibration periods based on the long-term 1950-1980 calibration results. These results show how different time periods can influence model calibration. It can be seen that the 1950 calibration represented the long-term average better than the 1960 and 1980 calibrations. However, the fluctuations for the 1960 and 1980 calibrations were within ±10 percent.

There are many sources of error that can contribute to modeling error. Data measurement errors, model parameter errors, and errors in the model's representation of the real world are the most important. For example, Dawdy and Bergmann (1969) stated that with a single rain gage in the basin, peak discharges can at best be

Table 14.--Results of Mann-Whitney nonparametric statistical test for homogeneity between the 1950 and 1980 streamflow time series

Reference point	Name	Computed Z statistic*
A	Elkhorn Cr. at Maitland, W. Va.	-0.086
B	Tug Fork at Welch, W. Va.	-.148
C	Tug Fork below Welch, W. Va.	-.117
D	Tug Fork at Iaeger, W. Va.	-.132
E	Dry Fork Cr. at Avondale, W. Va.	-.132
F	Tug Fork at Litwar, W. Va.	-.117
G	Panther Cr. near Panther, W. Va.	-.078
H	Tug Fork below Panther, W. Va.	-.117
I	Tug Fork at Matewan, W. Va.	-.117
I2	Knox Cr. near Kelsa, Va.	-.109
J	Tug Fork at Williamson, W. Va.	-.101
K	Pigeon Cr. near Lenore, W. Va.	-.140
L	Tug Fork near Kermit, W. Va.	-.132
M	Rockcastle Cr. near Inez, Ky	-.101
N	Tug Fork at Glenhayes, W. Va.	-.148

*Region of rejection of null H_0, that there was no difference between the two time series, for significance level = 0.05, $Z < -1.645$; and for significance level = 0.01, $Z < -2.326$.

Table 15.--Frequency analyses for observed, 1950-1980 calibration, 1950-calibration, 1960-calibration, and 1980-calibration streamflow data for Panther Creek near Panther, W. Va.

Recurrence interval (years)	1-day annual high streamflow, in ft^3/s				
	Observed	1950-1980	1950	1960	1980
2	768	701	701	776	631
5	1241	1028	1028	1109	935
10	1570	1294	1293	1362	1182
25	1993	1693	1692	1720	1551
50	2311	2040	2039	2016	1871
100	2629	2434	2433	2338	2235
200	2948	2883	2881	2691	2648
Differences, in percent, based on observed streamflow frequencies					
2		-8.7	-8.7	+1.0	-17.8
5		-17.2	-17.2	-10.6	-24.7
10		-17.6	-17.6	-13.2	-24.7
25		-15.1	-15.1	-13.7	-22.2
50		-11.7	-11.8	-12.8	-19.0
100		-7.4	-7.5	-11.1	-15.0
200		-2.2	-2.3	-8.7	-10.2
Differences, in percent, based on 1950-1980 calibration					
2			0	+10.7	-10.0
5			0	+7.9	-9.0
10			-0.1	+5.3	-8.7
25			-.1	+1.6	-8.4
50			-.05	-1.2	-8.3
100			-.04	-3.9	-8.2
200			-.07	-6.7	-8.2

predicted with a standard error of estimate on the order of 20 percent. Their analysis involved studying the effect of rainfall variability with 3 recording rain gages in a 9.7-square-mile basin in southern California. By far, the most important error in these tests was inadequate representation of actual Panther Creek basin rainfall. Input to the model was rainfall measured at Gary, W. Va., located about 20 miles outside the Panther Creek basin. At times, rainfall was measured at Gary with no corresponding rise in flow on Panther Creek, and vice versa. Thus the significant error and bias in computed flood discharges for Panther Creek may largely be attributed to inadequate rainfall representation.

PRMS APPLICATION TO HYPOTHETICAL MINING LAND-USE SCENARIOS

An analysis was made with the 1980 calibrated model for several hypothetical future land-use scenarios reflecting various increases in surface-mining activity in a particular part of the basin. Environmental regulations such as Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977, require that the probable hydrologic consequences of mining and the cumulative impacts on the environment be determined as part of the application process for a mining permit.

The 85.8-square-mile subwatershed, Tug Fork at Welch, W. Va., was selected as the area to be hypothetically disturbed and the effect of the disturbance was analyzed at its outlet and at downstream points along the Tug Fork at Litwar, Williamson, Kermit, and Glenhayes. Since 1950, mining has increased from 0.13 to 10.77 percent in this subwatershed. Hypothetical increases in mining of 50, 100, and 200 percent were simulated by increasing the present mined area to 9.24 mi^2, 13.87 mi^2, 18.48 mi^2, and 27.72 mi^2, respectively. Other model parameters remained the same for these analyses. Long-term rainfall data (1951-1980) were input to the model for present land-use conditions and land-use conditions representing the hypothetical mining increases.

Table 16 lists results of frequency analyses performed on each generated discharge time series for annual 1-day high streamflows. The effect at the subwatershed outlet (Tug fork at Welch, W. Va.) even for the greatest increase in mining activities, is only 1.5 percent for the 200-year recurrence interval flow. Downstream at the other stations there is essentially no effect from the increased mining occurring upstream.

As a further check on the potential impact, an additional scenario was simulated. This scenario assumes all precipitation falling on existing surface-mined and reclaimed areas in the Tug Fork basin directly drains to the streams and that none of the precipitation is stored on the surface or infiltrates the soil. This scenario then defines the possible range of impact from surface mining on flooding. Table 17 shows the increases and percent change for five of the points on the main stem of the Tug Fork. The true answer lies somewhere between zero and the increase illustrated for the worst condition in table 17. As the table shows, the percent

Table 16.--Hypothetical increases in surface mining applied to 85.8-square-mile basin, Tug Fork at Welch, W. Va., annual 1-day high streamflow in cubic feet per second

Station number	Station name	Location river mile	Percent increase in mining	Recurrence interval						
				2	5	10	25	50	100	200
03212600	Tug Fork at Welch, W. Va.	135.80	present	1357	2082	2711	3711	4628	5715	7006
			50	1358	2083	2714	3716	4636	5728	7025
			100	1358	2084	2717	3723	4649	5750	7058
			200	1360	2088	2723	3737	4672	5784	7108
03213000	Tug Fork at Litwar, W. Va.	107.00	present	7488	11423	14785	20052	24825	30425	37005
			50	7486	11415	14774	20037	24806	30403	36980
			100	7485	11418	14783	20060	24846	30468	37078
			200	7486	11417	14782	20059	24846	30469	37082
03213700	Tug Fork at Williamson, W. Va.	57.40	present	13920	19838	23716	28547	32092	35592	39071
			50	13919	19838	23716	28548	32095	35596	39076
			100	13914	19826	23699	28526	32068	35566	39043
			200	13915	19831	23710	28547	32099	35608	39098
03214000	Tug Fork near Kermit, W. Va.	38.40	present	16235	22811	26915	31820	35282	38592	41784
			50	16236	22810	26915	31819	35282	38593	41786
			100	16236	22816	26926	31839	35309	38628	41829
			200	16240	22828	26944	31868	35346	38674	41885
03214900	Tug Fork at Glenhayes W. Va.	9.50	present	19823	27716	32551	38233	42183	45912	49464
			50	19823	27716	32551	38233	42183	45912	49464
			100	19829	27721	32552	38228	42172	45894	49437
			200	19831	27725	32561	38243	42192	45921	49471

Table 17.--Comparison of present and worst case mining scenario for entire Tug Fork basin, annual 1-day high streamflow in cubic feet per second

Station number	Station name	Location river mile	Mining condition	Recurrence interval						
				2	5	10	25	50	100	200
03212600	Tug Fork	135.80	Present	1357	2082	2711	3711	4628	5715	7006
	at		Worst case	1556	2308	2960	3997	4948	6075	7414
	Welch,		Increase (%)	14.6	10.9	9.2	7.7	6.9	6.3	5.8
	W. Va.									
03213000	Tug Fork	107.00	Present	7488	11423	14785	20052	24825	30425	37005
	at		Worst case	8147	12182	15651	21111	26080	31937	38845
	Litwar,		Increase (%)	8.8	6.6	5.9	5.3	5.1	5.0	5.0
	W. Va.									
03213700	Tug Fork	57.40	Present	13920	19838	23716	28547	32092	35592	39071
	at		Worst case	14648	20669	24605	29503	33098	36647	40176
	Williamson,		Increase (%)	5.2	4.2	3.7	3.3	3.1	3.0	2.8
	W. Va.									
03214000	Tug Fork	38.40	Present	16235	22811	26915	31820	35282	38592	41784
	near		Worst case	16911	23667	27904	32986	36589	40047	43393
	Kermit,		Increase (%)	4.2	3.8	3.7	3.7	3.7	3.8	3.9
	W. Va.									
03214900	Tug Fork	9.50	Present	19823	27716	32551	38233	42183	45912	49464
	at		Worst case	20508	28527	33460	39285	43354	47214	50906
	Glenhayes		Increase (%)	3.5	2.9	2.8	2.8	2.8	2.8	2.9
	W. Va.									

change is less than 4 percent for all recurrence intervals at the Tug Fork at Glenhayes, W. Va.

The analysis in which hypothetical increases in mining were simulated and the scenario where all areas disturbed by mining were assumed totally impervious allow these conclusions to be made:

1. That the model output is not very sensitive to the parameters that were changed to reflect mining; and

2. The effects of surface mining cause the greatest change near the disturbed area.

SUMMARY

The Geological Survey PRMS rainfall-runoff model was calibrated and verified for the 1,560-square-mile Tug Fork basin located in Kentucky, Virginia, and West Virginia. Land-use changes have occurred in the basin during the last 30 years and the calibrated model was used to simulate long-term daily streamflow time series corresponding to 1950 and 1980 land-use conditions. The two time series were analyzed at 15 points in the basin to determine if a change in flood characteristics had occurred that could be attributed to surface-mining activities.

Non-parametric statistical tests were used to analyze the series of annual 1-day high flows abstracted from the long-term daily streamflow time series. Results from these statistical analyses indicate that there is no statistical difference between model-generated flood flows with the 1950 and 1980 conditions at any of 15 basin locations. An analysis to determine discrepancies in the modeling process or "model noise" was performed on the least-disturbed subwatershed in the basin, Panther Creek near Panther, W. Va. The results showed that "model noise" can produce bias in the computed frequencies for simulated discharges by as much as 20 percent. Because of data errors, due principally to nonrepresentation of rainfall characteristics, the failure of statistical tests to indicate significant differences between the modeled streamflow time series cannot be stated as conclusive evidence that flood flows have not increased as a result of mining activities.

An analysis was made of the 85.8-square-mile watershed, Tug Fork at Welch, W. Va., in the headwaters of the basin. Hypothetical land-use scenarios were simulated with the model to determine the hydrologic impacts and consequences of increasing mining within the small subwatershed by 50, 100, and 200 percent above present levels. This analysis showed that the increases in surface mining, even for the 200 percent increase, had little effect on streamflow in the immediate area and no effect on streamflow at downstream locations along the Tug Fork. Additional hypothetical conditions were tested with the model by assuming that all precipitation falling on surface-mined and reclaimed areas in the Tug Fork basin drained directly to the stream. These results showed that even if all the areas

disturbed by mining were made impervious that flows at the basin outlet (Tug Fork at Glenhayes, W. Va.) would only increase by less than 4 percent. However, changes in upstream flows could be more significant. These hypothetical analyses allow these conclusions to be made:

1. That the model output is not very sensitive to the parameters that were changed to reflect mining; and

2. The effects of surface mining cause the greatest change near the disturbed area.

This study has attempted to determine if land-use changes associated with surface mining in the Tug Fork basin have significantly affected the characteristics and patterns of storm runoff in the basin since 1950. The tools and techniques that were used did not prove that there has been a statistically significant change, because modeling discrepancies resulting from limited data were probably larger than possible changes due to surface mining, or the model did not adequately reflect the real changes that were taking place. Until the additional streamflow data from surface mining sites are incorporated, the modeling results obtained in this study must be accepted with reservations.

Hydrologic impacts from surface mining result largely from changes in (1) vegetation, (2) soils, (3) land configuration, and (4) removal of coal aquifers. This study focused primarily on the effects from changes in vegetation because of limited information on basin characteristics and streamflow data from surface mining sites that were not available to calibrate, in detail, the effects of soils, land configuration, and removal of coal aquifers. In order to evaluate the full impact of surface mining, all the changes must be considered.

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APPENDIX A

Model Input Data

Model input data values for selected parameters are presented in Appendix A. The variable used to represent the parameter in the model is defined as well as a brief definition of the parameter.

Climate Data

Values for potential shortwave radiation (in Langleys per day) for 24 specific dates from December 22 to June 22 were defined for 6 solar radiation planes.

Date(s)	Shortwave radiation, in Langleys per day					
	Solar radiation plane					
	HOR*	N20	NE10*	NE20	ENE1	E20
Dec. 22	359.2	190.5	299.7	245.6	327.8	361.7
Jan. 10, Dec. 3	383.6	214.5	324.3	269.9	352.3	385.8
Jan. 23, Nov. 19	425.5	257.0	366.9	312.3	394.5	427.2
Feb. 7, Nov. 5	485.0	319.9	428.2	374.1	454.8	486.0
Feb. 20, Oct 22	558.4	401.2	504.8	452.5	529.9	558.4
Mar. 7, Oct. 8	639.4	495.6	590.9	541.8	613.4	638.1
Mar. 21, Sep. 23	722.7	597.8	680.9	636.6	700.1	719.9
Apr. 4, Sep. 9	802.1	700.2	768.3	730.4	783.6	797.8
Apr. 19, Aug. 25	872.0	794.7	846.8	815.9	857.9	866.0
May 3, Aug. 10	930.2	877.0	913.5	889.7	920.5	922.9
May 18, July 27	974.3	942.0	965.1	947.6	968.4	965.8
June 1, July 12	1004.0	987.3	1000.4	987.7	1001.0	994.7
June 22	1020.9	1013.5	1020.6	1010.9	1019.5	1011.1

*For example, HOR is for a horizontal plane and NE10 is for a plane with a northeast aspect and 10 percent slope.

The monthly values listed below were used to describe the following variables:

PAT, the maximum air temperature (in degrees Fahrenheit) which when exceeded forces precipitation to be rain regardless of minimum temperature.

AJMX, adjustment factor for proportion of rain in a rain-snow mix event.

TLX, lapse rate for maximum daily air temperature.

TLN, lapse rate for minimum daily air temperature.

Month	PAT	AJMX	TLX	TLN
January	50.	1.0	1.5	1.5
February	50.	1.0	1.5	1.5
March	45.	1.1	1.5	1.5
April	40.	1.2	1.5	1.5
May	40.	1.1	1.5	1.5
June	40.	1.0	1.5	1.5
July	40.	1.0	1.5	1.5
August	40.	1.0	1.5	1.5
September	40.	1.0	1.5	1.5
October	40.	1.0	1.5	1.5
November	50.	1.0	1.5	1.5
December	50.	1.0	1.5	1.5

The following variables and associated values were also used in defining Climate Data.

Variable	Description	Value
PARS	Predicted solar radiation correction factor for summer day with precipitation.	0.44
PARW	Predicted solar radiation correction factor for winter day with precipitation.	.50
RDMX	Maximum percent of potential solar radiation.	1.00
CSEL	Climate station elevation, in feet.	1500.
RMXA	Proportion of rain in a rain-snow precipitation event above which snow albedo is not reset (snowpack accumulation stage).	.8
RMSM	Same as RMXA but for snowpack stage.	.6
CTS	Air temperature ET coefficient.	.0111
TST	Temperature index to determine specific date of start of transpiration.	1000.
CTW	Proportion of potential evapotranspiration that is sublimated from a snow surface (decimal form).	.75
ISP1	Julian date to start looking for spring snowmelt stage.	60.
ISP2	Julian date to force snowpack to spring snowmelt stage.	115
EAIR	Emissivity of dry air.	.85
FWCAP	Free water holding capacity of snowpack expressed as a decimal fraction of total snowpack water equivalent.	.04
DENI	Initial density of new-fallen snow.	.20
DENMX	Average maximum snowpack density.	.45
SETCON	Snowpack settlement time constant.	.10
BST	Temperature above which precipitation is all rain and below which it is all snow, in degrees Fahrenheit.	30.

Subwatershed Reservoir Information

The Tug Fork basin was divided into 15 subwatersheds as identified by outlet in table 1. Each subwatershed had one corresponding subsurface and ground-water reservoir. Some of the coefficients used in relationships to define flow into and out of these reservoirs have already been listed in table 8 (by individual HRU). The remaining coefficients are listed in the table below and their definitions are as follows:

KRSP(I), the index of the ground-water reservoir receiving seepage from subsurface reservoir I; I=1,NRES where NRES equals the number of subsurface flow routing reservoirs (15 in this study).

RES, the initial storage in each subsurface flow routing reservoir, in inches.

GW, the initial storage in each ground-water flow routing reservoir, in inches.

RESMX, coefficient for computing seepage from subsurface reservoir I to its designated ground-water reservoir.

REXP, exponent coefficient for computing seepage from subsurface reservoir I to its designated ground-water reservoir.

GSNK, coefficient used in computing the seepage rate from ground-water reservoir I to a ground-water sink.

Subwatershed Outlet, (see reference point, table 1)	KRSP(I) I=1,15	RES (in inches)	GW (in inches)	RESMX Subsurface Coefficient	REXP Subsurface Exponent Coefficient	GSNK Ground-Water Coefficient
A	1	0.2	1.0	1.0	1.0	0.0
B	2	.2	1.0	1.0	1.0	0.0
C	3	.2	1.0	1.0	1.0	0.0
D	4	.2	1.0	1.0	1.0	0.0
E	5	.2	1.0	1.0	1.0	0.0
F	6	.2	1.0	1.0	1.0	0.0
G	7	.2	1.0	1.0	1.0	0.0
H	8	.2	1.0	1.0	1.0	0.0
I2	9	.2	1.0	1.0	1.0	0.0
I	10	.2	1.0	1.0	1.0	0.0
J	11	.2	1.0	1.0	1.0	0.0
K	12	.2	1.0	1.0	1.0	0.0
L	13	.2	1.0	1.0	1.0	0.0
M	14	.2	1.0	1.0	1.0	0.0
N	15	.2	1.0	1.0	1.0	0.0

HRU Information

Table 8 listed selective measured basin characteristics for each of the 44 HRUs. There were 27 other model parameters that had to be defined for each HRU. These are defined below. Seven of the 27 parameters were assigned constant values throughout the basin while the remaining 20 parameters were given different values. Data for the 20 parameters are presented in the table that follows the parameter definitions.

IRU, Hydrologic Response Unit identification

IRD, Solar radiation plane index associated with this HRU. Six solar radiation planes were defined under Climate Data. The index and associated identification is as follows:

IRD	Solar Radiation Plane
1	HOR
2	N20
3	NE10
4	NE20
5	ENE1
6	E20

COVDNS, Summer vegetation cover density (decimal)

COVDNW, Winter vegetation cover density (decimal)

TRNCF, Transmission coefficient for shortwave radiation through the winter vegetation canopy (decimal form)

SNST, Interception storage capacity of major winter vegetation for snow (inches-water equivalent)

RNSTS, Summer interception storage capacity of major vegetation (inches)

RNSTW, Winter interception storage capacity of major vegetation (inches)

ITST, Month to look for start of transpiration; assigned a constant value of 4 (April) for each HRU

ITND, Month transpiration ends; assigned a constant value of 11 (November) for each HRU

CTX, Air temperature coefficient for evapotranspiration computations

TXAJ, Adjustment for maximum air temperature for slope and aspect; assigned a constant value of 0.0 for each HRU

TNAJ, Adjustment for minimum air temperature for slope and aspect; assigned a constant value of 0.0 for each HRU

SMAV, Current available water in soil profile, in inches

REMX, Maximum available water-holding capacity of soil recharge zone, in inches

RECHR, Current available water-holding capacity of soil profile, in inches (.3-15 bars)

SRX, Maximum daily snowmelt infiltration capacity of soil profile, in inches; assigned a constant value of 3.5 for each HRU

SCX, Maximum possible contributing area as proportion of total HRU area (decimal form)

IMPERV, Effective impervious area as proportion of total HRU (decimal form)

RETIP, Maximum retention storage of impervious area; assigned a constant value of 0.0 for each HRU

ISOIL, Soil type, 1 = sand, 2 = loam, 3 = clay; assigned a constant value of 2 for each HRU

SCN, Empirical coefficient that influences the amount of surface runoff

SC1, Empirical coefficient that influences the amount of surface runoff

SMAX, Maximum available water-holding capacity of soil profile, in inches (.3-15 bars)

RCF, Subsurface flow routing coefficient

RCP, Subsurface flow routing coefficient

SEP, Constant seepage rate from subsurface to ground-water reservoir, in inches/day

RCB, Ground-water flow routing coefficient

IRU	IRD	COVDNS	COVDNW	TRNCF	SNST	RNSTS	RNSTW
1	1	0.0	0.0	1.0	0.0	0.0	0.0
2	1	.8	.5	.25	.0	.05	.02
3	5	.6	.1	.78	.01	.10	.06
4	1	.0	.0	1.0	.0	.0	.0
5	1	.8	.5	.25	.0	.05	.02
6	4	.6	.1	.78	.01	.10	.06
7	1	.0	.0	1.0	.0	.0	.0
8	1	.8	.5	.25	.0	.05	.02
9	4	.6	.1	.78	.01	.10	.06
10	1	.0	.0	1.0	.0	.0	.0
11	1	.8	.5	.25	.0	.05	.02
12	6	.6	.1	.78	.01	.10	.06
13	1	.0	.0	1.0	.0	.0	.0
14	1	.8	.5	.25	.0	.05	.02
15	4	.6	.1	.78	.01	.10	.06
16	1	.0	.0	1.0	.0	.0	.0
17	6	.6	.1	.78	.01	.10	.06
18	1	.0	.0	1.0	.0	.0	.0
19	1	.8	.5	.25	.0	.05	.02
20	2	.6	.1	.78	.01	.10	.06
21	1	.0	.0	1.0	.0	.0	.0
22	1	.8	.5	.25	.0	.05	.02
23	3	.6	.1	.78	.01	.10	.06
24	1	.0	.0	1.0	.0	.0	.0
25	1	.8	.5	.25	.0	.05	.02
26	4	.6	.1	.78	.01	.10	.06
27	1	.0	.0	1.0	.0	.0	.0
28	1	.8	.5	.25	.0	.05	.02
29	3	.6	.1	.78	.01	.10	.06
30	1	.0	.0	1.0	.0	.0	.0
31	1	.8	.5	.25	.0	.05	.02
32	4	.6	.1	.78	.01	.10	.06
33	1	.0	.0	1.0	.0	.0	.0
34	1	.8	.5	.25	.0	.05	.02
35	4	.6	.1	.78	.01	.10	.06
36	1	.0	.0	1.0	.0	.0	.0
37	1	.8	.5	.25	.0	.05	.02
38	4	.6	.1	.78	.01	.10	.06
39	1	.0	.0	1.0	.0	.0	.0
40	1	.8	.5	.25	.0	.05	.02
41	3	.6	.1	.78	.01	.10	.06
42	1	.0	.0	1.0	.0	.0	.0
43	1	.8	.5	.25	.0	.05	.02
44	3	.6	.1	.78	.01	.10	.06

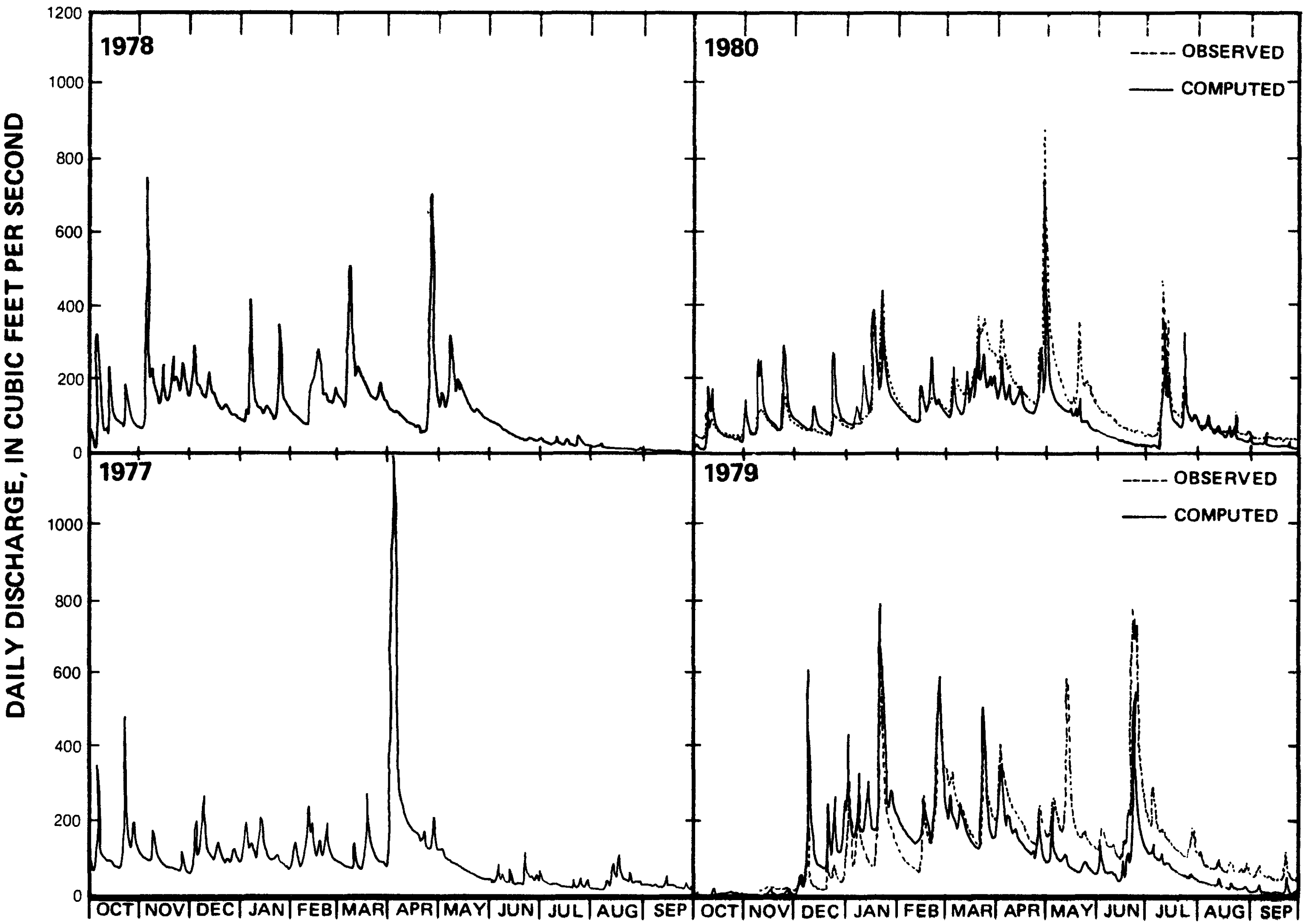
IRU	CTX	SMAV	REMXW	RECHR	SCX	IMPERV
1	19.59	2.350	0.1274	0.0500	0.70	0.0000
2	19.59	2.350	.1274	.0500	.50	.0000
3	19.59	2.350	.1274	.0500	.50	.0063
4	19.87	2.320	.1288	.0500	.70	.0000
5	19.87	2.320	.1288	.0500	.50	.0000
6	19.87	2.320	.1288	.0500	.50	.0048
7	20.27	2.503	.1200	.0500	.70	.0000
8	20.27	2.503	.1200	.0500	.50	.0000
9	20.27	2.503	.1200	.0500	.50	.0765
10	20.37	2.503	.1200	.0500	.70	.0000
11	20.37	2.503	.1200	.0500	.50	.0000
12	20.37	2.503	.1200	.0500	.50	.0026
13	19.97	2.300	.1204	.0500	.70	.0000
14	19.97	2.300	.1204	.0500	.50	.0000
15	19.97	2.300	.1204	.0500	.50	.0027
16	20.45	2.503	.1200	.0500	.70	.0000
17	20.45	2.503	.1200	.0500	.50	.0033
18	20.42	2.503	.1200	.0500	.70	.0000
19	20.42	2.500	.1200	.0500	.50	.0000
20	20.42	2.503	.1200	.0500	.50	.0000
21	20.47	2.503	.1200	.0500	.70	.0000
22	20.47	2.503	.1200	.0500	.50	.0000
23	20.47	2.500	.1200	.0500	.50	.0000
24	20.47	1.900	.1209	.0500	.70	.0000
25	20.47	1.900	.1209	.0500	.50	.0000
26	20.47	1.900	.1209	.0500	.50	.0000
27	20.47	2.850	.1316	.0500	.70	.0000
28	20.47	2.850	.1316	.0500	.50	.0000
29	20.47	2.850	.1316	.0800	.50	.0018
30	20.77	3.600	.1500	.0500	.70	.0000
31	20.77	3.600	.1500	.0500	.50	.0000
32	20.77	3.600	.1500	.0500	.50	.0073
33	20.62	2.500	.1200	.0500	.70	.0000
34	20.62	2.500	.1200	.0500	.50	.0000
35	20.62	2.500	.1200	.0500	.50	.0008
36	20.92	3.300	.1412	.0500	.70	.0000
37	20.92	3.300	.1412	.0500	.50	.0000
38	20.92	3.300	.1412	.0500	.50	.0033
39	21.02	2.500	.1600	.0500	.70	.0000
40	21.02	2.500	.1600	.0500	.50	.0000
41	21.02	2.500	.1600	.0500	.50	.0025
42	21.12	2.500	.1496	.0500	.70	.0000
43	21.12	2.500	.1496	.0500	.50	.0000
44	21.12	2.500	.1496	.0500	.50	.0010

IRU	SCN	SC1	SMAX	RCF	RCP	SEP	RCB
1	0.0011	0.3428	3.970	0.1000	0.2000	0.450	0.0372
2	.0011	.3428	3.970	.1000	.2000	.450	.0372
3	.0011	.3428	3.970	.1000	.2000	.450	.0372
4	.0009	.4000	4.916	.1500	.2000	.129	.0178
5	.0009	.4000	4.916	.1500	.2000	.129	.0178
6	.0009	.4000	4.916	.1500	.2000	.129	.0178
7	.0009	.4000	4.795	.1566	.2000	.125	.0099
8	.0009	.4000	4.795	.1566	.2000	.125	.0099
9	.0009	.4000	4.795	.1566	.2000	.125	.0099
10	.0009	.4000	4.795	.1566	.2000	.125	.0067
11	.0009	.4000	4.795	.1566	.2000	.125	.0067
12	.0009	.4000	4.795	.1566	.2000	.125	.0067
13	.0009	.4000	4.716	.1651	.2000	.125	.0099
14	.0009	.4000	4.716	.1651	.2000	.125	.0099
15	.0009	.4000	4.716	.1651	.2000	.125	.0099
16	.0009	.4000	4.795	.1566	.2000	.125	.0067
17	.0009	.4000	4.795	.1566	.2000	.125	.0067
18	.0009	.4000	5.006	.3400	.3000	.125	.0149
19	.0009	.4000	5.006	.3400	.3000	.125	.0149
20	.0009	.4000	5.006	.3400	.3000	.125	.0149
21	.0009	.4000	4.928	.2300	.2000	.120	.0300
22	.0009	.4000	4.928	.2300	.2000	.120	.0300
23	.0009	.4000	4.928	.2300	.2000	.120	.0300
24	.0009	.5000	3.874	.4200	.2000	.050	.0020
25	.0009	.5000	3.874	.4200	.2000	.050	.0020
26	.0009	.5000	3.874	.4200	.2000	.050	.0020
27	.0009	.4000	4.928	.2300	.2000	.120	.0300
28	.0009	.4000	4.928	.2300	.2000	.120	.0300
29	.0009	.4000	4.928	.2300	.2000	.120	.0300
30	.0009	.4000	4.928	.2300	.2000	.120	.0300
31	.0009	.4000	4.928	.2300	.2000	.120	.0300
32	.0009	.4000	4.928	.2300	.2000	.120	.0300
33	.0009	.4000	5.006	.2700	.2000	.150	.0100
34	.0009	.4000	5.006	.2700	.2000	.150	.0100
35	.0009	.4000	5.006	.2700	.2000	.150	.0100
36	.0009	.4000	6.884	.5466	.2000	.125	.0094
37	.0009	.4000	6.884	.5466	.2000	.125	.0094
38	.0009	.4000	6.884	.5466	.2000	.125	.0094
39	.0009	.3524	5.006	.3111	.2000	.255	.0200
40	.0009	.3524	5.006	.3111	.2000	.255	.0200
41	.0009	.3524	5.006	.3111	.2000	.255	.0200
42	.0009	.4000	5.006	.3111	.2000	.100	.0065
43	.0009	.4000	5.006	.3111	.2000	.100	.0065
44	.0009	.4000	5.006	.3111	.2000	.100	.0065

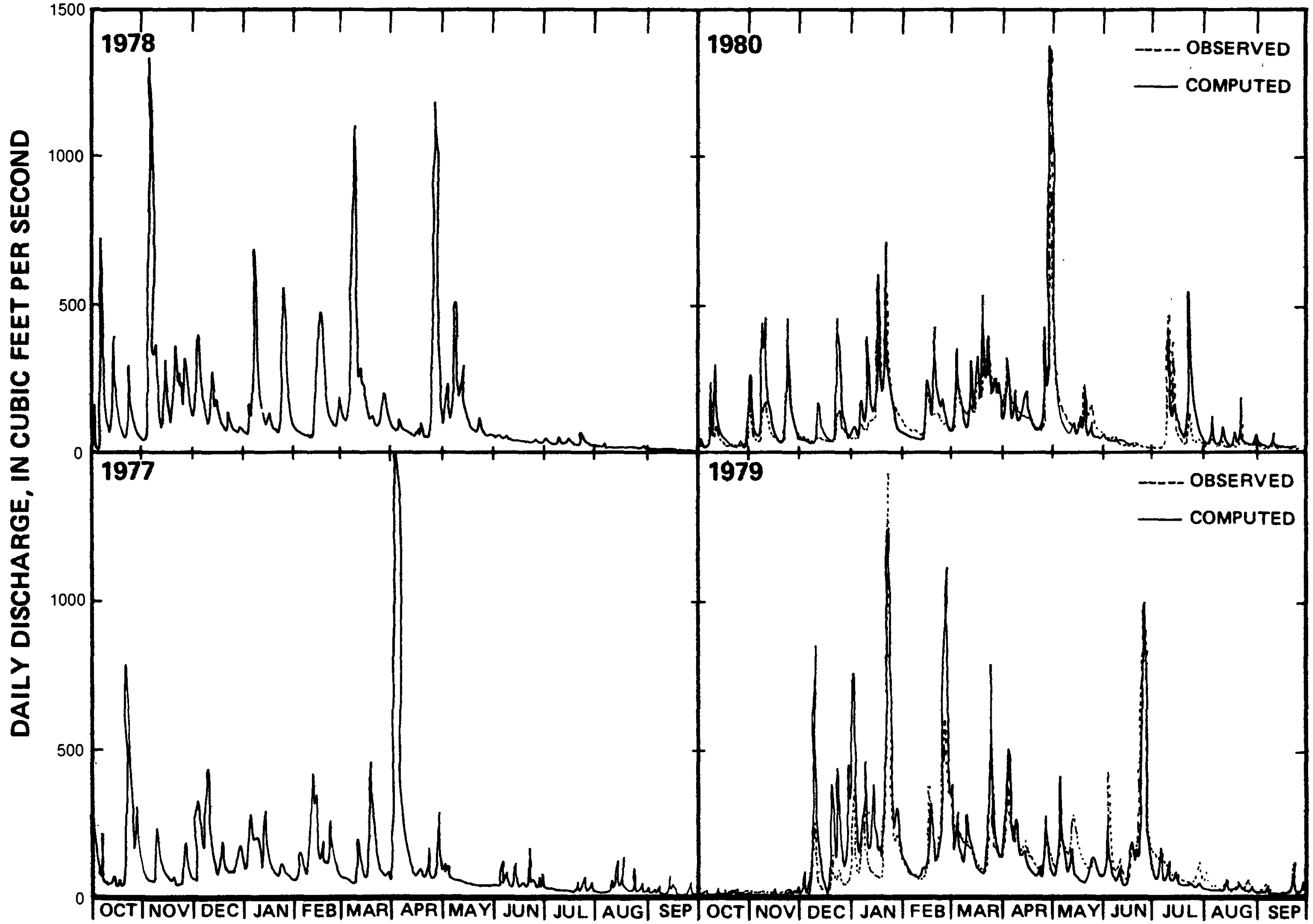
APPENDIX B

Observed and computed mean daily discharge hydrographs for 11 gaging stations in the Tug Fork basin for water years 1977-1980.

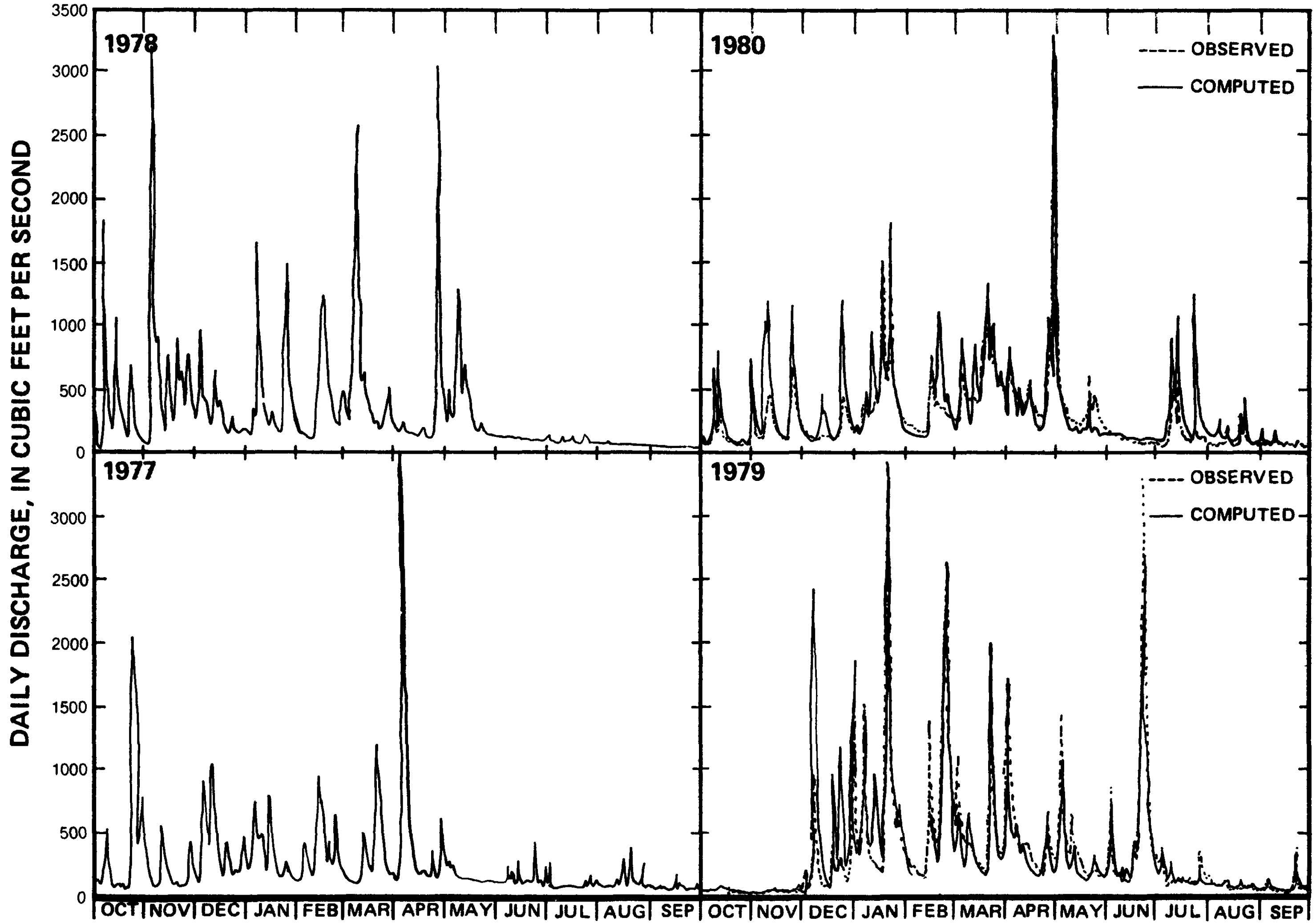
ELKHORN CREEK AT MAITLAND, W. VA.



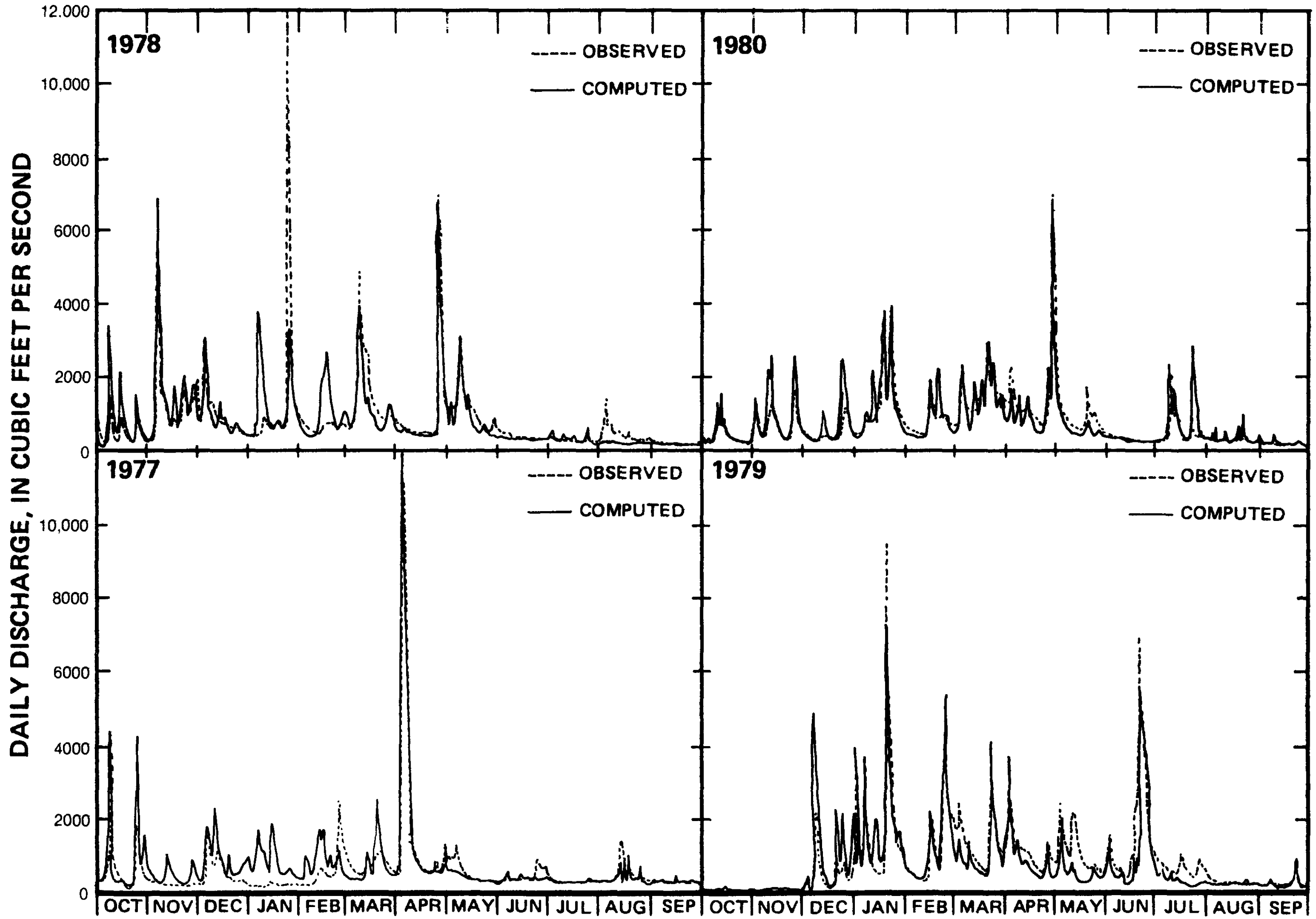
TUG FORK AT WELCH, W. VA.

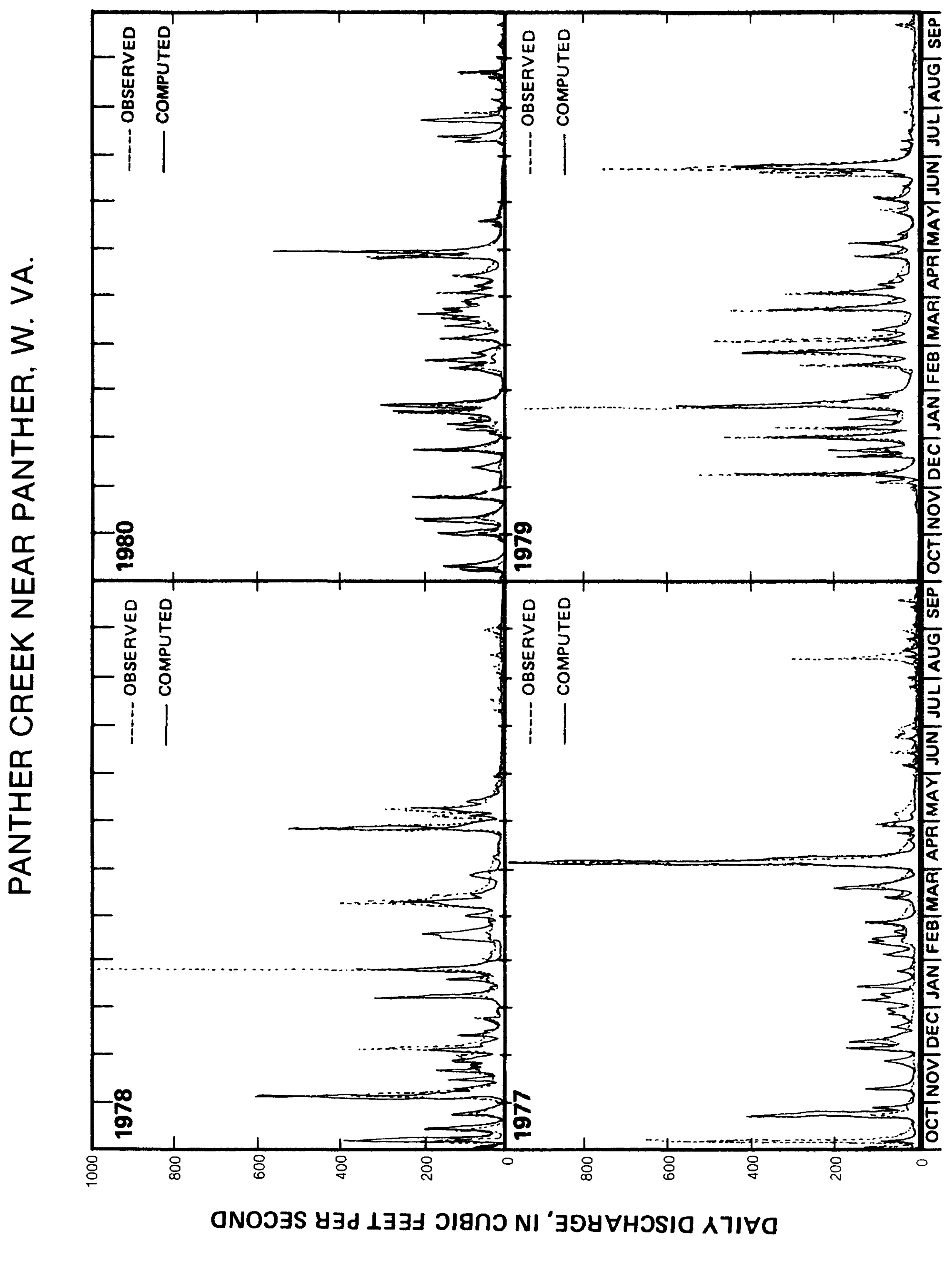


DRY FORK AT AVONDALE, W. VA.

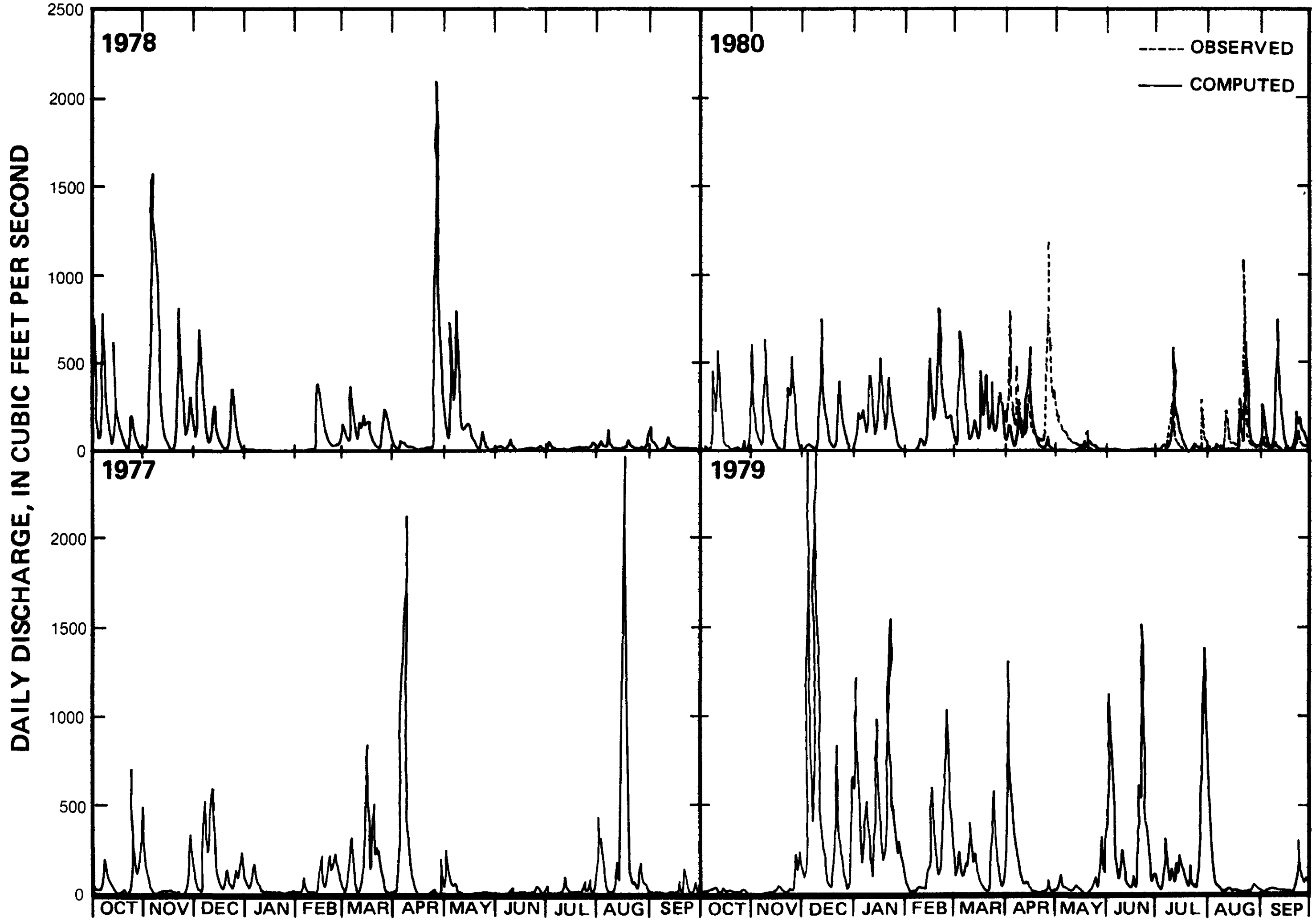


TUG FORK AT LITWAR, W. VA.

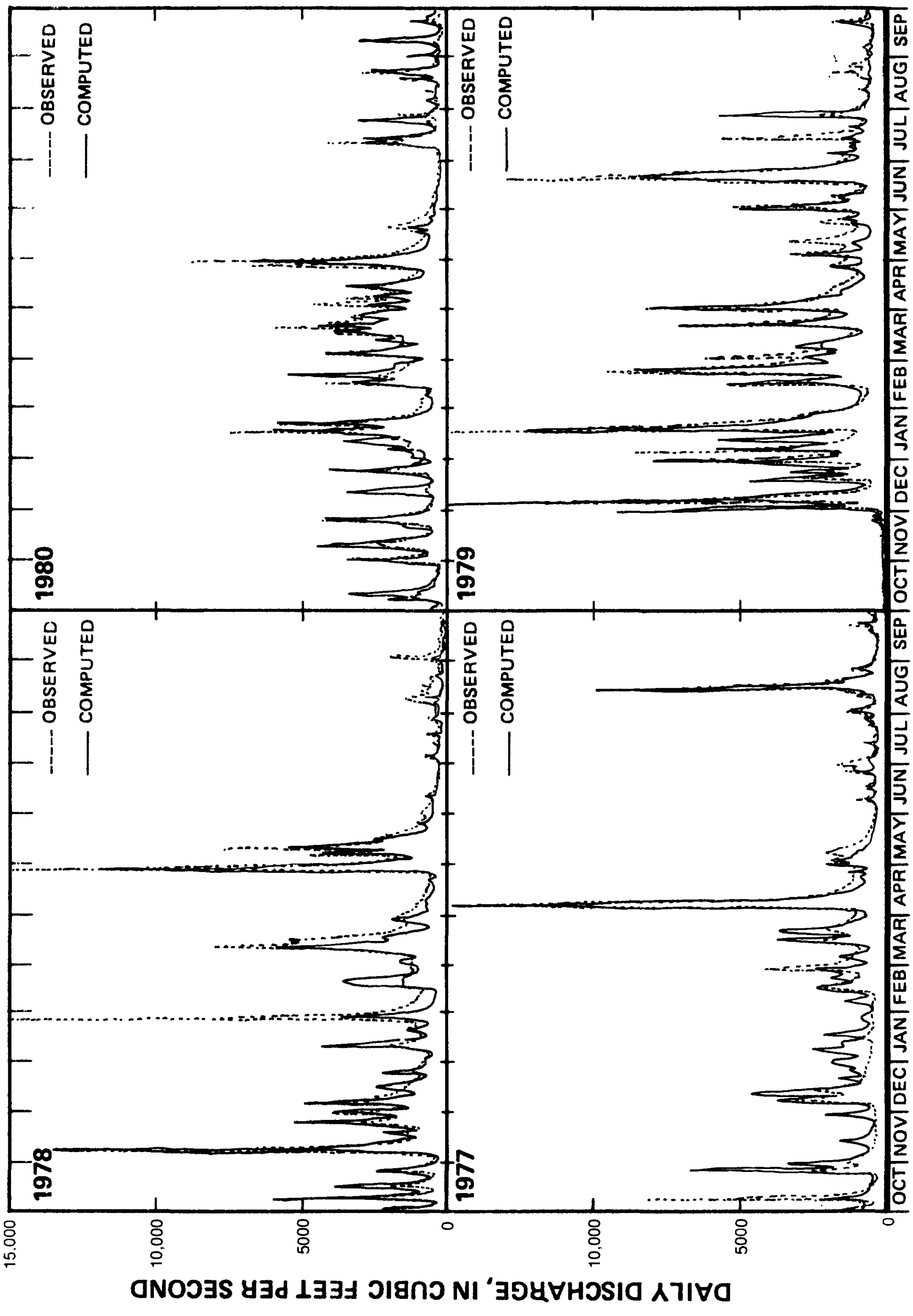



PANTHER CREEK NEAR PANTHER, W. VA.
1978
1980
1977
1979
OBSERVED
COMPUTED
DAILY DISCHARGE, IN CUBIC FEET PER SECOND
0
200
400
600
800
1000
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

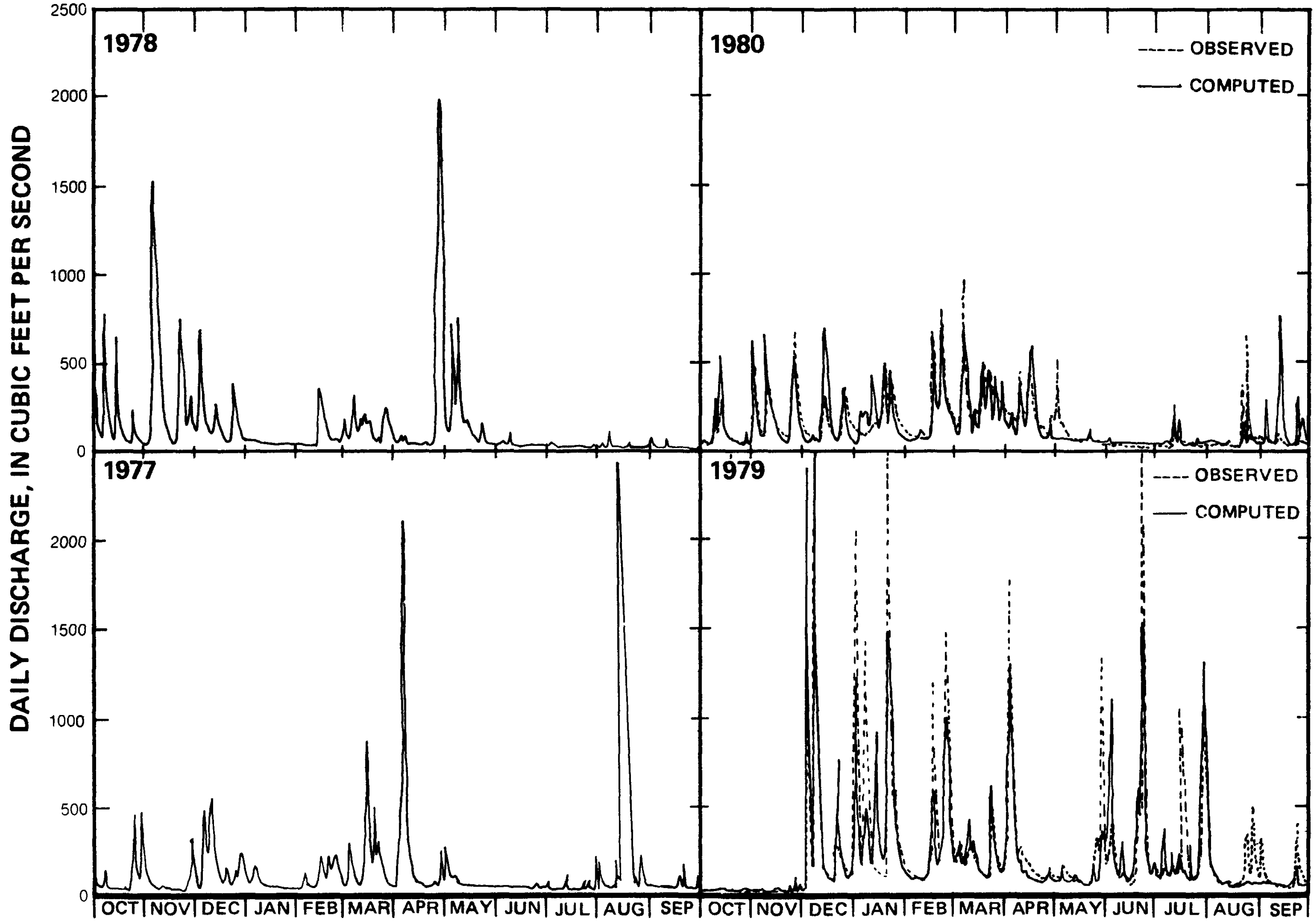
KNOX CREEK NEAR KELSA, VA.



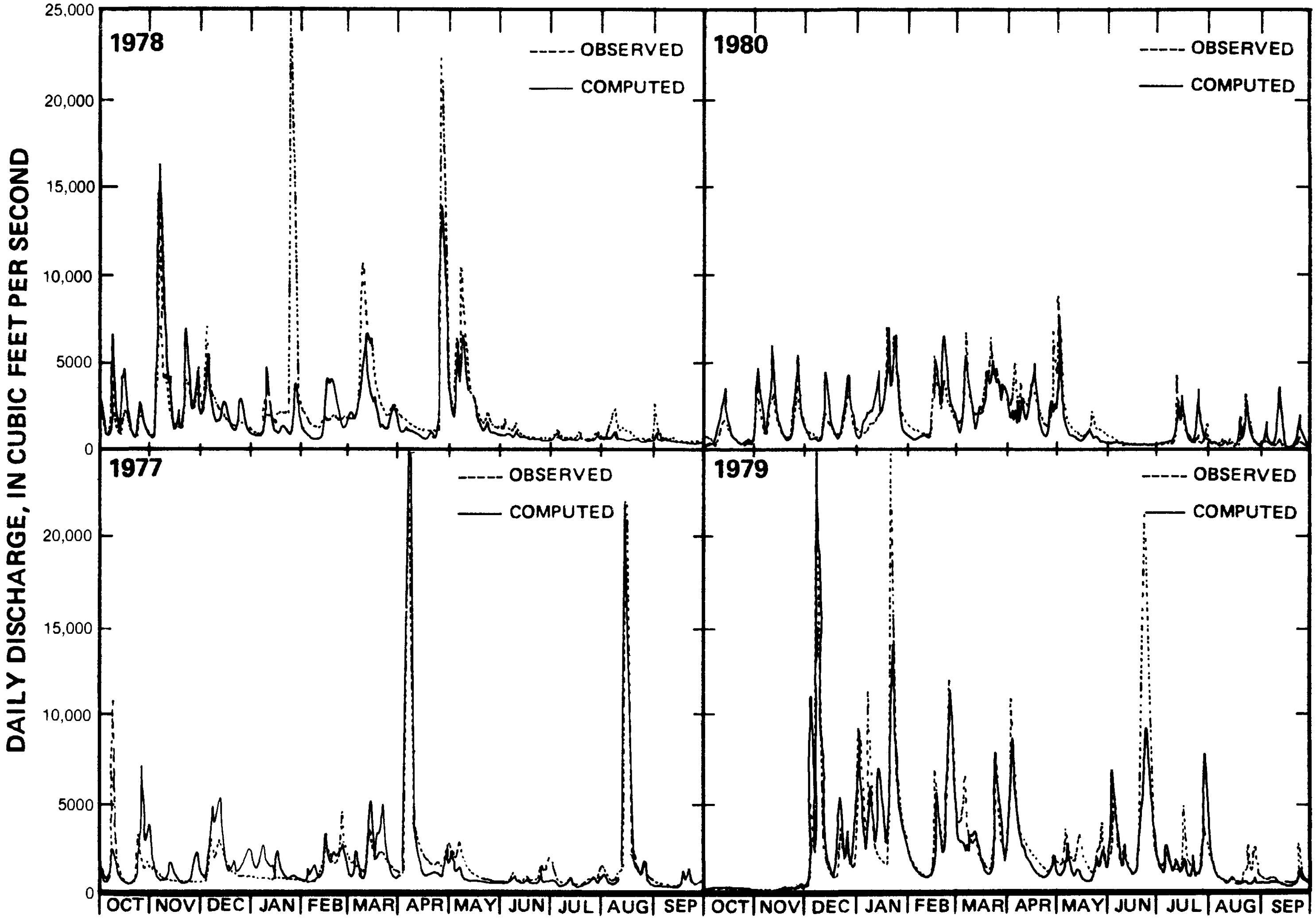
TUG FORK AT WILLIAMSON, W. VA.



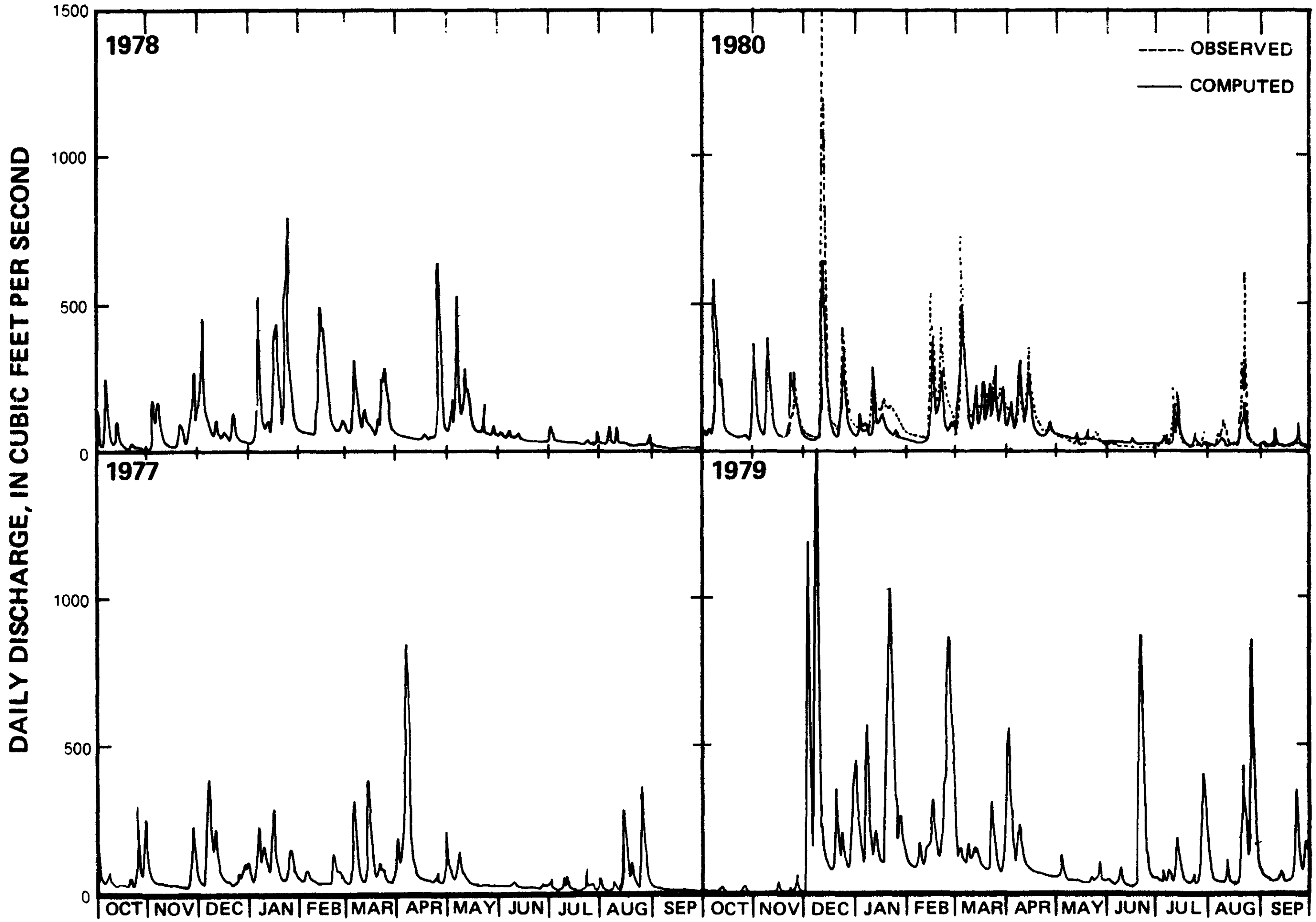
PIGEON CREEK NEAR LENORE, W. VA.



TUG FORK NEAR KERMIT, W. VA.



ROCKCASTLE CREEK NEAR INEZ, KY.



TUG FORK AT GLENHAYES, W. VA.