INVESTIGATION OF TRENDS IN FLOODING IN THE TUG FORK BASIN OF KENTUCKY, VIRGINIA, AND WEST VIRGINIA

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Office of Surface Mining Reclamation
and Enforcement
and the U.S. Bureau of Mines

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By Robert M. Hirsch, Arthur G. Scott, and Timothy Wyant

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UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Doyle G. Frederick, Acting Director

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CONVERSION FACTORS

Multiply	By	To obtain SI Units
	Length	
inches (in)	2.54×10^{1}	millimeters (mm)
	2.54×10^{-2}	meters (m)
feet	3.048×10^{-1}	meters (m)
	1.609×10^{0}	kilometers (km)
	Area	
acres	4.047×10^{3}	square meters (m^2)
	4.047×10^{-1}	square hectometers (hm^2)
	4.047×10^{-3}	square kilometers (km^2)
square miles	2.590×10^{0}	square kilometers (km^2)
	Flow	
cubic feet per second (ft^3/s)	2.832×10^{1}	liters per second (L/s)
	2.832×10^{1}	cubic decimeters per second (dm^3/s)
	2.832×10^{-2}	cubic meters per second (m^3/s)
	Mass	
tons (short)	9.072×10^{-1}	megagrams (Mg) or metric tons

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TUG FORK BASIN OF KENTUCKY, VIRGINIA, AND

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ABSTRACT

Statistical analysis indicates that the average size of annual flood peaks of the Tug Fork (West Virginia and Kentucky) has been increasing. However, additional statistical analysis does not indicate that flood levels exceeded typically once or twice a year in the period 1947-1979 are any more likely to be exceeded now than in 1947. Possible trends in stream-channel size are also investigated at three locations. No discernable trends in channel size are noted. Further statistical analysis of the trend in the size of annual flood peaks shows that much of the annual variation is related to nearby rainfall and to the "natural" hydrologic response in a relatively undisturbed sub-basin. However, some statistical indication of trend persists after accounting for these natural factors, though the indication is of borderline statistical significance. This suggests the need for further study in the basin that may relate flood magnitudes to both rainfall and to land use.

INTRODUCTION

The Tug Fork basin encompasses about 1,560 mi^2 of the mountainous area of Kentucky, Virginia, and West Virginia (figure 1). The river serves as the

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Figure 1 near here.

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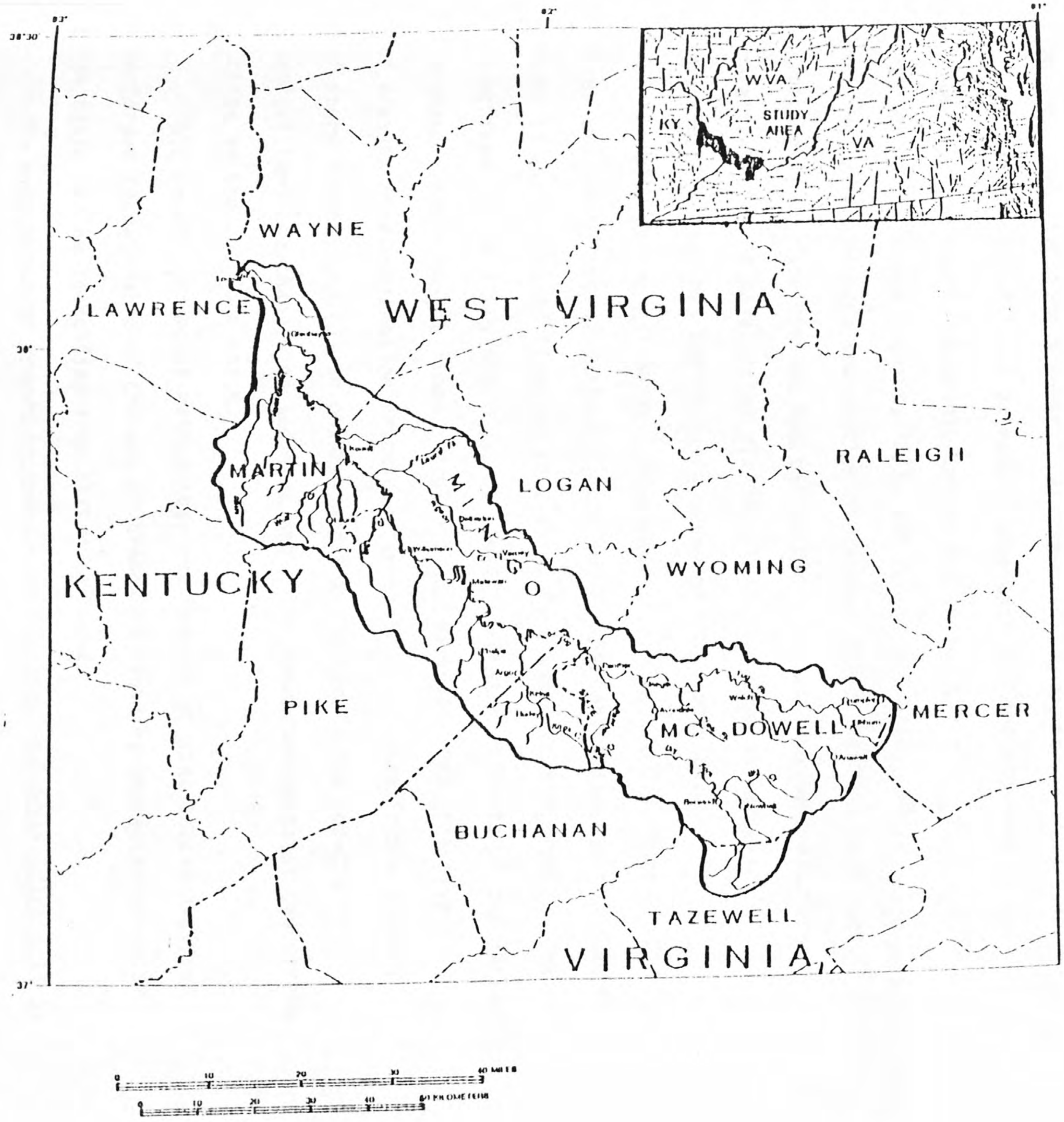
political boundary between Kentucky on the west and West Virginia on the east. It joins the Levisa Fork at Louisa, Kentucky, to become the Big Sandy River. The Big Sandy River flows northward to join the Ohio River at Catlettsburg, Kentucky. Mining of the extensive coal deposits is the primary industry in the basin.

Flooding has long been a major problem in the basin. Most of the inhabitable land lies on the narrow flood plains between steep mountains. Both the Tug Fork and the Big Sandy River basins have a long history of devastating floods. Carol Crowe-Carraco (1979), referring to a Civil War experience of 1862 in the Big Sandy River basin, states "Orlando Bowles, a young lieutenant of the Fortieth Ohio and later a prominent Big Sandian, could not have enjoyed the Middle Creek campaign and his first days in the Big Sandy. It was raining and had been for several weeks. The ground was soaked, and mud covered the infantrymen from head to toe as they slogged along. The Big Sandy River, swollen by rain and melting snow, had risen sixty feet from its lowest watermark and was flooding. Yellow torrents of water seemed to be everywhere. Paintsville was under water; Piketon (sic.) had steamboats on Main Street; and at Camp Buell, Bowles's tent and equipment were swept away by the raging river. The record flood of January-February 1862 played havoc with the countryside, and supplies from downriver were cut off." And in reference to 1927, "In the midst of reduced production and wage cuts came the most devastating flood the region had suffered in years.



WAYNE
LAWRENCE
WEST VIRGINIA
MARTIN
LOGAN
RALEIGH
KENTUCKY
WYOMING
PIKE
MERCER
MC DOWELL
BUCHANAN
TAZEWELL
VIRGINIA
W VA
KY
STUDY AREA
VA

During the night of May 30, 1927, rain fell for twelve hours, and the Big Sandy River and its tributaries flooded their banks with unprecedented vehemence. A wall of water thirty feet high inundated the valley's log cabins and frame dwellings, and close to a hundred people died. Automobiles vanished, and livestock drowned." (Crowe-Carraco, 1979)

On April 4-5, 1977, an extremely devastating flood occurred in the Big Sandy River basin. Economic damage approached $50 million in the Tug Fork valley alone (Runner, 1979, and Runner and Chin, 1980). This flood has prompted much speculation as to what affect various land uses, particularly surface mining, has had on the flood and sediment discharge characteristics of Appalachian rivers. There has been no large-scale investigation that has definitively answered this question.

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 of flooding in the Tug Fork basin (Scott, 1980). The objectives of the study are: (1) to identify relative effects of the various land-use changes on the flood hydrology; (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.

This report documents methodology and results of statistical analyses performed to determine if changes or trends in flooding characteristics of the basin can be identified from historical data.

The evaluation of trends or changes in flooding characteristics will be considered in four parts. The first is the univariate statistical analysis of annual flood series data from the three long-term stream gages. The second is the univariate statistical analysis of the partial-duration series data at these same stations. The third part is a multiple-regression analysis of annual-flood discharges at two gages downstream of substantial amounts of surface-mined land. This third analysis explores the extent to which any trends found in the analysis of part one can be related to rainfall, flood discharges in a relatively unmined area, and coal production indices. The fourth part explores the possibility that channel-geometry changes have occurred, which affect the stage-discharge relationship.

BASIN DESCRIPTION

Physiography and Topography

The Tug Fork basin encompasses nearly 1,560 mi^2 of Kentucky, Virginia, and West Virginia. Some of the principal tributaries to the Tug Fork are Pigeon Creek, Panther Creek, Elkhorn Creek, and Dry Fork in West Virginia, Knox Creek in Virginia, and Rockcastle Creek in Kentucky. About 60 percent of the basin is in West Virginia, 30 percent in Kentucky, and 10 percent in Virginia. Nearly the entire basin is in the Kanawha section of the Appalachian Plateau physiographic province as defined in Fenneman and Johnson (1946).

The topography of the basin is characterized by narrow river valleys bordered by steeply rising mountains. It is not uncommon for mountains to rise 1,300 feet above the valley floor. Maximum elevation of about 3,400 feet occurs in the headwaters and the minimum elevation of about 530 feet occurs at the mouth.

Geology

The following general description of the geology of the Tug Fork basin is taken from a report by U.S. Army Corps of Engineers (1979) except for the stratigraphic names which have been capitalized to conform with U.S. Geological Survey usage.

"The Tug Fork basin lies on the southwestern fringes of the deepest portion of the Appalachian sedimentary basin. The northern portion of the study area displays the classical concentric outcrop pattern of horizontal strata in which the younger Pennsylvanian bedrock (Conemaugh Group) is found in the uplands while the older Pennsylvanian bedrock (Kanawha Formation) is exposed in the stream valleys. The Conemaugh Group is composed primarily of a cyclic sequence of shale, siltstone, and sandstone with thin limestone and coal beds. Underlying the Conemaugh in the north is the Allegheny Formation, consisting of cyclic sequences of sandstone, siltstone, shale, limestone, and coal. The underlying Pottsville Group, composed of the Kanawha Formation, the New River Formation, and the Pocahontas Formation, is the most prevalent exposed bedrock in the Tug Fork basin. The group is composed of over 50 percent sandstone with some shale, siltstone, and coal. It is in this group of sedimentary rock that most of the coal resources of the area can be found. All of the bedrock in the study area, with one minor exception, is Pennsylvanian in age.

The outcrop pattern shows that the strata in the southern portion of the Tug Fork basin dip to the northwest, so that progressively older formations are exposed in the south. The surface drainage system also exposes these older beds in the stream valleys. The extreme southeastern portion of the basin contains the only Mississippian-age outcropping sandstone in the study area, along the axis of the Dry Fork Anticline.

A series of extremely gently sloping anticlines and synclines, trending approximately east-west, cross the basin in the north. The Warfield Fault, also cutting across the northern part of the study area, is a normal fault in the Pennsylvania-age bedrock, with the upthrown side to the south. There is about 200 feet of vertical displacement along this fault, and the surface topography remains relatively undisturbed over it.

The Quaternary deposits consist of recent river alluvium (sands and gravels) deposited on the floodplain floor of the Tug Fork and along the banks of its major tributaries. The source material for the majority of these deposits comes from the upland slopes at the head waters and along the banks of the rivers. Soil cover on these slopes tends to be relatively thin because the steep slopes allow the soils to be washed into the river during periods of even moderate rainfall. The river can carry a large load of sediment during times of high flow or flooding (usually the spring). It deposits the sediments on its banks and at different points in the channel as its load-carrying capacity and energy are reduced during periods of low flow. Floodplain deposition occurs when flood waters recede and suspended material is laid down on the floodplain. Channel deposition occurs when physical constraints cause the river water velocity to be reduced, thus decreasing its carrying capacity. The deposits may occur as point bars along the inside of sharp bends, while the outside of the bend is simultaneously being scoured. Deposition also may occur as delta bars, formed by tributary streams building deltas into the channel of the main stream. Deposits, ranging in size from fine silts to boulders, are commonly found in the channel and have been carried considerable distances downstream during floods and high water."

Climate

The climate of the area is characterized by a moderately severe winter with frequent alternations of fair and stormy weather and hot, showery summers. Mean-annual precipitation is about 44 inches. The mean-minimum-January temperature is about 28° F. and mean-maximum-July temperature is about 88° F. The basin is in an area of prevailing westerly winds that, during the colder portions of the year, are interrupted by northward surges of warm air and and southward surges of cold air associated with the passage of high- and low-pressure cells. The low-pressure areas are the large-dimension storms known as extratropical cyclones. Because of these fluctuations, most snowstorms are followed by thawing periods and there is no wide-scale spring melt of an accumulated snowpack. Snowfall varies greatly within the area, but the area west of longitude 81°30' receives about 15 inches per year (Horn and McGuire, 1960; Anderson, 1959; Crockett, 1971).

The mean monthly temperatures and normal monthly precipitation for Williamson, West Virginia, (1941-70) shown in figures 2 and 3 are typical of much of the basin (data from National Oceanic and Atmospheric Administration, 1973).

Figures 2 and 3 near here.

Intense rainfall is a common source of flooding in the basin. An extreme storm occurred in April of 1977. Maximum observed rainfall for this event was 15.5 inches in about 30 hours at Jolo, West Virginia, which is more than twice the amount expected for a 100-year recurrence-interval storm (Runner and Chin, 1980).

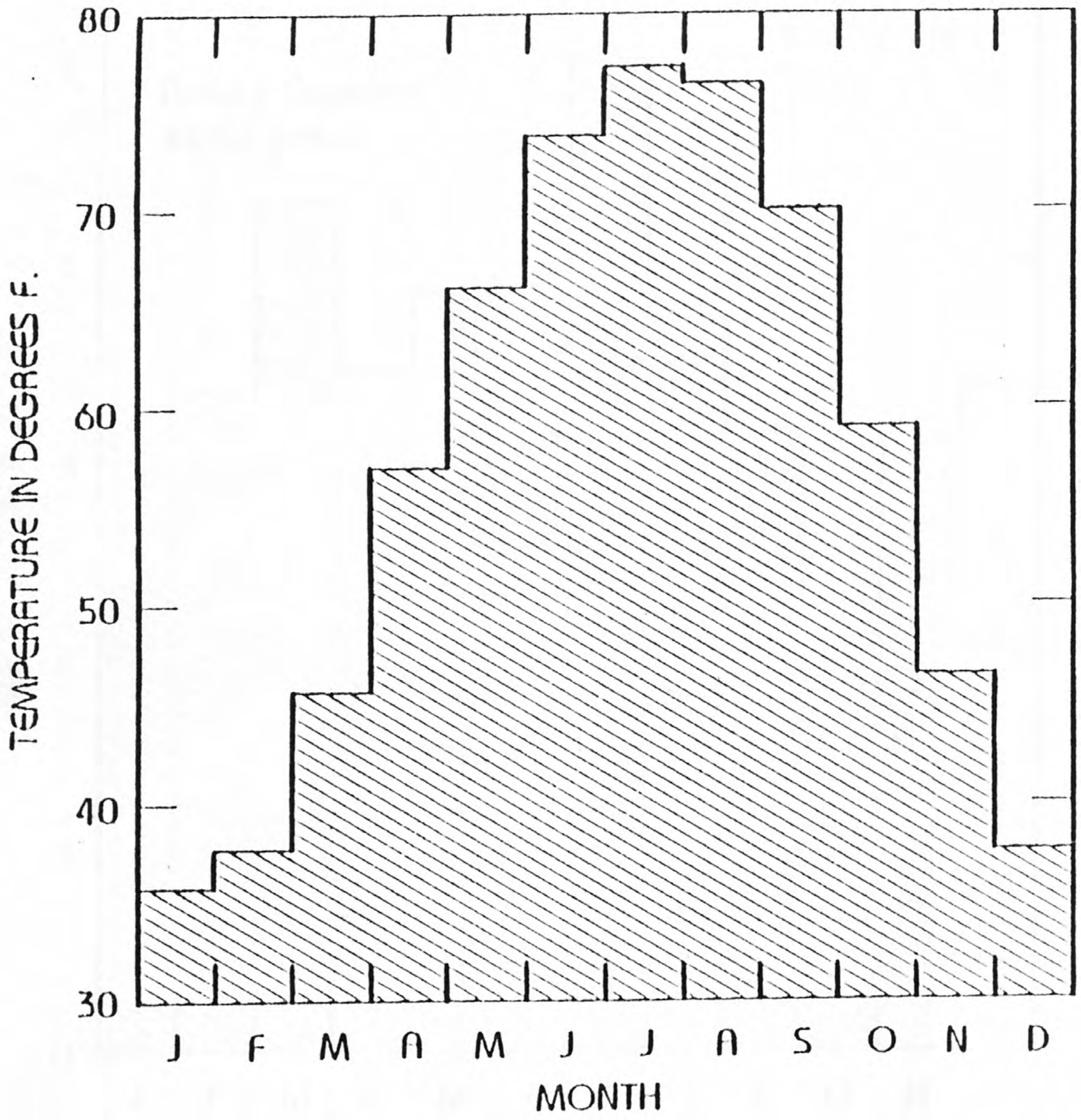


Figure 2. Mean-monthly temperature (1941-1970) at Williamson, West Virginia

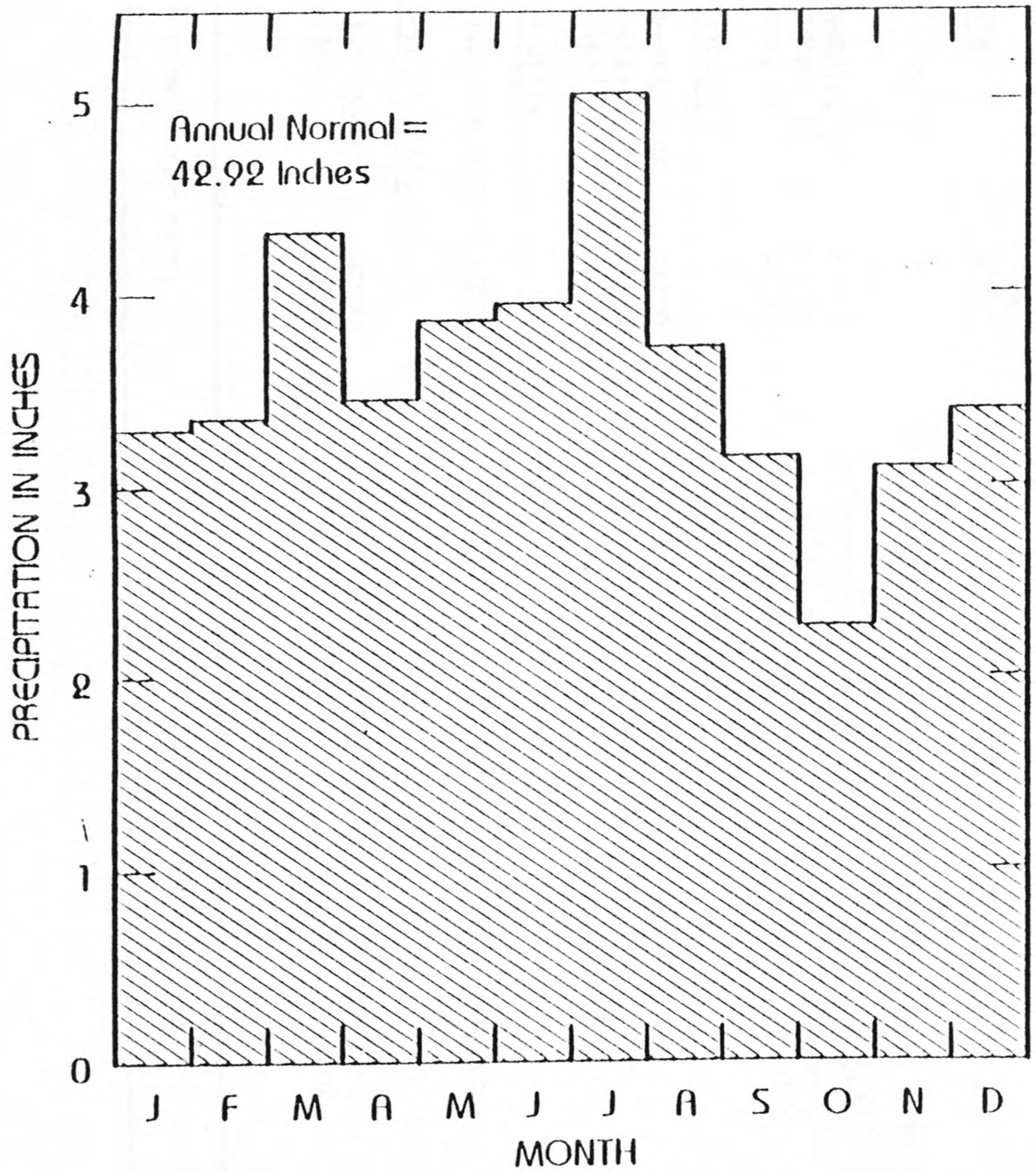


Figure 3. Normal-monthly precipitation (1941-1970) at Williamson, West Virginia

The following table shows the name, number, location, and period of record for National Weather Service recording precipitation stations established prior to 1955 in and near the Tug Fork basin. The location of these sites is shown on figure 4.

Table 1.--Recording precipitation stations established prior to 1955 in or near the Tug Fork basin

Name	NWS Number	Location Latitude	Location Longitude	Period of record
		TUG FORK BASIN		
Davella, KY	52053	37°48'	82°35'	1940-present
Hurley, VA	44180	37°25'	82°01'	1941-present
Gary, WV	63353	37°22'	81°33'	1941-present
Kentucky		ADJACENT		
Burdine 2 NE	51120	37°13'	82°35'	1951-present
Louisa 2 NE	54946	38°07'	82°38'	1941-present
Pikeville 2	56353	37°29'	82°32'	1934-present
Virginia				
Davenport 2 NE	42269	37°07'	82°06'	1940-present
West Virginia				
Flat Top	63072	37°35'	81°06'	1940-present
Logan	65353	37°51'	82°00'	1941-present

Figure 4 near here.

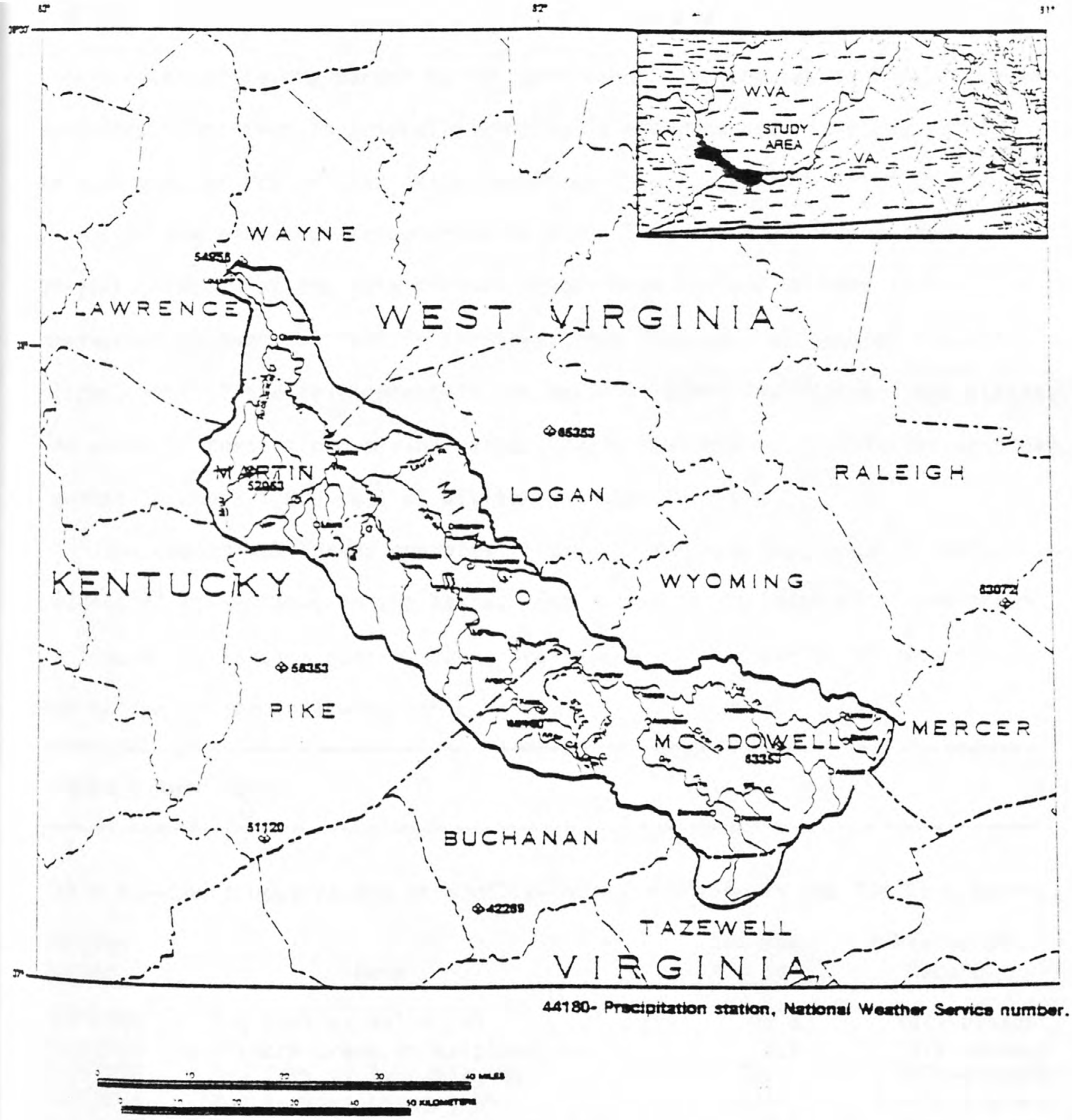


Figure 4. Recording precipitation stations established prior to 1955 in or near the Tug Fork basin

Hydrology

The Tug fork flows northwest for about 150 mi from its headwaters on the West Virginia-Virginia border to its confluence with the Levisa Fork at Lousia, Kentucky. The river is generally winding in a narrow steeply-sided valley through most of its length. River depth at base (low) flow varies from a few inches in the headwater tributaries to about 10 feet at Glenhayes, West Virginia. Width of the main channel ranges from 50 feet or less in the headwaters to over 250 feet in the downstream reaches. Because of the steep slopes, much of the development in the basin is along the narrow flood plains. The width of these flood plains varies from a few hundred feet in the upstream reaches to about 1,800 feet at Williamson, West Virginia.

The Geological Survey operates 11 gaging stations that provide continuous records of streamflows in the basin. The locations of these sites are shown in figure 5. Station number, name, drainage area, and period of record are listed in the following table:

Figure 5 near here.

Table 2.--Continuous-record streamflow-gaging stations in the Tug Fork basin.

Station number	Name	Drainage Area (mi^2)	Period of Record
03212600	Tug Fork at Welch, WV	85.8	1979-present
03212700	Elkhorn Creek at Maitland, WV	73.3	1979-present
03212985	Dry Fork at Avondale, WV	225	1979-present
03213000	Tug Fork at Litwar, WV	505	1930-present
03213500	Panther Creek near Panther, WV	31.0	1946-present
03213590	Knox Creek near Kelsa, VA	84.3	1980-present
03213700	Tug Fork at Williamson, WV	936	1967-present
03213800	Pigeon Creek near Lenore, WV	93.9	1979-present
03214000	Tug Fork near Kermit, WV	1,188	1934-present
03214700	Rockcastle Creek near Inez, KY	-	1980-present
03214900	Tug Fork at Glenhayes, WV	1,507	1976-present

Figure 5. Continuous-record streamflow-gaging stations in the Tug

Runoff in the basin is generally highest during February and March and lowest during September and October. A typical distribution of streamflow is illustrated in figure 6, a hydrograph of the mean of monthly discharges for 1934 through 1979 for station 03214000 Tug Fork near Kermit, West Virginia.

Figure 6 near here.

The maximum observed discharge in the basin was 104,000 ft^3/s. This flow occurred during April 1977 at station 03214000 Tug Fork at Kermit, West Virginia. The recurrence interval of this discharge at this site is in excess of 100 years (Runner and Chin, 1980). Other major floods in the basin occurred during 1875, 1918, 1955, 1957, 1963, and 1967.

Systematic collection of suspended sediment and other water-quality data in the basin has started only recently. Suspended sediment data are currently (1980) being continuously collected by the Geological Survey at the following stations:

Table 3.--Suspended-sediment stations in the Tug Fork basin.

Station Number	Name	Period of Record
03212600	Tug Fork at Welch, WV	October 1978 - present
03212700	Elkhorn Creek at Maitland, WV	November 1978 - present
03212985	Dry Fork at Avondale, WV	October 1978 - present
03214900	Tug Fork at Glenhayes, WV	March 1977 - present

The maximum observed daily suspended sediment load at station 03214900 for the period of record was 320,000 tons on April 5, 1977; minimum was 2.2 tons on September 29 and 30, 1978. Maximum observed daily mean concentration was 4,020 mg/L on April 5, 1977; minimum daily mean was 4 mg/L on September 29 and 30, 1978.

Continuous data on specific conductance are also collected at station 03214900.

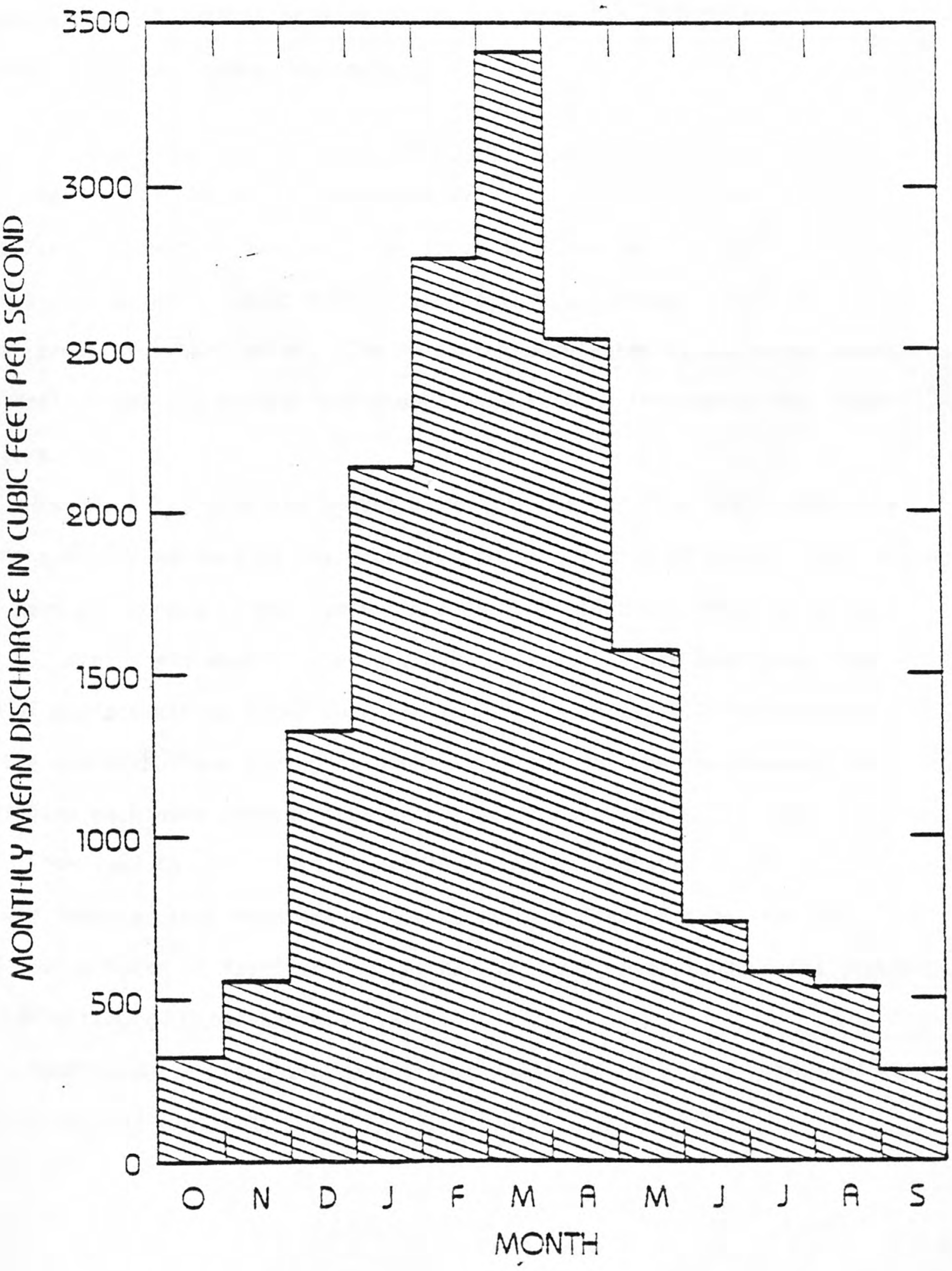


Figure 6. Mean-monthly discharge (1934-1977) at gaging station 03214000 Tug Fork near Kermit, West Virginia

All of these data are published annually in the U.S. Geological Survey annual series of reports on water resources data for each State (U.S. Geological Survey, annual series).

Land Use and Cover

The Tug Fork basin is predominantly rural. The cities of Williamson, West Virginia, with a population of about 5,500 and Welch, West Virginia, with a population of about 4,600 (U.S. Geological Survey, 1970) are the major areas of urbanization. The remaining population is scattered among the small towns and single-family dwellings located throughout the river valleys.

Historically, land use in the basin has changed from small individual homesteads and gardens to the extensive surface mining of today. Coal mining has been widespread in the basin since the late 1800's. Prior to World War II, mining was mostly by underground methods. Since that time, the use of surface-mining techniques has accelerated greatly. The increase in the use of surface mining is probably because of the improvement in stripping machinery and the growing energy-related demands for coal.

From 1880 to 1910, logging was an important industry in the basin. It was reported that hundreds of log rafts were floated along the Tug and Levisa Forks in May 1903, and by May 11, 1903, over 1,000 rafts docked at Catlettsburg (Crowe-Carraco, 1979).

Vegetation in the basin consists primarily of deciduous hardwoods with some scattered conifers.

Figures 7, 8, and 9 are photographs showing various types of land use in the basin. Figure 7 shows urban and highway utilization of a flood plain, figure 8 shows logging, and figure 9 shows surface mining.

Figures 7, 8, and 9 near here.

Recent land-use mapping (U.S. Geological Survey, 1976, 1978a, and 1978b) identified the following land use and cover categories within the basin:

<u>Urban or Built-up</u>

Residential
Commercial and services
Industrial
Mixed urban or built-up land

<u>Agricultural</u>

Cropland and pasture

<u>Forest</u>

Deciduous forest
Mixed forest

<u>Water</u>

Reservoirs

<u>Barren</u>

Strip mines, quarries, and gravel pits
Transitional areas

An explanation of these categories is contained in U.S. Geological Survey Professional Paper 964, "A Land Use and Land Cover Classification System for Use with Remote Sensor Data" (Anderson and others, 1976). Table 4 shows the area and percent of the total basin devoted to each of these land-use categories for the 1973-1976 period.

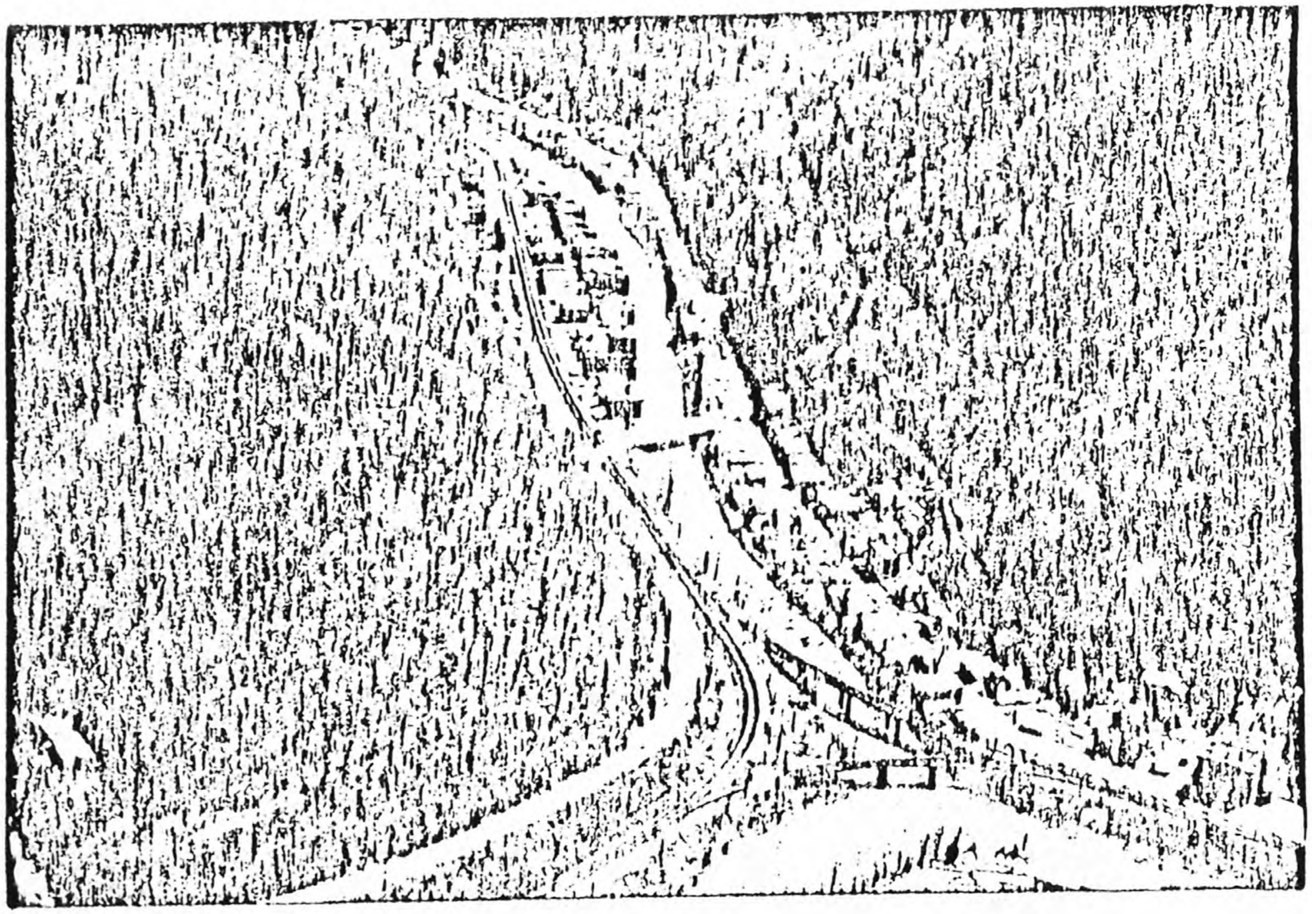


Figure 7. Urban and highway utilization of flood plain along Tug Fork.

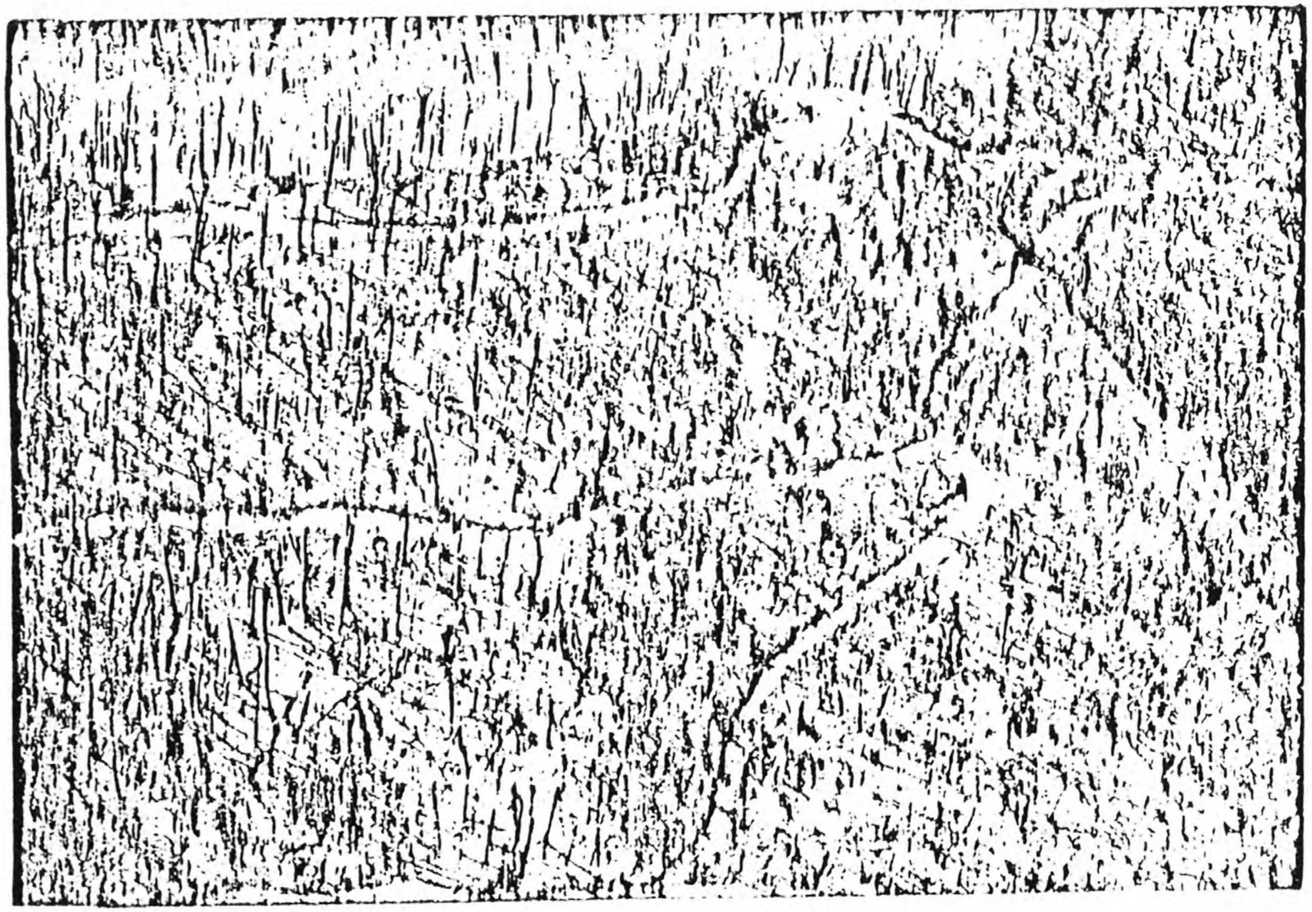


Figure 8. Logged Area in Tug Fork basin.

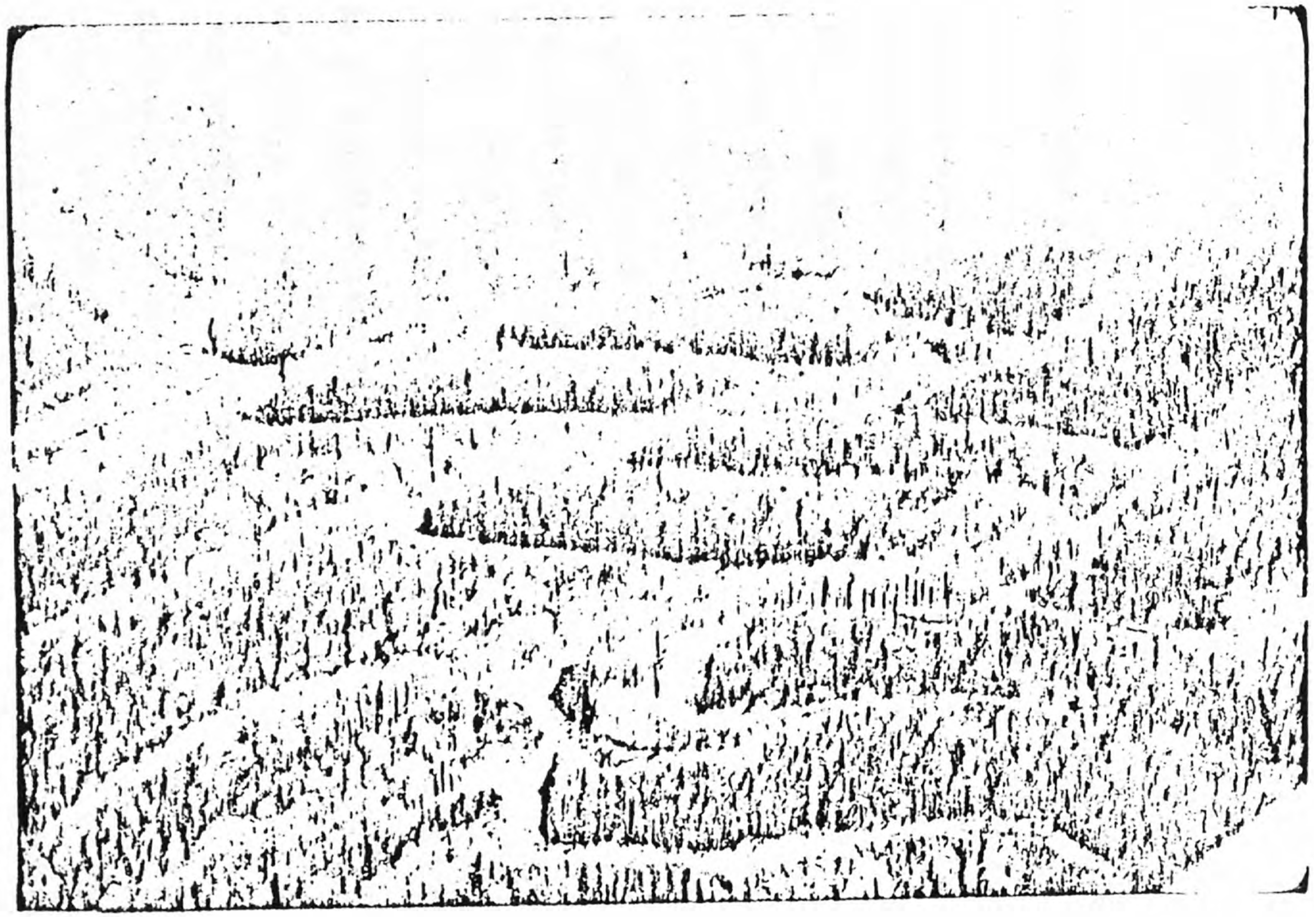


Figure 9. Surface-mined area in Jug Fork basin.

Table 4.--Land use in the Tug Fork basin for 1973-76.
(From U.S. Army Corps of Engineers, 1979)

USGS Land Use Category	Acres[a]	% of Total
Urban or builtup land	34,099	3.4
Crop and pasture land	5,325	0.5
Deciduous forest	907,930	91.6
Mixed forest	9,523	1.0
Reservoirs	307	b
Strip mines, quarries, and gravel pits	25,702	2.6
Transitional areas	9,114	.9
Total	992,000	100.0

[a] Figures are estimates using an areagraph chart which has 97% accuracy

[b] Less than .1%

The largest single classification in the basin is "deciduous forest." However, it should be noted that areas of streams and channels are not included and areas of strip mining may be underestimated because of mapping limitations. Only waterways of over 660 feet in width and over 10 acres in extent are identified. Also, the areal extent of surface mining determined from these maps may not reflect the total area of surface disturbance due to mining because only mines that have widths greater than 660 feet and cover areas greater than 10 acres are mapped. Another estimate of the area affected by surface mining is 50,000 to 80,000 acres or 5 to 8 percent of the basin area (Tug Valley Recovery Center, 1978). A quantative history of land use in the Tug Fork basin is under development.

It is not possible, at the present time, to quantitavely describe the history of land disturbance by surface mining. However, there is information on surface coal production on a county-by-county basis (R. Harris, U.S. Department of Energy, written communication, 1980). Two time series of annual surface coal production were developed from these data. The first is for the Tug Fork basin upstream of Litwar, West Virginia. This is assumed to be equal to the production of McDowell County, West Virginia. The second series is for the Tug Fork basin upstream of Kermit, West Virginia. This is assumed to be equal to the sum of the production of McDowell County, West Virginia, 23 percent of the Buchanan County, West Virginia production, 28 percent of the Pike County, Kentucky, production, and 76 percent of the Mingo County, West Virginia production. These percentages represent the percentage of the total area of each county in the basin. It should be emphasized that the accuracy of these latter two time series is unknown because information on the spatial distribution of production in the various counties over the years was not available. In addition, these time series may not accurately measure land disturbance. Mining practices have changed over the years due to technological and regulatory changes so that the effect on the landscape of a ton of coal mined in 1947 may be very different than the effect of a ton mined in 1978. The two coal production time series are shown in table 5 and figure 10.

Figure 10 near here

The Litwar production figures show a rapid rise from the early 1940's, peaking in 1951. This is followed by later highs in 1957, 1967-1970 and lows in 1959 and 1974. For the period 1948-1978, there has been no secular increase or decrease, only a series of fluctuations. The Kermit production figures are similar to the Litwar figures from the 1940's. However, the Kermit production figure rose and remained high through the 1970's while the Litwar figures remained relatively constant.

Table 5.--Annual surface-coal production in millions of tons, Tug Fork basin, West Virginia, Kentucky and Virginia.

	annual production in millions of tons	
year	basin above Litwar, WV	basin above Kermit, WV
1940	0.00	0.00
1941	0.00	0.00
1942	0.00	0.00
1943	0.00	0.10
1944	0.01	0.17
1945	0.11	0.35
1946	0.04	0.52
1947	0.06	0.87
1948	0.58	1.56
1949	0.87	1.21
1950	0.84	1.21
1951	1.05	1.32
1952	0.69	0.84
1953	0.63	0.85
1954	0.62	0.97
1955	0.60	1.10
1956	1.08	1.77
1957	1.50	2.37
1958	0.85	1.21
1959	0.34	0.66
1960	0.60	0.91
1961	0.61	0.89
1962	0.62	1.18
1963	0.77	1.74
1964	1.09	2.35
1965	0.78	1.76
1966	1.16	2.60
1967	1.39	2.85
1968	1.49	2.68
1969	1.37	2.58
1970	1.48	3.52
1971	1.01	3.88
1972	0.86	3.51
1973	0.70	3.10
1974	0.36	3.83
1975	0.77	3.46
1976	0.97	3.84
1977	0.86	3.41
1978	0.60	2.43

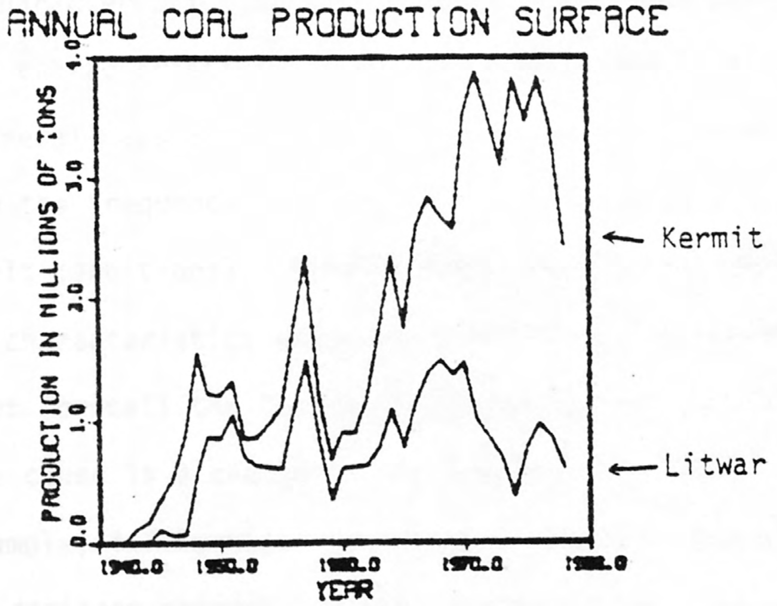


Figure 10.--Annual surface-coal production in millions of tons, Tug Fork basin, West Virginia, Kentucky and Virginia. Upper line is basin above Kermit, West Virginia. Lower line is basin above Litwar, West Virginia.

STATISTICAL ANALYSIS

The purpose of the statistical analyses is to explore the general hypothesis that the flooding characteristics of the Tug Fork basin have changed over time. Changes in flooding characteristics, if they have occurred, can be attributed to either of two general causes (or both). The first is meteorological: That is, changes in the frequency distribution of storm rainfall (perhaps coupled with snowmelt conditions). Finding that such factors have caused a change in flooding characteristics sheds no light on future flooding characteristics if one cannot foretell the future of storm-rainfall characteristics. The second possible cause is a change in the hydrologic response arising from changes in (for example) infiltration rates, soil moisture capacities, integration of the drainage network, channel roughness, or some combination of these. If the second were the cause of a change in flooding, then the future flooding characteristics could be predicted based on projections of the future status of these hydrologic response characteristics.

First, through examinations of the annual series and partial-duration series records, the question of trend in flooding is considered without regard to cause. Then, in the multiple-regression section, focus shifts to trends in the hydrologic response. The first analyses provide a basic background description of what has occurred. The multiple-regression analysis then focuses on cause--meteorological versus hydrologic response.

Analysis of Annual-Flood Series

There are three stream gaging stations in the Tug Fork basin with more than 20 years of annual-flood data: 03213000 Tug Fork at Litwar, West Virginia (1931-1979), 03213500 Panther Creek near Panther, West Virginia (1947-1979) and 03214000 Tug Fork near Kermit, West Virginia (1935-1979). The locations of these stations are shown in figure 5. The annual-series-flood data for these stations are plotted in figures 11, 12, and 13 and are listed

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Figures 11, 12 and 13 near here.

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in appendix A. The two stations on the Tug Fork are located downstream of substantial areas (perhaps as much as 8 percent of the basin) of surface-mined land. In contrast, most of the basin above the Panther Creek station is in Panther State Forest and not subject to mining. Less than 1 percent of this basin has been disturbed by mining and in 1980 all of it was in a revegetated condition.

The first question of interest is whether the flood-frequency distribution has been constant over time. If the frequency distribution is constant, this means that the probability of exceeding any specified discharge is the same from one year to the next. A good method for evaluating these annual-flood data for trend (change in flood-frequency distribution) is the Mann-Kendall test for trend (Bradley, 1968). The Mann-Kendall test for trend was selected because, unlike classical tests such as the τ-test, it does not assume that the random variable (flood magnitude) is normally distributed. Clearly all three flood series violate this assumption of normality (see the skewness coefficients in table 6). Where the data arise from a non-normal highly-skewed population with trend, the Mann-Kendall test is more powerful than the classical tests. The Mann-Kendall test is not as sensitive to the abnormally large value of the 1977 flood as a classical test would be.

27a follows

The null hypothesis of the Mann-Kendall test is that the data are a random sample which are independent and identically distributed. The statistic τ reported here is a measure of association between the random variable (annual-flood discharge) and time. Kendall (1975) refers to it as a measure of rank correlation. It is like the product-moment-correlation coefficient in that $|\tau| \leq 1$ and when the discharges are identically distributed over all values of time, the expected value of τ is zero.

p. 28 follows

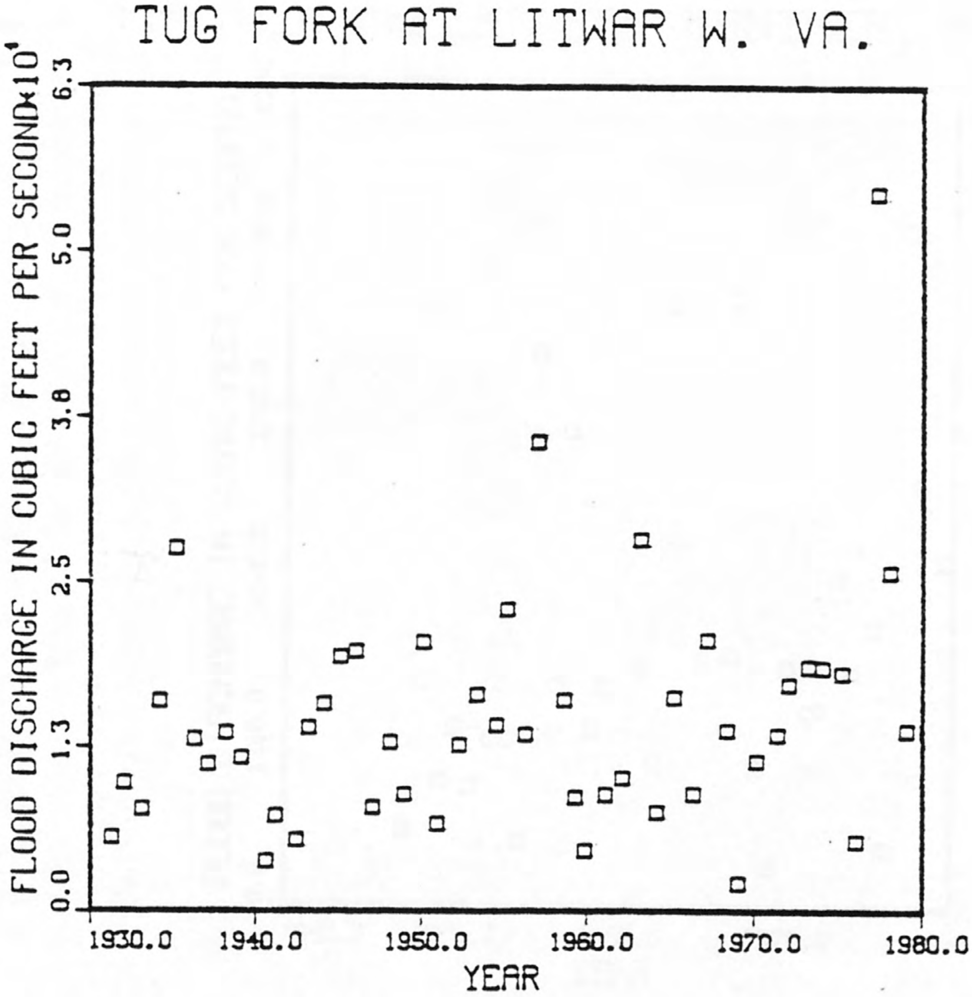

Figure 11.--Annual flood series data for the Tug Fork at Litwar, West Virginia, 1931-1979 (03213000).

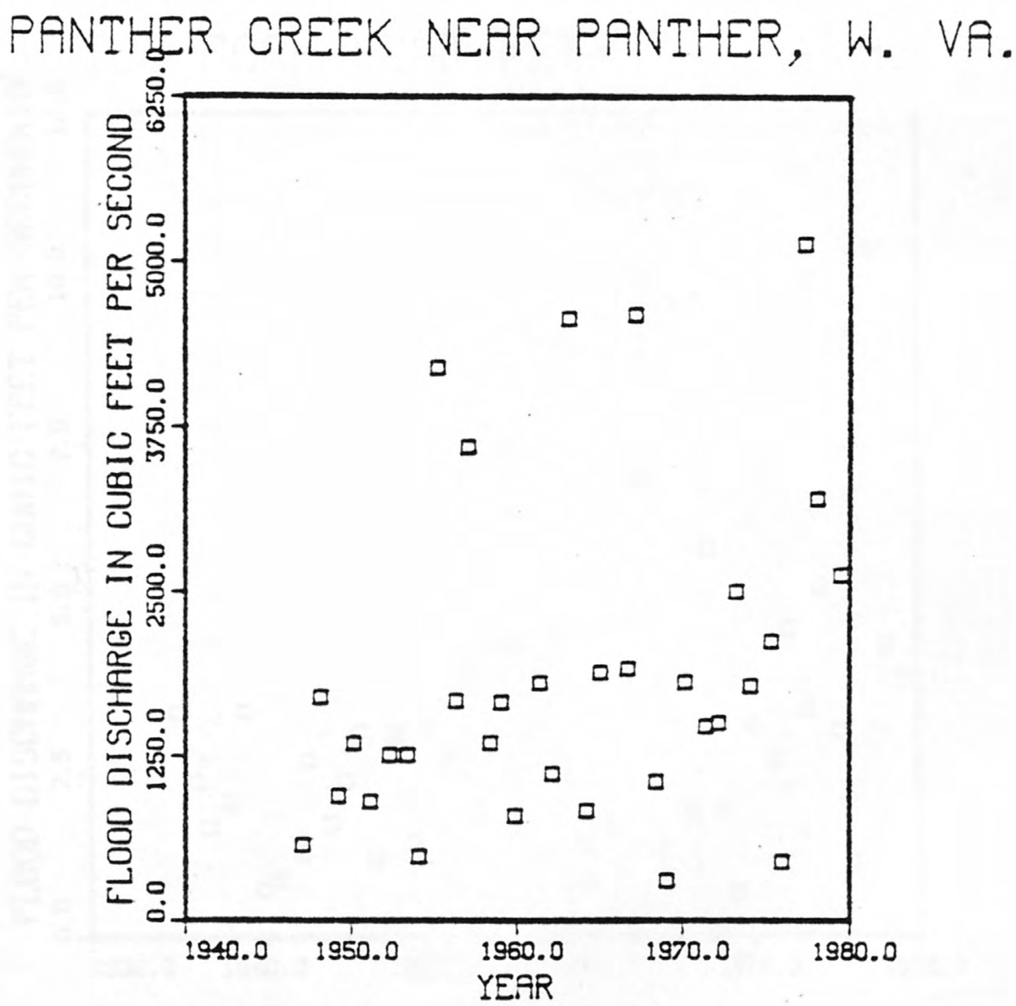

Figure 12.--Annual flood series data for Panther Creek near Panther, West Virginia, 1947-1979 (03213500).

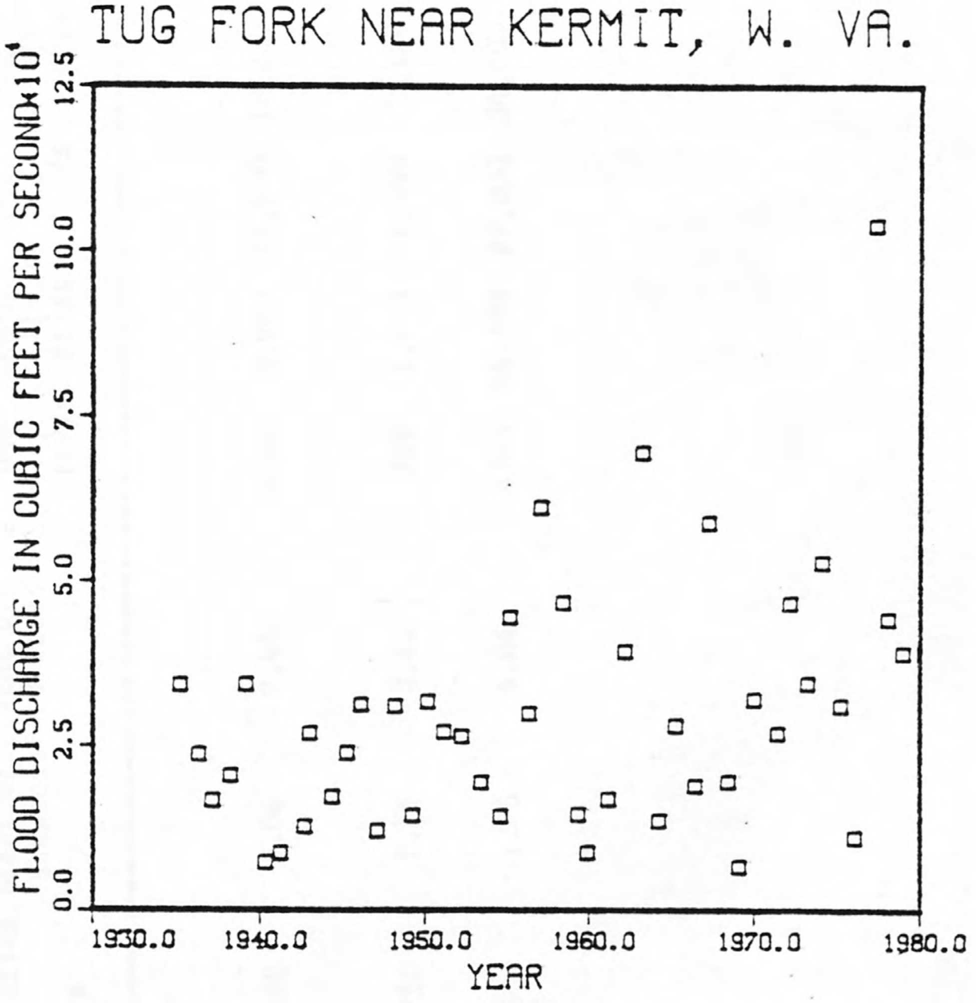

Figure 13'.--Annual flood series data for the Tug Fork near Kermit, West Virginia, 1935-1979 (03214000).

Table 6.--Statistics of Annual Flood Series

	Record length in years	Average ft^3/s	Standard deviation ft^3/s	Coefficient of skewness	Coefficient of kurtosis	Minimum ft^3/s	Lower quartile ft^3/s	Median ft^3/s	Upper quartile ft^3/s	Maximum cfs	Mann-Kendall test for trend τ	Mann-Kendall test for trend p
Tug Fork at Litwar, W. Va.	49	14,700	8,880	2.06	9.48	2230	8,900	13,500	18,200	54,500	0.182	0.066
Panther Creek nr Panther, W. Va.	33	1,900	1,250	1.16	3.45	308	1,060	1,660	2,130	5,140	0.269	0.029
Tug Fork near Kermit, W. Va.	45	29,700	18,600	1.65	6.84	6760	16,700	27,000	34,600	104,000	0.236	0.023

At all three stations the value of τ is positive (suggesting upward trend) and is significant at the 10 percent (two-sided) significance level. The value of τ and associated p value (probability of $|\tau|$ being greater than or equal to the given τ value under the null hypothesis) are given in table 6 along with some summary statistics characterizing the annual flood series at the three stations.

All of the associated p values (or "significance levels") are small--the largest is 0.066. Thus it is unlikely that chance variation of floods would produce τ values this large, and therefore the results at all three stations indicate trend. This is true even for Panther Creek, which has experienced by far the least surface mining (as a fraction of basin area) among the three basins. A useful graphical refinement of the basic time-series plots in figures 11-13 is to break the records into different periods--1931-1946, 1947-1963, and 1964-1979 were selected--and then construct box plots (Kleiner and Graedel, 1980) for each period as shown in figure 14. The box plots

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Figure 14 near here.

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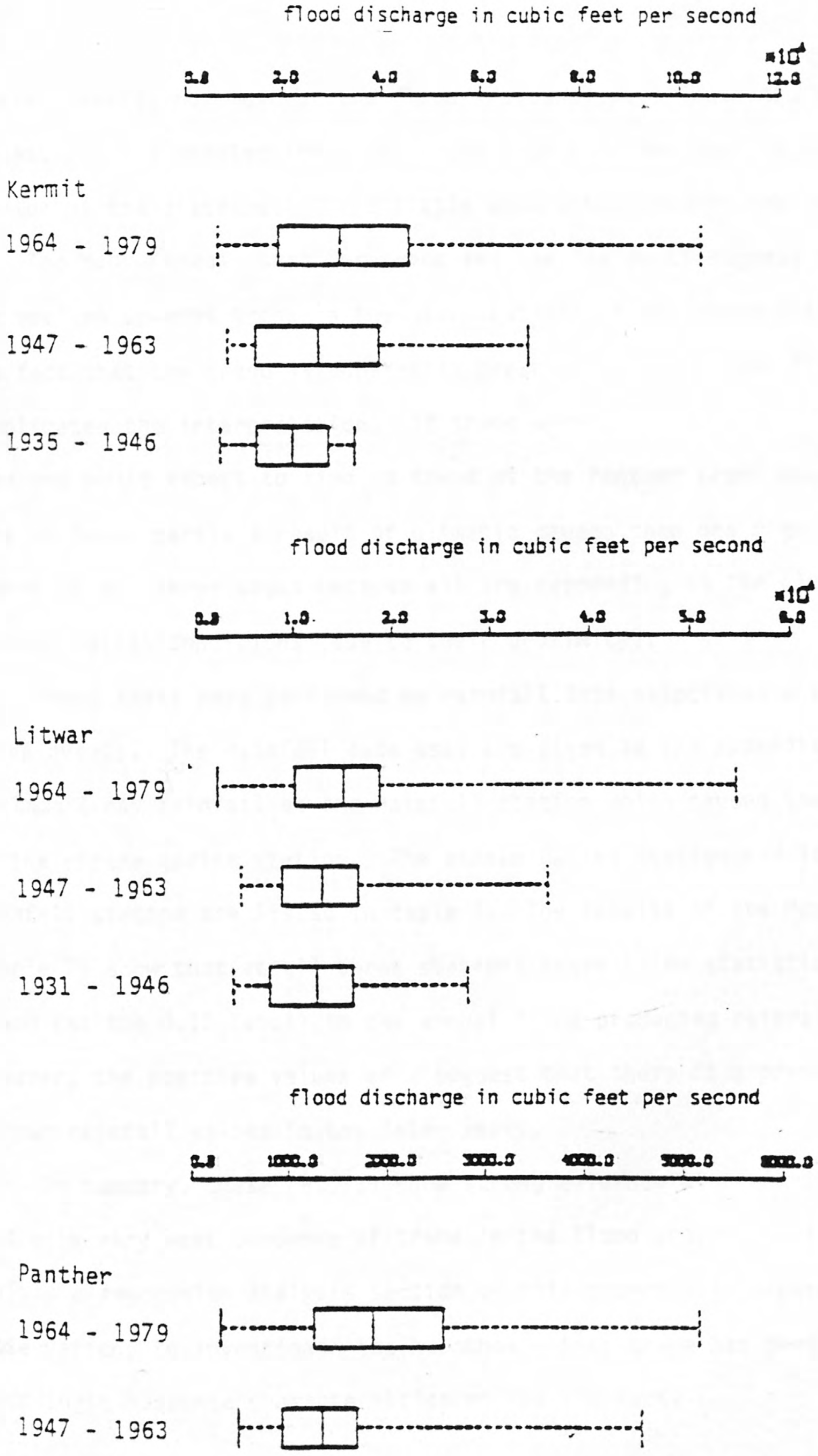
show the median (line inside the box), upper and lower quartiles (ends of the box) and minimum and maximum values (bars at the ends of dashed lines). For all three stations there is an increase from one period to the next in the lower, median, and upper quartile and maximum values (with the exception of the lower quartile value for the Kermit gage which is slightly lower in the 1947-1963 period than in the pre-1947 period). These box plots show a



ure 14.--Box plots of annual flood data for the three stations, for three time periods. Box plots show the extreme values, quartiles and medians of each sample.

general upwards movement of the flood frequency distributions, with some suggestion of a greater increase in the high extremes than in the central portion of the distribution and little apparent change in the low extreme.

The Mann-Kendall test for trend and the box plots suggest that there has been an upwards trend in the distributions at all three stations. The fact that the trend is apparently present at the Panther Creek gage complicates the interpretation. If trend were a result of surface mining then one would expect to find no trend at the Panther Creek gage. If trend were at least partly a result of climatic causes then one might expect to find trends at all three gages because all are responding to the closely-related meteorological conditions (due to their proximity).

Trend tests were performed on rainfall data associated with the annual flood events. The rainfall data used are given in the appendix. They are the maximum 2-day rainfall at the rainfall station which caused the annual flood at the stream gaging station. The stream gaging station and its associated rainfall station are listed in table 7. The results of the Mann-Kendall tests (table 7) show that at all three stations there is no statistically significant trend (at the 0.10 level) in the annual flood producing rainfalls amounts. However, the positive values of τ suggest that there is a preponderance of larger rainfall values in the later years.

In summary, these results show strong evidence of trend in flood discharge and only very weak evidence of trend in the flood producing rainfall. The multiple-regression analysis section of this report will proceed from these observations to investigate the hypothesis that there has been a change in the hydrologic response characteristics of the Tug Fork.

Table 7.--Trends in the maximum 2-day rainfall associated with the annual flood.

Rain gage	Associated stream gage	Record length in years	Mann Kendall test for trend τ	p
Gary, W. Va.	Tug Fork at Litwar, W. Va.	40	0.063	0.592
Hurley, Va.	Panther Creek near Panther W. Va.	33	0.181	0.224
Davella, Ky.	Tug Fork near Kermit W. Va.	40	0.121	0.329

Analysis of Partial-Duration Series

In addition to searching for trends in the magnitude of annual floods, an attempt was also made to identify trends in the number of times each year that floods exceeded certain threshold values at Kermit, Litwar, and Panther, West Virginia. These historic exceedance frequencies (or partial-duration series) were examined for two different thresholds at each of these three stream-gaging sites. As in the box-plot analysis of the previous section, each record was broken into three periods--1931-1946, 1947-1963, and 1964-1979 and then examined for evidence of systematic increases or decreases in average annual exceedance frequencies across the three periods. Some changes in statistical presentation are appropriate because frequency data are now being considered rather than magnitude data.

For each stream site, threshold discharges, and time period it was assumed that exceedance frequencies follow a Poisson distribution. This is a common assumption in analysis of partial-duration series (see, for example, Shane and Lynn, 1964) and standard statistical tests of goodness-of-fit (Snedecor and Cochran, 1967, p. 236-237) show no reason to discard the Poisson assumption. Both references discuss the properties of the Poisson distribution in detail.

Figure 15 near here.

Figure 15 shows the average annual frequencies of exceedance for the different thresholds and different time periods, together with 95-percent confidence intervals based on the Poisson assumption (Johnson and Kotz, 1969). The line in the center of each box represents the average exceedance frequency. The

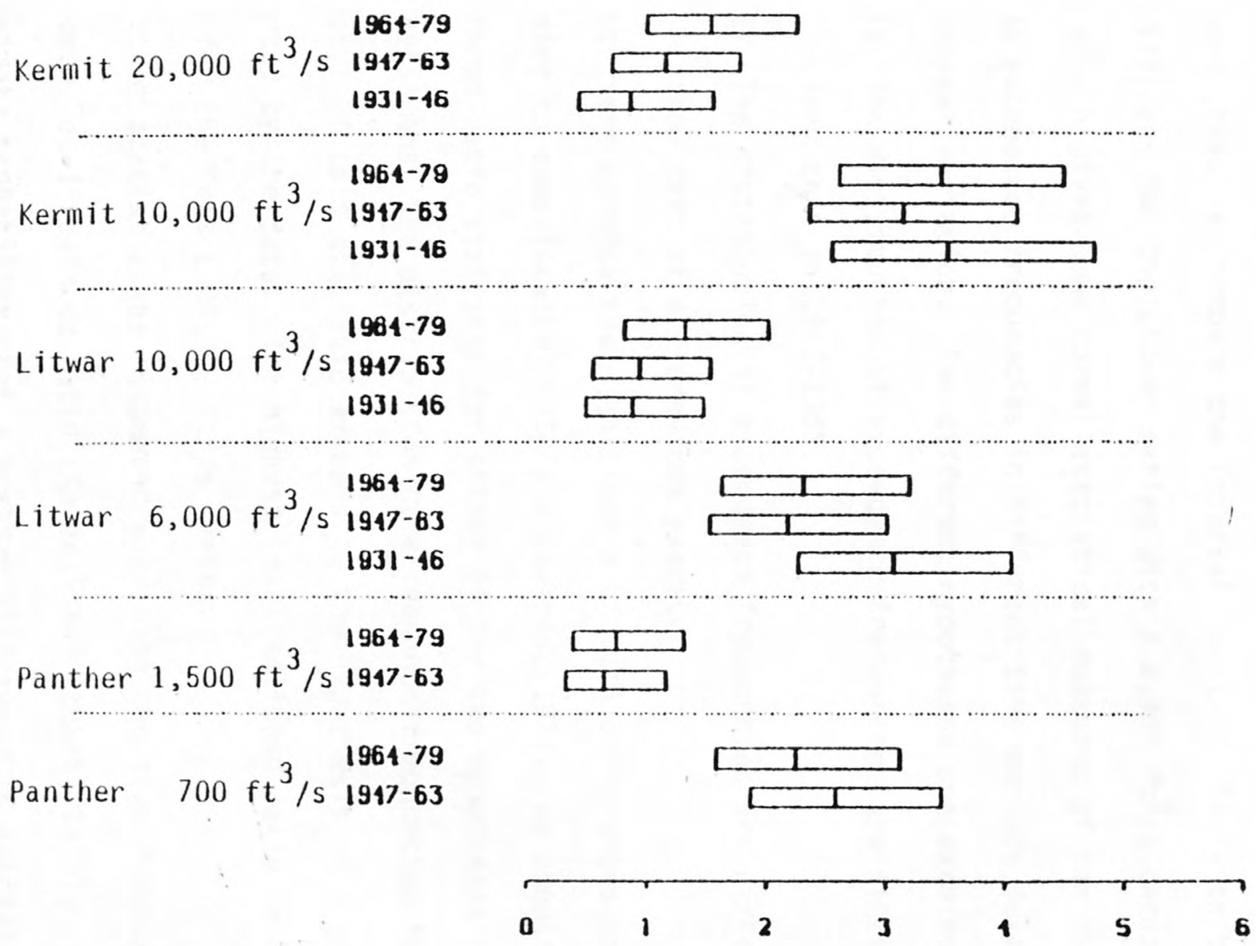


Figure 15.--Expected frequencies of exceedance for different thresholds and time periods. The boxes denote 95 percent confidence intervals for the expected frequencies.

ends of each box represent the ends of the 95-percent confidence intervals for mean exceedance frequencies. As a rule-of-thumb, the average exceedance frequencies in two different periods differ significantly relative to basic year-to-year variation when the confidence-interval ends do not overlap the average exceedance frequencies. For the different time periods and threshold values in figure 15, this occurs only for the Kermit series with a 20,000 ft^3/s threshold (that is, compare the interval for 1931-1946 with the interval for 1964-1979) and for the Litwar series with a 6,000 ft^3/s threshold.

Table 8 gives some formal statistical measures of the differences between average exceedance frequencies in different time periods relative to basic year-to-year variation. Two different hypotheses are examined:

1) The distribution of exceedance frequencies are different in 1964-1979 from that in 1947-1963.

2) The distribution of exceedance frequencies are different in 1964-1979 from that of all previous years.

Statisticians examine the significance of such differences in different ways. According to some (Akaike, 1970 and Edwards, 1972), we should look at the log-likelihood ratio statistic for either of the two hypotheses relative to the hypothesis that the distribution of exceedance frequencies is the same for all periods. If this statistic exceeds 2, the hypothesis of a change is strongly supported by the data. The highest log likelihood ratio in table 8 is only 0.96, for the Kermit 20,000 ft^3/s series.

Other statisticians recommend examining the significance level associated with each log-likelihood ratio (Kendall and Stuart, 1973). This is the approximate probability that a greater difference in average exceedance

Table 8.--Test statistics for expected frequencies of exceedance.

Site	Number of years	Flood series	Alternative hypothesis	Log likelihood ratio	Significance level
Kermit	45	20,000 ft^3/s	A2	0.60	0.27
			A3	0.96	0.17
		10,000 ft^3/s	A2	0.30	0.43
			A3	0.35	0.40
Litwar	49	10,000 ft^3/s	A2	0.49	0.32
			A3	0.84	0.19
		6,000 ft^3/s	A2	0.13	0.61
			A3	0.29	0.45
Panther	33	1,500 ft^3/s	A2	0.01	0.89
			A3	0.01	0.89
		700 ft^3/s	A2	0.37	0.39
			A3	0.37	0.39

The null hypothesis is that the whole series comes from a single Poisson distribution. Alternative hypothesis A2 is that the Poisson distribution and expected exceedance frequency in 1964-1979 differ from those in 1947-1963. Alternative hypothesis A3 is that the Poisson distribution and expected exceedance frequency in 1964-1979 differ from those in all years of record prior to 1964.

frequencies between time periods would occur by chance alone, given basic year-to-year variation. The only significance levels below 20 percent are those for the Litwar and Kermit series with the larger base flows.

To the extent that these data suggest anything, it is that there has been an upward trend in frequency of larger floods at Litwar and Kermit. But even under the mild requirement of a 10 percent significance level, these results are not statistically significant.

Multiple Regression Methods

Analysis in earlier sections indicated an upwards trend in annual peak flood sizes at the Litwar, Kermit, and Panther gages. The Litwar and Kermit stream gages, as noted earlier, are on the Tug Fork below areas of substantial surface-mining activity. The Panther stream gage is on Panther Creek, a tributary of the Tug Fork, below a relatively undisturbed area.

Increases in peak flood size could be caused by increases in storm rainfall or by changes in the hydrologic response. Changes in the hydrologic response would be a result of changes in vegetation cover (affecting interception of rainfall) or in surficial characteristics of the watershed (relative amounts of soil, bare rock, fractured rock, man-made pavements), changes in porosity and permeability of surficial deposits, and integration and density of the drainage networks. Land-use practices (including farming, timber harvesting, urban development, road building, surface-coal mining and mine reclamation) can be expected to change many of these characteristics and hence change the basin flood response. For any change in land use, it is not immediately clear what the magnitude or even direction of the change in flood response will be. For example, Bryan and Hewlett (1981) report that in small eastern Kentucky watersheds, surface coal mining changed the hydrologic response resulting in increased peak summer flows and slightly decreased peak winter flows.

If there has been no change in the hydrologic response of the Panther Creek basin and no change in hydrologic response of the Tug Fork basin above Litwar or Kermit, then no change with time would be expected in the relationship between concurrent annual peak discharges for the basins. There would be some random variation around this relationship depending on the variability over the basins of the flood-producing storms. This random variation limits the ability to detect a trend in the response of the Tug Fork. This variation can be reduced by using the Tug Fork storm rainfall data. By use of regression methods, an attempt is made to determine if there is a trend in the flood discharges of the Tug Fork relative to those of Panther Creek that the Tug Fork rainfall data cannot explain

The primary statistical tool used in investigating these relative flood trends was ordinary least-squares regression analysis (OLS). The following regression model was fitted to the annual flood series at Litwar and Kermit:

$$Q = bR + (c+dY)P$$

or

$$Q = bR + cP + dYP$$

where

Q is the annual-peak discharge

R is the maximum two-day rainfall in inches corresponding to the annual peak

P is the coincident peak discharge at Panther

Y is the year of the annual peak minus 1960

b, c, d are the coefficients of the fitted equation

The coefficients of fitted equations were examined for statistical significance by following the standard multiple regression procedures found in many texts (see, for example, Draper and Smith, 1966). A significant value of c, for example, implies a significant relationship of Q to floods at Panther Creek. A significant value of d indicates that this relationship has changed since 1940.

The YP variable is referred to in regression analysis as the "interaction term." It is, in the above equation, also the relative trend term because a sicnificant value of d indicates a significant relative trend in annual-flood characteristics. This method of trend detection using interaction terms is described by Brown and others, 1975.

Considerable effort was expended on selecting this regression equation as a reasonable descriptor of peak-flood behavior at Litwar and Kermit. This model selection effort was both empirical--via stepwise regression techniques--and judgemental, in that missing data prevented direct statistical comparison of some explanatory variables and in that some variables seemed more reasonable for certain stream gages. Standard stepwise regression methods (Draper and Smith, 1966) and maximum R^2 improvement methods (Hocking, 1977) were used in the empirical model building.

Initially, attempts were made to explain as much of peak-flood variation as possible with only rainfall data. Nine different storm durations at eight different rain gages (fig. 5) were examined. Various functional forms involving logs and polynomials were considered.

Simply using the maximum 2-day storm duration served as well as any complicated linear combination of storm durations. Simple models seemed to account for as much flood variation as could be explained by the data. Models with more than two rain gages were not found to provide a worthwhile improvement over simpler models. The rainfall record from Hurley, Virginia near the center of the basin was the best explanatory variable at all three stream gages. Davella, Kentucky was useful in addition for the Kermit flood series and Gary, Virginia was useful for the Litwar flood series. This is exactly as expected by looking at the map of the basin in figure 5.

Rainfall models with as many as four rain gages as explanatory variables had R^2 values (percent of flood variation explained) below 70 percent. Models based on the final regression form have R^2 values as high as 86 percent and use fewer explanatory variables. These R^2 values are not strictly comparable because the regressions are computed with two different subsets of the data, because of missing data at various rain gages, and are computed with and without intercept terms, because the intercepts were never significant, changing the usual definition of R^2. Nonetheless, the size of the difference coupled with the number of explanatory variables involved gives a reasonable, though rough guide to the improvement represented by the final model form.

Panther Creek flood discharges were included, in addition to rainfall, as an explanatory variable in the final equation for Litwar and Kermit. Using those discharges instead of Hurley, West Virginia rainfall data (the nearest rain gage) substantially improved model fit.

Finally, trend and interaction terms were added to the model to see whether the relationship of the flood series to the best explanatory variables has changed over time. The intercept term, two of the interaction terms, and a year term were dropped from the final model as statistically insignificant.

→ 43 follows

here new

Final regression analyses were performed on four different sets of data (see tables 9 and 10). For Litwar, the "standard data set" uses rainfall at the Gary, West Virginia rain gage and coincident flood peaks at Panther, West Virginia as explanatory variables. Because this information is available for only 29 annual-flood peaks at Litwar, an "augmented data set" was also constructed. Rainfall at Pikeville, Kentucky was substituted for missing data at Gary. Estimated values of missing flood peaks at Panther were obtained from a regression relationship between Panther flood peaks and rainfall at Hurley, Virginia. Augmenting the standard data set in this way provided explanatory variables for 37 annual-flood peaks at Litwar. Results of regression analyses of relative trend at Litwar for both the standard and augmented data sets are shown in table 9. Similarly, the data set for annual flood peaks at Kermit were augmented and the regression results are shown in table 10. For Kermit, the standard data set has 25 observations and the augmented data set has 37 observations. All four data sets are listed in the appendix.

The 1977 Tug Fork flood peak at both Litwar and Kermit was enormous compared to those in the other years of record--see figures 11-13. Statistical analyses should extract general patterns from data but such an unusual observation can greatly influence the fit of a regression model. Where results of statistical analyses depend largely on one observation, they must be interpreted cautiously. A statistical technique that contrives to summarize in one pass a set of data that contains a maverick observation may give a distorted picture of any overall patterns. To protect against such an influence, regression analyses of relative trend in annual flood peaks were performed using all data except that for 1977. The results of these analyses are also presented in tables 9 and 10.

Table 9.--Tug Fork at Litwar--regression analysis of relative trends in annual flood peaks.

Standard data set

Q = 4.09R +	3.65P +	0.111YP		"R^2" =	0.862
(0.68)	(0.71)	(0.037)	s.e.	df =	26
5.98	5.12	3.05	t		

Standard data set with 1977 censored out

Q = 3.87R +	3.79P +	0.0466YP		"R^2" =	0.745
(0.61)	(0.64)	(0.0398)	s.e.	df =	25
6.33	5.96	1.17	t		

Augmented data set

Q = 4.23R +	3.54P +	0.120YP		"R^2" =	0.759
(0.76)	(0.78)	(0.034)	s.e.	df =	34
5.54	4.52	3.51	t		

Augmented data set with 1977 censored out

Q = 4.11R +	3.46P +	0.0846YP		"R^2" =	0.580
(0.75)	(0.77)	(0.0398)	s.e.	df =	33
5.50	4.51	2.13	t		

Definitions

Q = annual flood peak at Litwar (10^3 ft^3/s)
R = associated 2-day maximum precipitation at Gary (inches)
P = associated flood peak at Panther (10^3 ft^3/s)
Y = year of annual flood minus 1960

in augmented data set

if precipitation data for Gary is missing, Hurley is used

if Panther discharge is missing, then regression relationship between 2-day maximum precipitation at Hurley and Panther Creek peak discharge is used (R^2 = 0.706)

s.e. is standard error of estimate for coefficients
t is t statistic for coefficients

"R^2" is $1 - \frac{\Sigma(\hat{Q}-Q)^2}{\Sigma(Q-\bar{Q})^2}$

d.f. is degrees of freedom (number of observations minus 3)

Table 10.--Tug Fork near Kermit--regression analysis of relative trends in annual flood peaks.

Standard data set

$Q = 5.22R$	$+ 11.5P$	$+ 0.224YP$		"R^2"	= 0.866
(1.21)	(1.4)	(0.089)	s.e.	df	= 22
4.32	7.94	2.52	t		

Standard data set with 1977 censored out

$Q = 5.64R$	$+ 10.9P$	$+ 0.0363YP$		"R^2"	= 0.819
(1.09)	(1.3)	(0.109)	s.e.	df	= 21
5.16	8.21	0.33	t		

Augmented data set

$Q = 5.31R$	$+ 10.9P$	$+ 0.250YP$		"R^2"	= 0.831
(1.07)	(1.3)	(0.072)	s.e.	df	= 34
4.95	8.47	3.48	t		

Augmented data set with 1977 censored out

$Q = 5.61R$	$+ 10.3P$	$+ 0.166YP$		"R^2"	= 0.759
(1.04)	(1.3)	(0.080)	s.e.	df	= 33
5.41	8.20	2.07	t		

Definitions

Q = annual flood peak at Kermit (10^3 ft^3/s)
R = associated 2-day maximum precipitation at Davella (inches)
P = associated flood peak at Panther (10^3 ft^3/s)
Y = year of annual flood minus 1960

in augmented data set

if precipitation data for Davella is missing, Pikeville is used

if neither Davella nor Pikeville precipitation data are available, Hurley is used

if Panther discharge is missing, then regression relationship between 2-day maximum precipitation at Hurley and Panther Creek peak discharge is used (R^2 = 0.706)

s.e. is standard error of estimate for coefficients
t is t statistic for coefficients

"R^2" is $1 - \dfrac{\Sigma(\hat{Q}-Q)^2}{\Sigma(Q-\bar{Q})^2}$

d.f. is degrees of freedom (number of observations minus 3)

Table 9 gives results for Litwar. If the t-statistics for the regression coefficients exceed 2.0, the coefficients are significant at about the 5 percent level. The relative trend term YP--the product of the Panther Creek flood and the year index--has a significant coefficient in three of the four regression analyses. The only exception for Litwar occurs when 1977 is dropped from the standard data set. This indicates that the abnormally large 1977 flood does in fact have undue influence on the overall regression fit. The four regressions taken together, however, provide statistical evidence for an upwards trend in annual flood peaks at Litwar relative to coincident flood peaks at Panther. They indicate that the factor by which one multiplies Panther Creek floods to get reasonable approximations of annual flood peaks at Litwar has increased since 1940.

Neither the analyses that treat 1977 the same as any other year nor the analyses that assume the 1977 data to be entirely lacking in useful information are wholly satisfactory. On the one hand the 1977 data probably contains some useful information, on the other, there may be other abnormal years that distort the overall picture. As an additional check on these results, the "robust regression" method of iterated weighted least squares (Mosteller and Tukey, 1977) was also used. This method invokes a mechanical procedure to automatically assign weights to observations based on residuals of an initial regression fit. These weights may fall anywhere between zero and one. Observations with smaller residuals from the regression are given relatively larger weights. Weighted least squares is then run (Draper and Smith, 1966), and new weights computed. Refits using weighted least squares can be performed several times, depending on the choice of stopping rule or convergence criterion. We use the bisquare-weight function (Gross, 1977, Mosteller and Tukey, 1977) with starting weights computed from prediction residuals of an ordinary regression fit (Allen, 1971).

Results of the robust regressions for Litwar appear in table 11. The trend coefficient in the robust regression using the augmented data set falls between the two ordinary regression trend coefficients, but closer to the coefficient where 1977 is excluded. The trend coefficient is significant in both robust regressions.

Tables 10 and 11 contain the various robust regression results for annual flood peaks at Kermit. The results are similar to those for Litwar. There is evidence for an upward relative trend compared to flood peaks at Panther. However, it again appears that the magnitude of the relative trend may be smaller than that indicated when the abnormal flood of 1977 is included in an ordinary regression analysis.

We can examine graphically the strength of the statistical evidence for upwards relative trends at Litwar and Kermit. Figures 16 and 17 are "adjusted variable plots" (Cleveland, 1981, and Mosteller and Tukey, 1977) showing the

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Figures 16 and 17 near here.

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relationship of floods to the relative trend term after correcting for rainfall and Panther Creek floods. The vertical axis shows the residuals of floods after regressing on rainfall and Panther Creek floods. In effect, this is the remaining unexplained variation in floods before considering trend. The horizontal axis shows the residuals of the relative trend term after regressing it on rainfall and Panther Creek floods. In effect, this is the additional explanatory power of the relative trend term once all colinearity with rainfall and Panther Creek discharges has been removed. The slope of a simple regression fitted to these points is the coefficient of the relative trend term in the full multiple regression equation.

Table 11.--Additional relative trend results for Litwar and Kermit using robust regression.

Litwar standard data set

Q =	3.57R +	4.11P +	0.113YP	
	(0.68)	(0.71)	(0.36)	s.e
	5.26	5.81	3.10	t

Litwar augmented data set

Q =	4.17R +	3.83P +	0.0908YP	
	(0.85)	(0.87)	(0.038)	s.e
	4.93	4.41	2.39	t

Kermit standard data set

Q =	4.87R +	11.1P -	0.00384YP	
	(0.71)	(0.86)	(0.052)	s.e.
	6.83	13.0	-0.07	t

Kermit augmented data set

Q =	4.94R +	10.9P +	0.194YP	
	(0.98)	(1.18)	(0.065)	s.e.
	5.02	9.21	2.94	t

See tables 9 and 10 for definitions.

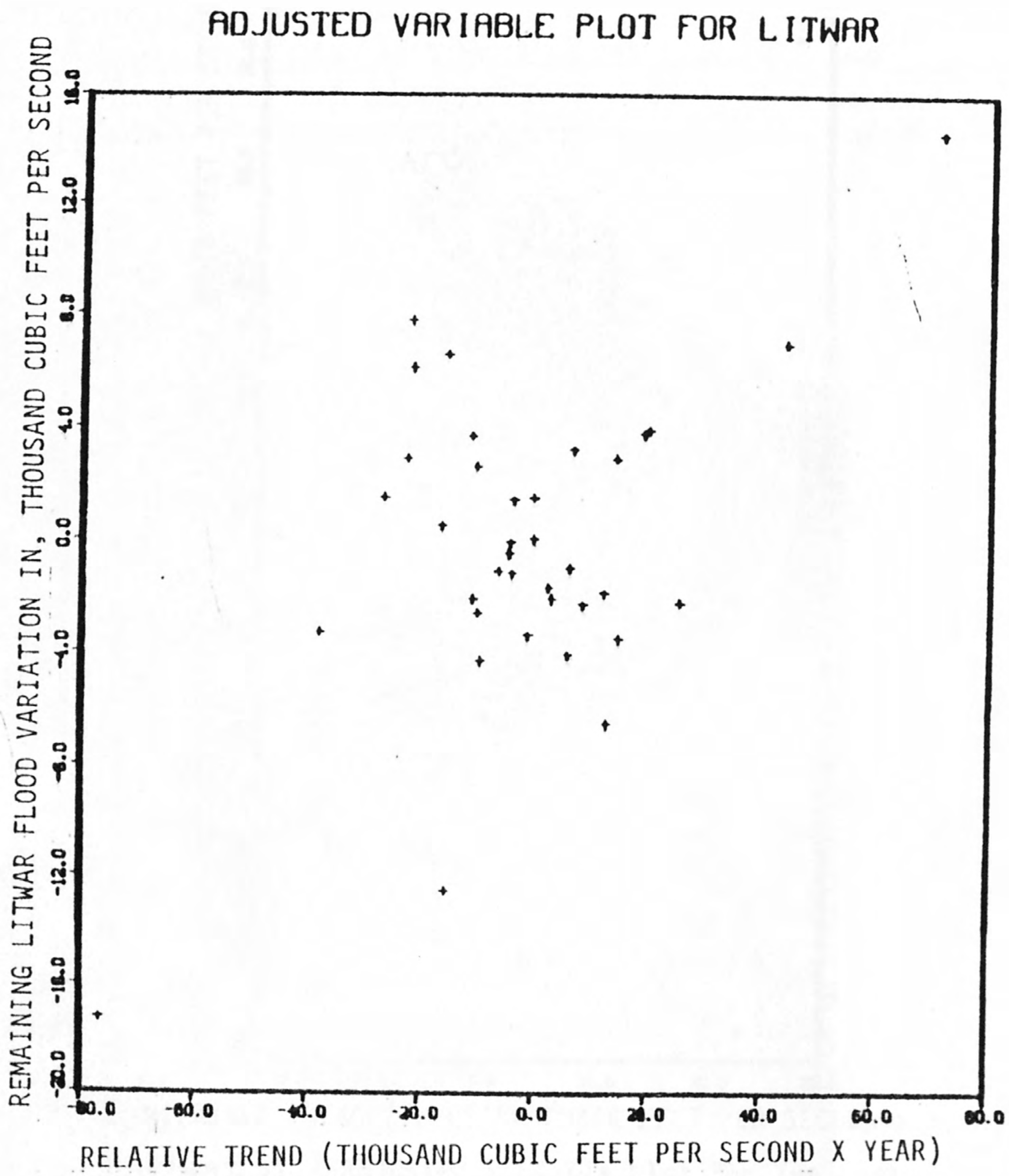

Figure 16.--Adjusted variable plot for Tug Fork annual flood peaks at Litwar.

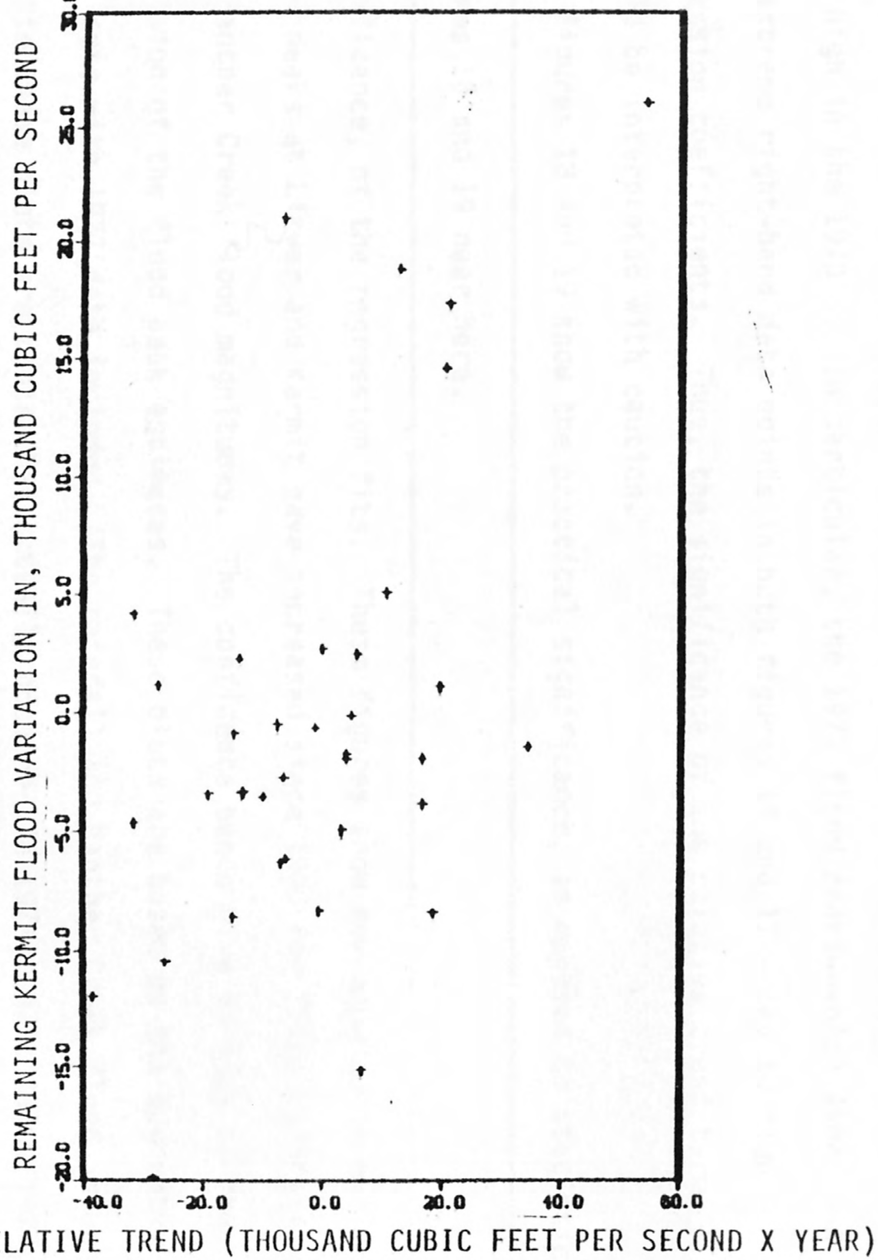

Figure 17.--Adjusted variable plot for Tug Fork annual flood peaks near Kermit.

The graphs reveal the trend patterns in annual flood peaks at Litwar and Kermit that result in the significant t-statistics for relative trend in the regression fits. But they also show that this statistical significance depends on just a few annual flood peaks that are either very low in the 1940's or very high in the 1970's. In particular, the 1977 flood peaks--which appear as the extreme right-hand data points in both figures 16 and 17--lead to high regression coefficients. Thus, the significance of the relative trend term should be interpreted with caution.

Figures 18 and 19 show the practical significance, as opposed to statistical

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Figures 18 and 19 near here.

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significance, of the regression fits. These figures show how expected annual-flood peaks at Litwar and Kermit have increased since 1940 for fixed rainfall and Panther Creek flood magnitudes. The confidence bands give an idea of the precision of the flood peak estimates. These plots are based on the augmented data sets with 1977 data included. The rainfall and Panther Creek flood values used in these plots are those that actually occurred in 1974, 1975, 1976, 1977, and 1978. For example, for the first graph of figure 19 (1974), the rainfall at Davella is 2.86 inches and the Panther Creek flood is 1.79 10^3 ft^3/s. Setting Y to -20 (representing the year 1940) the estimated value of discharge at Kermit is 25.7 10^3 ft^3/s. Setting Y to +20 (representing the year 1980) the estimated value of discharge at Kermit is 43.6 10^3 ft^3/s. The actual size of the 1974 flood was 53.0 10^3 ft^3/s.

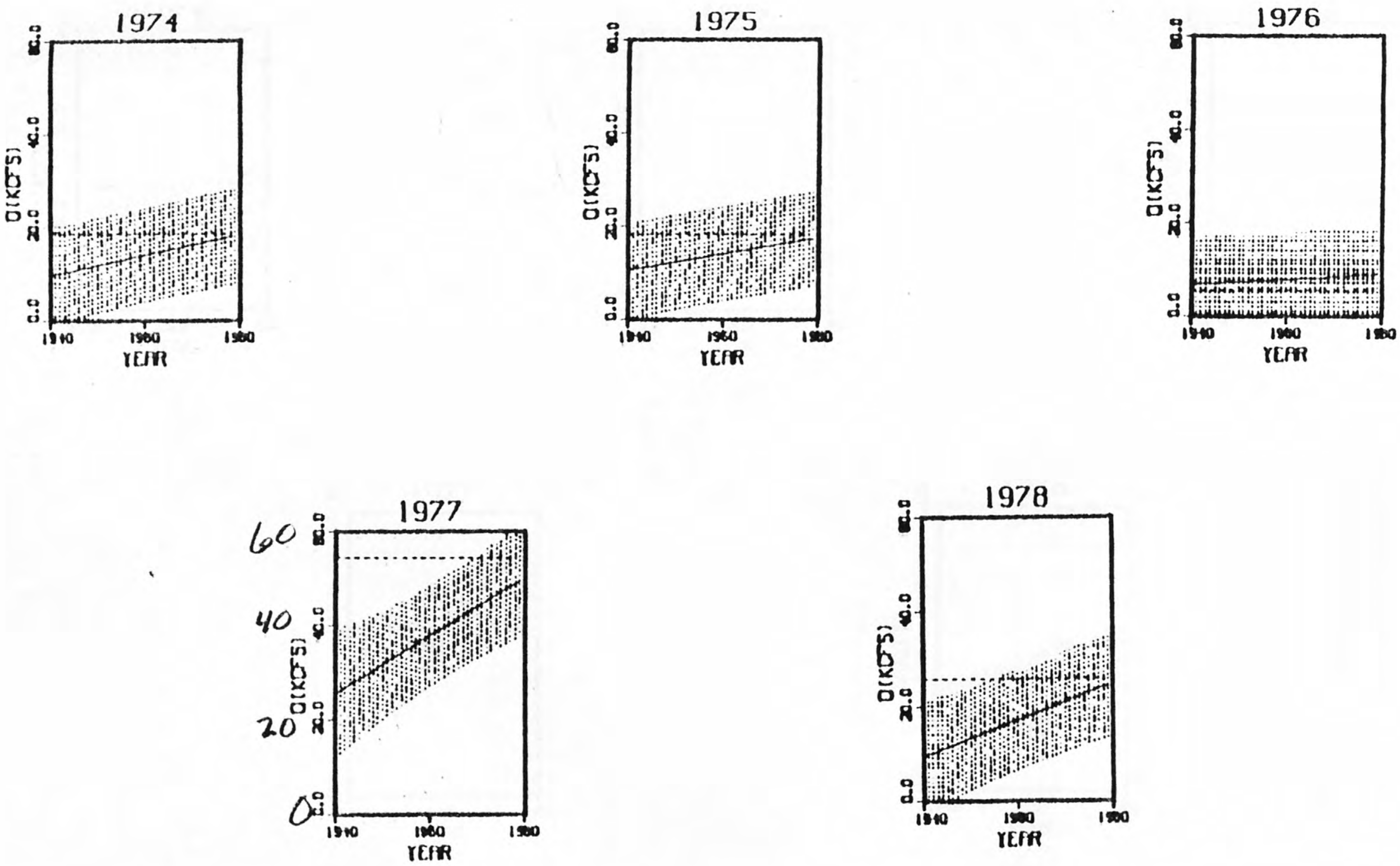


Figure 18.--Estimated trend in Tug Fork annual flood peaks at Litwar, given 1974 - 1978 meteorological conditions. The dashed lines show the actual 1974 - 1978 annual flood peaks near Litwar. The solid lines show regression model estimates of the flood that would have occurred each year, 1940 - 1980, for the given meteorological conditions. The dotted area shows the 95 percent confidence intervals for the regression estimates.

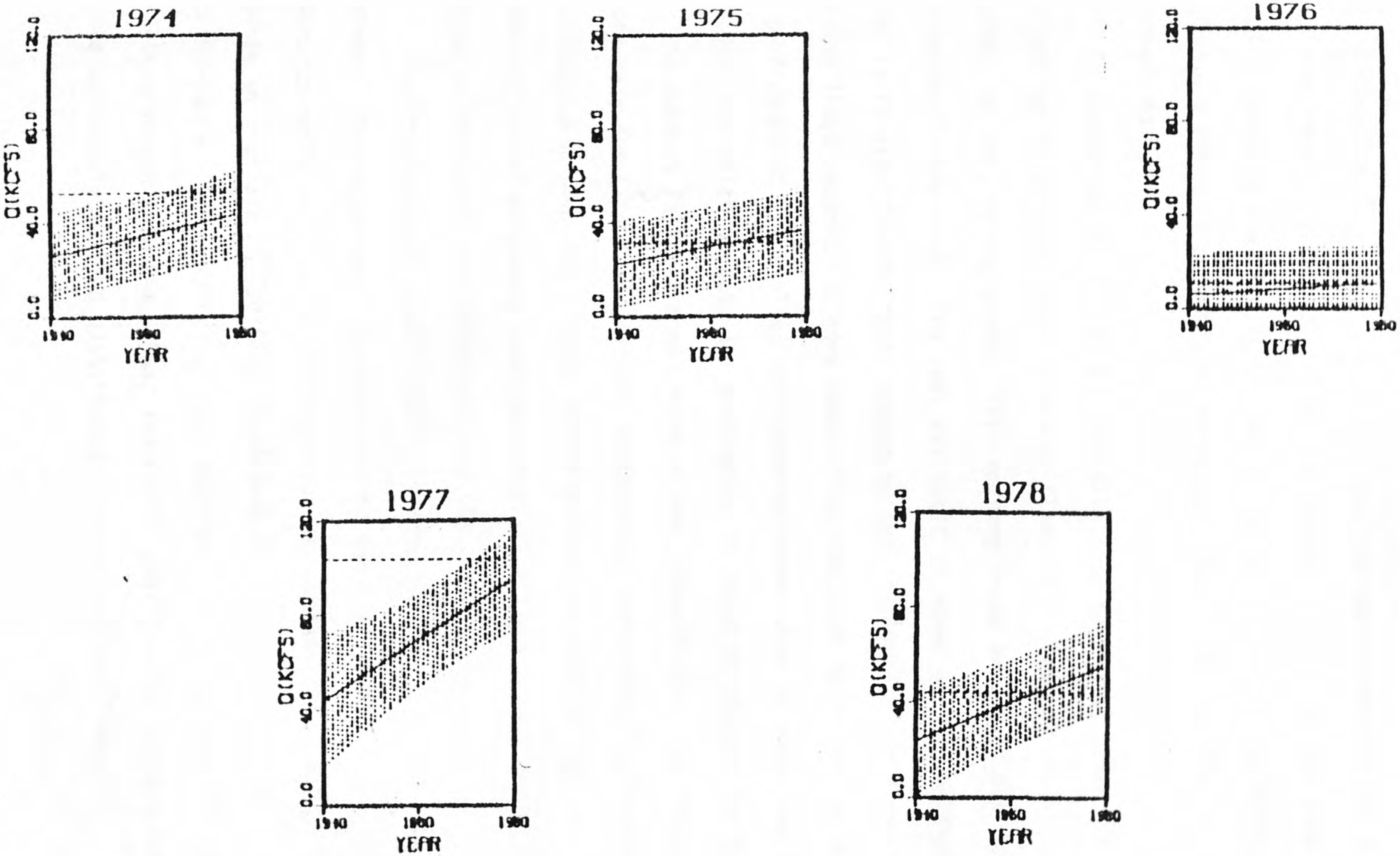


Figure 19.--Estimated trend in Tug Fork annual flood peaks near Kermit, given 1974 - 1978 meteorological conditions. The dashed lines show the actual 1974 - 1978 annual flood peaks near Kermit. The solid lines show regression model estimates of the flood that would have occurred each year, 1940 - 1980, for the given meteorological conditions. The dotted area shows the 95 percent confidence intervals for the regression estimates.

A final check on the validity of the regression results was made by examining residuals to check normality assumptions. This was done both statistically (Shapiro and Wilk, 1965) and graphically (Daniel and Woods, 1971). No reason was found to reject the regression results for departure from normality assumptions.

To summarize the multiple regression results so far, there is some statistical indication of upwards trend in annual flood peak sizes at Litwar and Kermit that cannot, as yet, be explained. This seeming trend may be caused by chance variation in the data. The test statistic is never of overwhelming significance. When it is significant, it is caused by the influence of only two or three years of the flood record. In some model fits, the test statistic fails to attain significance at all. Also, this seeming trend could be explained by natural factors for which no data are available, or could be related to factors overlooked by the authors in their model formulation. Nonetheless, for the most complete data sets for Litwar and Kermit, statistical indication of a possible trend persists even when the abnormally large flood of 1977 is ignored. Thus, the possibility of an upward trend in annual-flood-peak sizes cannot be discarded based on presently available data and the analysis to date.

Are the possible upward trends in annual flood peaks related to surface mining? Any major basin disturbances in the Litwar and Kermit watersheds that do not also occur in the state forest upstream from Panther could cause an increase in Tug Fork flood peaks. Surface mining could be such a disturbance. At present, only surface-coal-production data for the Tug Fork basin upstream from the Litwar and Kermit gaging sites are available, but no data on associated land disturbance--see table 5 and figure 10.

It is unclear how best to relate production in tons to extent of land disturbance. Tables 12 and 13 give some regression results using three different coal production indices for Litwar and Kermit: total coal production each year, total coal production each year and the two preceding years, and total coal production from each year back through 1940. Each coal production index is a possible measure of mining-related land disturbance. A relative trend term is formed by multiplying the Panther Creek flood levels by the given coal production index. Each regression analysis of relative trend answers the following question: If the size of annual flood peaks on the Tug Fork is predicted by accounting for available rainfall information and then multiplying the Panther Creek flood by some factor, should this factor change for different values of the given coal-production index?

From tables 12 and 13, the answer is yes--but for Litwar flood peaks and annual and three-year production indices the yes is tentative. (The t-statistics for trend in these cases are 1.37 and 1.85, compared to the value of 2.0 needed for statistical significance at about the 5 percent level.) However, in no case does relating flood peak trend to a coal-production index give markedly better regression fits than simply relating flood-peak trends to year. Thus, though there is some indication of upward trends in annual flood peaks on the Tug Fork relative to floods in the Panther Creek basin (where there is little surface mining), there is no additional evidence relating these trends to any specific coal-production index.

Table 12.--Tug Fork at Litwar--regression analysis of trends in annual flood peaks related to different coal production indices (based on augmented data set).

Annual coal production

Q = 4.03R +	2.96P +	1.39CP			
(0.86)	(1.24)	(1.02)	s.e.	"R^2" =	0.689
4.66	2.33	1.37	t	df =	34

Three-year coal production

Q = 3.90R +	2.40P +	0.790CP			
(0.86)	(1.29)	(0.43)	s.e.	"R^2" =	0.697
4.55	1.86	1.85	t	df =	33

Coal production since 1940

Q = 4.20R +	1.36P +	0.138CP			
(0.77)	(1.01)	(0.041)	s.e.	"R^2" =	0.755
5.46	1.95	3.40	t	df =	34

Definitions

C = the given coal production index in millions of tons
Q = annual flood peak at Litwar (10^3 ft^3/s)
R = associated 2-day maximum precipitation at Gary (inches)
P = associated flood peak at Panther (10^3 ft^3/s)
Y = year of annual flood minus 1960

in augmented data set

if precipitation data for Gary is missing, Hurley is used

if Panther discharge is missing, then regression relationship between 2-day maximum precipitation at Hurley and Panther Creek peak discharge is used (R^2 = 0.706)

s.e. is standard error of estimate for coefficients
t is t statistic for coefficients

"R^2" is $1 - \frac{\Sigma(\hat{Q}-Q)^2}{\Sigma(Q-\bar{Q})^2}$

d.f. is degrees of freedom (number of observations minus 3)

Table 13.--Tug Fork near Kermit--regression analysis of trends in annual flood peaks related to different coal production indices. (based on augmented data set).

Annual coal production

$Q = 4.55R +$	$7.34P +$	$2.34CP$			
(1.03)	(2.01)	(0.68)	s.e.	"R^2"	= 0.841
4.41	3.66	3.43	t	df	= 33

Three-year coal production

$Q = 4.78R +$	$7.53P +$	$0.766CP$			
(1.03)	(1.87)	(0.207)	s.e.	"R^2"	= 0.844
4.65	4.03	3.70	t	df	= 32

Coal production since 1940

$Q = 5.12R +$	$8.59P +$	$0.110CP$			
(1.06)	(1.69)	(0.031)	s.e.	"R^2"	= 0.843
4.84	5.10	3.53	t	df	= 33

Definitions

C = the given coal production index in millions of tons.
Q = annual flood peak at Kermit (10^3 ft^3/s)
R = associated 2-day maximum precipitation at Davella (inches)
P = associated flood peak at Panther (10^3 ft^3/s)
Y = year of annual flood minus 1960

in augmented data set

if precipitation data for Davella is missing, Pikeville is used

if neither Davella nor Pikeville precipitation data are available, Hurley is used

if Panther discharge is missing, then regression relationship between 2-day maximum precipitation at Hurley and Panther Creek peak discharge is used ($R^2 = 0.706$)

s.e. is standard error of estimate for coefficients
t is t statistic for coefficients

"R^2" is $1 - \frac{\Sigma(\hat{Q}-Q)^2}{\Sigma(Q-\bar{Q})^2}$

d.f. is degrees of freedom (number of observations minus 3)

CHANGES IN STREAM-CHANNEL SHAPE AND ALTITUDE

The purpose of this analysis is to determine if the shape of the stream channels and/or the altitude of the streambeds in the Tug Fork basin have changed significantly over time. And if so, if the rates of these changes have increased or decreased during specific time periods.

As evidenced by our continually changing landscape, streams and rivers are dynamic systems. They are continually changing with time. Generally, changes such as deepening, widening, meander migration, and lateral movement of stream channels take place rather imperceptably over long periods of time. The stream channel represents a composite of all the hydrologic and hydraulic factors acting on the surrounding soils. Such factors as flow quantity, stream gradient, cohesiveness of banks, type of bed material, and quantity of suspended sediment all act to determine the size and shape of stream channels. If a substantial change takes place in any one of these variables, the stream channel will adjust itself to accommodate the change.

To investigate whether any of these changes may have taken place at specific sites in the Tug Fork basin, data from the following three long-term gaging station were used:

03213000 Tug Fork at Litwar, West Virginia

03213500 Panther Creek near Panther, West Virginia

03214000 Tug Fork near Kermit, West Virginia

The locations of these stations are shown in figure 5.

At each gaging station where records of flow are to be computed, a relationship must be established between the altitude of the water surface (gage height) and the rate of flow (discharge). Discharge is normally measured in cubic feet per second and gage height in feet. This relation (rating curve) is empirically determined for each gage site by measuring discharges at various gage heights, plotting these values on a graph, and drawing a smooth curve through the points. An example of a rating curve for station 03214000 Tug Fork near Kermit, West Virginia, is shown in figure 20.

Figure 20 near here.

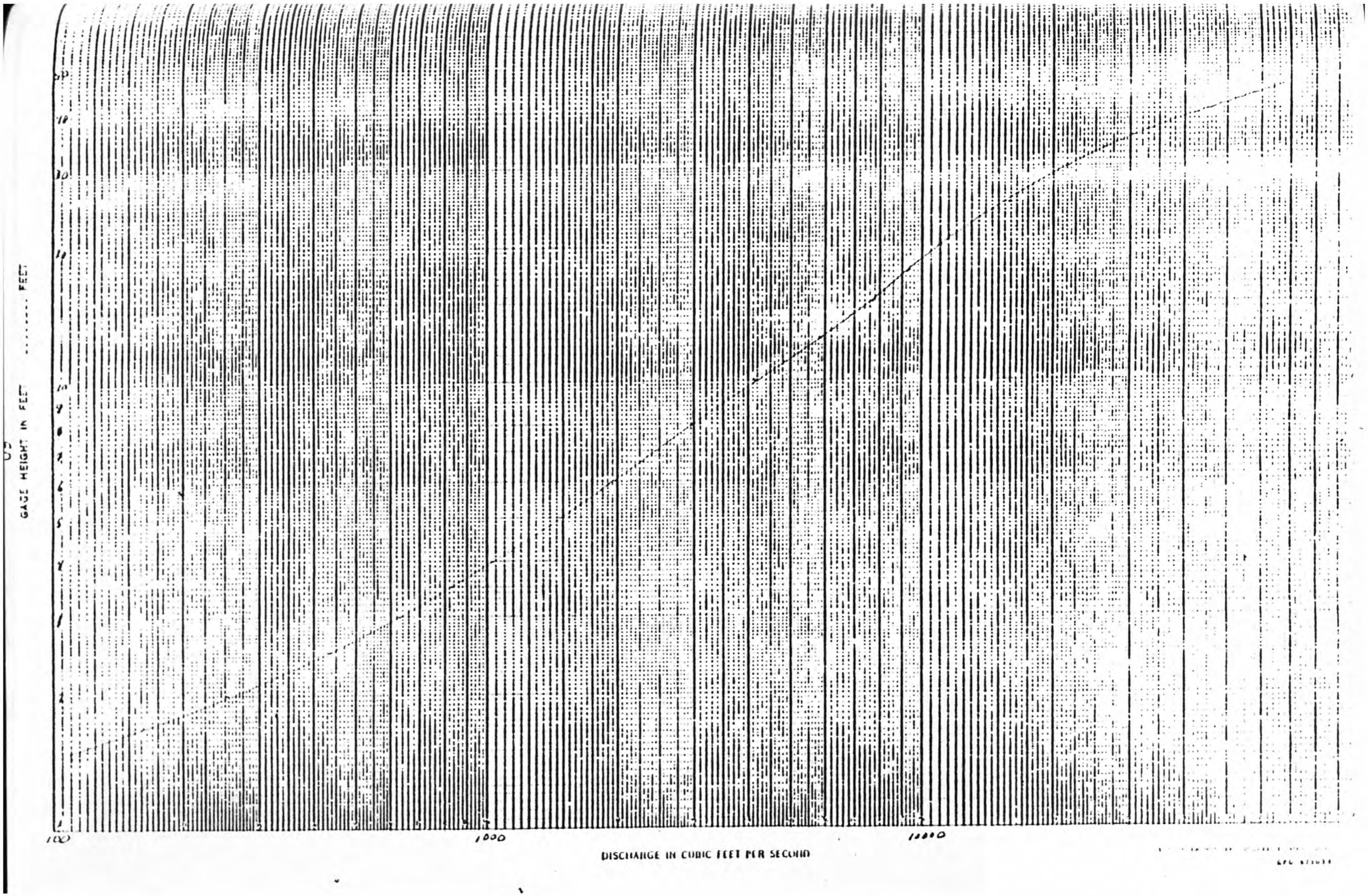
As changes occur in the flow-carrying characteristics of the stream channel, they are reflected as changes in this relationship. This necessitates making periodic streamflow measurements to identify when changes take place and redefining the rating as required.

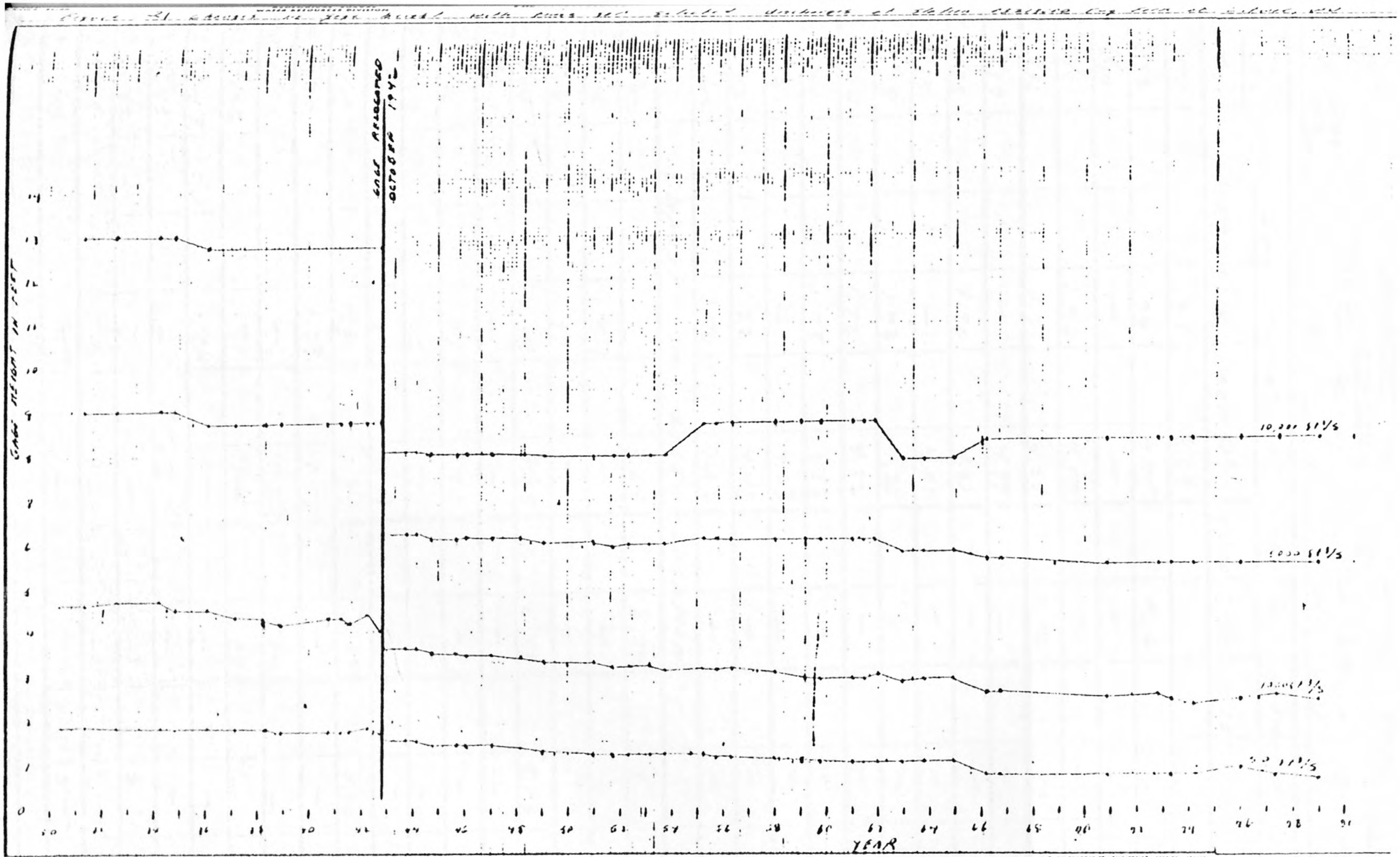
It should be noted that the relationship between gage height and discharge, for a specific gage site, is a function of such factors as channel width, channel depth, channel roughness, and streambed slope. Also, a rating curve is only representative of a single cross section or a single reach of river referred to as the "control" for the gaging station.

The gage height for selected discharges was determined from all ratings developed during the period of record for each of the three long-term gaging stations in the basin. These gage heights for selected discharges at each station were plotted against time and are shown in figures 21, 22, and 23. These gage heights and their period of use are

Figures 21, 22, and 23 near here.

listed in tables 14, 15, and 16.


GAGE HEIGHT IN FEET
100
1000
10000
DISCHARGE IN CUBIC FEET PER SECOND



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UNITED STATES
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able 14. Gage height for selected discharges at gaging station 03213000 Tug Fork at Litwar WV

iod of ting use		Gage height in feet for indicated discharges			
om	To	50 ft³/s	1000 ft³/s	5000 ft³/s	10000 ft³/s
/30	4/31	1.83	4.63		
/31	9/32	1.94	4.75	9.06	13.00
/32	3/34	—	—	—	—
/34	10/34	1.40	4.57	—	—
/34	1/36	1.31	4.55	8.76	11.99
/36	2/37	—	4.39	—	—
/37	3/38	1.80	4.20	—	—
/38	4/38	—	4.31	—	—
/38	11/38	1.73	4.20	—	—
/38	9/40	1.72	4.32	—	—
/40	3/41	1.73	4.35	—	—
/41	7/41	—	4.23	—	—
/41	3/42	1.82	4.43	—	—
/42	10/42	1.70	4.02	—	—
		CHANGE IN	GAGE LOCATION		
0/42	12/42		3.65	6.23	8.10
/42	9/43	1.53	—	—	—
/43	2/44	1.57	—	—	—
/44	9/44	1.48	3.55	6.19	8.03
/44	9/45	—	—	—	—
/45	1/46	1.47	3.50	—	—
/46	1/47	1.45	—	—	—
/47	2/48	1.40	3.46	6.17	—
/48	1/49	1.31	3.36	6.09	8.00
/49	12/50	1.23	3.32	—	—
/50	9/51	—	3.22	5.94	—
/51	4/52	—	—	6.00	—
/52	2/53	1.24	—	—	—
/53	9/53	—	3.19	—	—
/53	3/55	—	—	6.11	8.71
/55	9/55	1.19	3.20	—	—
/55	7/56	—	—	—	8.75

— No change from previous value

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Table 4. (Continued)

Period of rating use		Gage height in feet for indicated discharges				
From	To	50 ft³/s	1000 ft³/s	5000 ft³/s	10,000 ft³/s	
/56	12/57	1.14	3.00	—	—	
/57	1/59	1.11	2.98	—	—	
/59	9/59	1.08	2.95	6.10	—	
/59	12/60	—	2.97	—	—	
/60	5/61	1.02	—	6.12	—	
/61	12/61	—	3.02	—	—	
/61	11/62	—	2.88	5.81	7.90	
/62	9/63	1.07	2.93	5.85	—	
/63	11/64	—	—	—	—	
/64	2/66	0.78	2.65	5.69	8.37	
/66	9/66	—	2.63	—	—	
/66	10/70	.73	2.51	5.53	—	
/70	8/72	.77	2.58	—	—	
/72	4/73	.73	2.48	—	—	
/73	3/74	—	2.35	—	—	
/74	12/75	.90	2.45	—	—	
/75	4/77	.73	2.54	—	—	
/77	—	.63	2.43	—	—	

— No change from previous value.

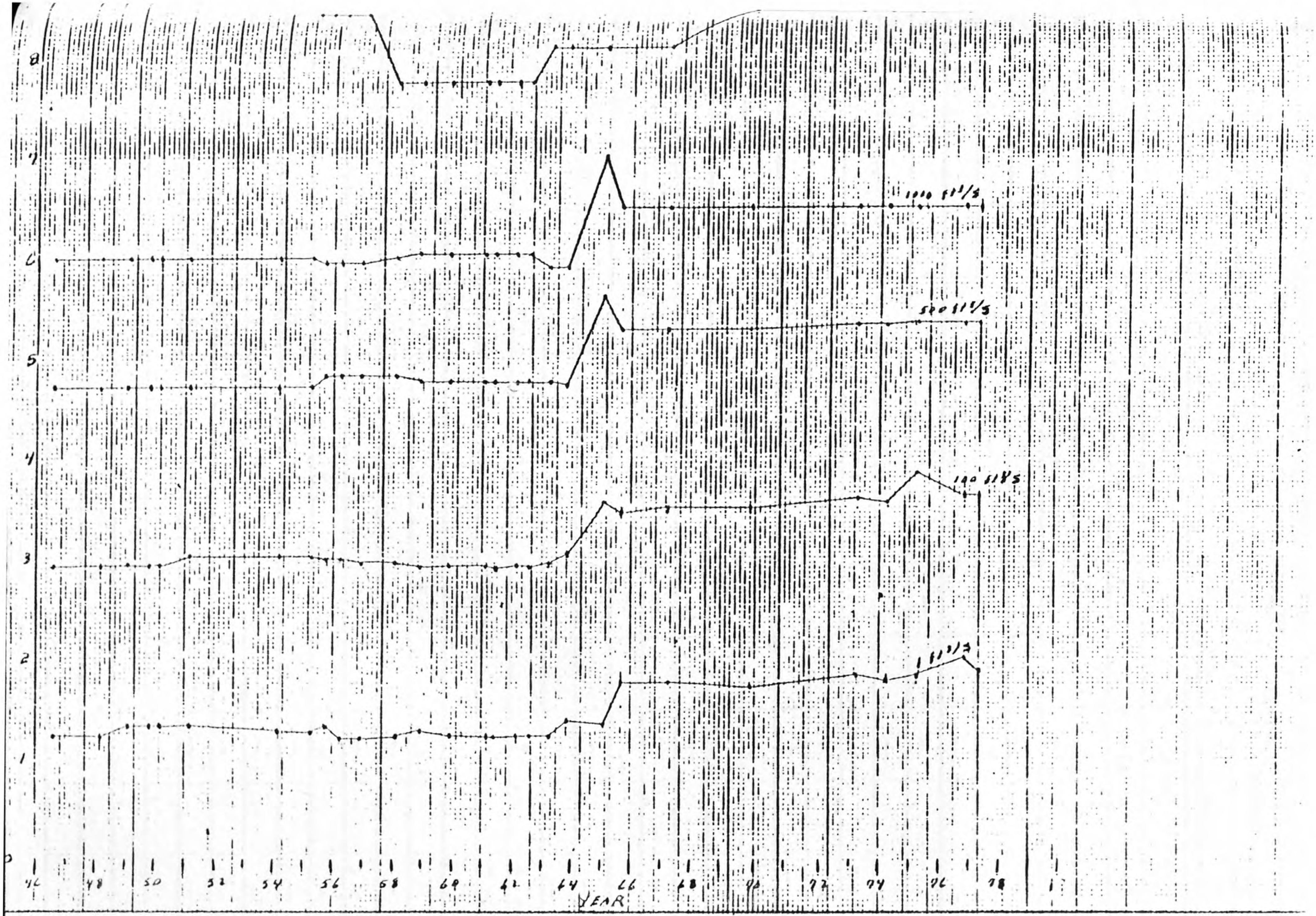

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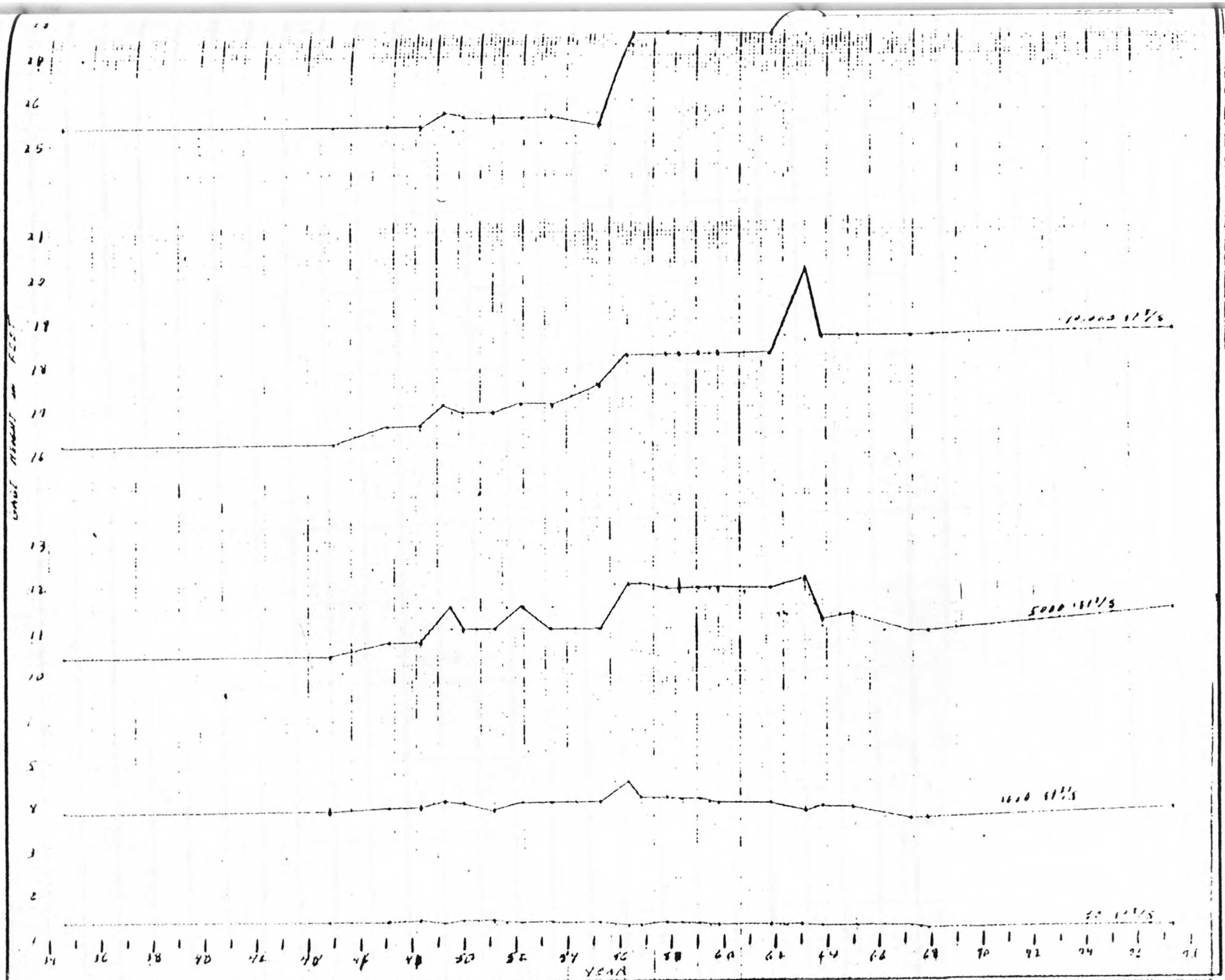
Table . Gage height for selected discharges at gaging station 03213500 Panther Creek near Panther, WV

Period of rating WSC From	To		Gage height in feet for indicated discharge 1 ft³/s	100 ft³/s	500 ft³/s	1000 ft³/s	2500 ft³/s
7/46	2/48		1.23	2.92	4.72	6.02	Not defined
2/48	1/49		1.32	2.94	—	—	
1/49	10/49		—	—	—	—	
10/49	2/50		1.33	—	—	—	
2/50	2/51		—	3.01	—	—	
2/51	2/54		1.28	—	—	—	
2/54	3/55		1.26	—	—	—	
3/55	9/55		1.31	2.99	4.93	5.97	8.53
9/55	3/56		1.20	—	—	—	—
3/56	11/56		—	2.95	—	—	—
11/56	1/58		1.21	—	—	6.02	7.75
1/58	11/58		1.27	2.91	4.78	6.05	—
11/58	11/59		1.23	—	—	—	—
11/59	2/61		1.21	—	—	—	—
2/61	5/61		—	2.90	—	—	—
5/61	2/62		1.22	2.92	—	—	—
2/62	7/62		1.21	2.91	—	—	—
7/62	3/63		—	2.95	4.76	5.93	8.14
3/63	10/63		1.39	3.05	4.74	5.92	8.12
10/63	1/65		1.34	3.56	5.64	7.01	—
1/65	8/65		1.75	3.45	5.30	6.52	—
8/65	3/67		1.76	3.50	—	—	—
3/67	10/67		1.71	—	—	—	8.69
10/67	3/73		1.84	3.60	5.35	—	—
3/73	3/74		1.78	3.56	—	—	—
3/74	3/75		1.83	3.95	5.37	—	—
3/75	10/76		2.00	3.62	—	—	—
10/76	4/77		1.88	—	—	—	—

— No change from previous value.



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able 5. Gage height for selected discharges at gaging station
03214000 Tug Fork near Hermit WV

Period of rating use		Gage Height in Feet For Indicated Discharges				
From	To	50 ft³/s	1000 ft³/s	5000 ft³/s	10000 ft³/s	20,000 ft³/s
/34	10/44	1.35	3.85	10.4	16.2	25.4
/44	1/47	—	3.93	10.7	16.6	—
/47	4/48	1.39	—	—	—	—
/48	3/49	1.33	4.07	11.5	17.1	25.7
/49	12/49	1.39	4.03	11.0	16.9	25.6
/49	2/51	—	3.88	—	—	—
/51	3/52	1.31	4.03	11.5	17.1	—
/52	5/53	1.32	—	—	—	—
/53	3/55	—	—	11.0	17.5	25.4
/55	4/56	1.26	4.50	12.0	18.2	27.6
/56	10/56	—	4.17	—	—	—
/56	10/57	1.30	4.15	11.9	—	—
/57	5/58	—	4.10	—	—	—
/58	1/59	—	—	—	—	—
/59	10/59	1.26	4.00	—	—	—
/59	10/61	—	—	11.8	—	—
/61	12/62	—	3.83	12.1	20.1	29.5
/62	10/63	1.22	3.93	11.2	18.6	28.2
/63	2/65	1.21	3.90	11.3	—	—
/65	3/67	—	3.67	10.9	—	—
/67	11/67	1.15	—	—	—	—
/69	4/77	1.19	3.85	11.4	18.7	—

— No change from previous value

A general trend in aggradation or degradation of stream channels is not discernable from the graphs. Neither are general trends in changes in the flow-carrying characteristics of channels apparent. Changes that do occur at individual sites are scattered in time and do not indicate general trends for specific time periods.

It must be kept in mind, when drawing inferences from these relations, that the accuracy of each may vary. The accuracy of the relations is a function of the accuracy of each discharge measurement and the number of discharge measurements used to define the gage height-discharge relation.

A discussion of the results for each individual station follows:

03213000 Tug Fork at Litwar, West Virginia

This station is located about 0.5 mi downstream from Litwar, West Virginia. Drainage area above the station is 505 mi^2. The present low-water control for the station is a natural rock riffle located about 500 feet downstream from the station. This station was located about 0.5 mi upstream prior to October 1942. The ratings for this station indicate a very uniform drop in gage height for a given discharge from 1930 to 1979. This is true for both gage locations. From 1943 to 1979, the gage heights fell about 1 foot. The water-surface elevation for high (10,000 ft^3/s or greater) discharges increased slightly. That is, for a discharge of 10,000 ft^3/s in 1944, the gage height would have been about 8.0 feet; in 1979, it would have been about 8.3 feet. Because of the poor accuracy of high flow measurements, this alone does not necessarily indicate any change in channel capacity. In fact, for flows up to 5,000 ft^3/s, the channel capacity appears to have generally increased for a given gage height.

This capacity increase appears to be so uniform in time that it is probably caused either by degradation or widening of the control section. The location of the control in a narrow, steeply-banked channel, indicates that degradation probably took place.

03213500 Panther Creek near Panther, West Virginia

This station is located in Panther State Forest about 3 mi southwest of Panther, West Virginia. Drainage area above the station is 31.0 mi^2 and is almost undisturbed. Only about 0.3 mi^2 of area located in the headwaters of the basin have been disturbed by mining. The low-water control for this station was a rock outcrop located downstream from the gage until March 1963, when a large flood destroyed this outcrop and a rock riffle became the control. This situation existed until 1979 when a concrete weir was installed. The ratings prior to and subsequent to the 1963 flood indicate no trends in the channel characteristics at this site.

03214000 Tug Fork near Kermit, West Virginia

This gaging station, located about 3 mi upstream from Kermit, West Virginia, has a drainage area of 1,188 mi^2. The gage is in a deep, narrow, heavily-vegetated reach of the river. The low-water control for this station is a natural rock riffle and the high-water control is the river channel.

The high-water rating characteristics at this site exhibit a significant change during the period of record. The gage height for flows larger than 10,000 ft^3/s has increased over 2 feet during the period of record. For example, the gage height for 20,000 ft^3/s was about 25.7 feet in

1950 and 28.4 feet in 1976. Most of the increase in gage height took place as a result of the February 1955 flood. The change could be caused by such occurrences as sloughing of banks, deposition of sediment on flood plains, or build-up of debris or vegetation downstream. However, the exact cause is not known.

Channel cross sections obtained at various times are shown in figure 24. These cross sections were obtained from discharge measurements

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Figure 24 near here.

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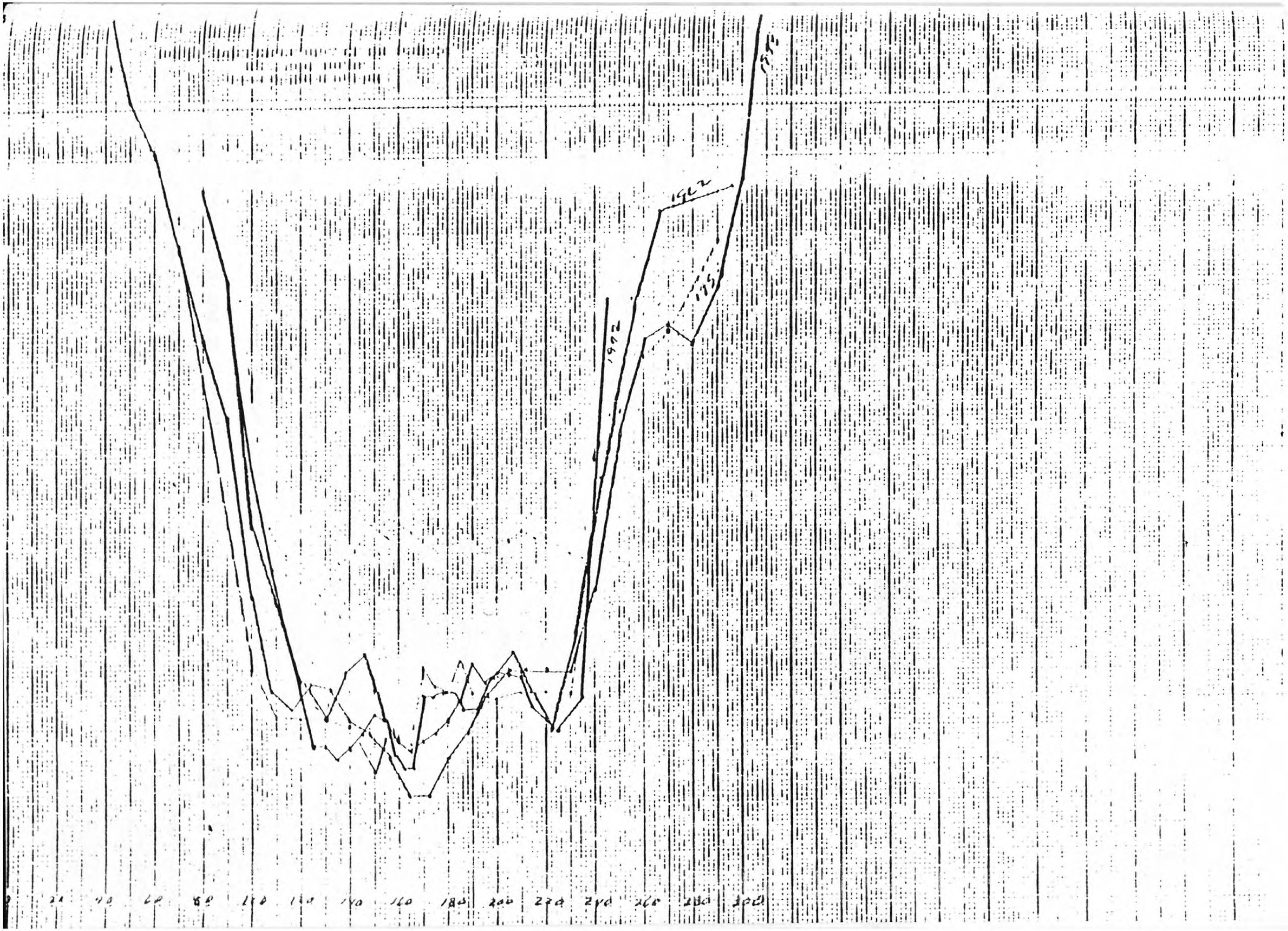
made from a cableway located about 0.5 mi downstream from the station and indicate no significant reduction in channel area at this site.

The low-water control has evidently degraded slightly during the period of record. At a discharge of 50 ft^3/s, this degradation has resulted in a drop in gage height of about 0.2 foot during the period.



1972
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300

SUMMARY

Historical streamflow data from three gaging stations in the Tug Fork basin of Kentucky, Virginia, and West Virginia were analyzed to determine if changes or trends in flooding characteristics have occurred. Streamflow data from the following stations were utilized:

03213000 Tug Fork at Litwar, West Virginia

03213500 Panther Creek near Panther, West Virginia

03214000 Tug Fork near Kermit, West Virginia

Initial anlayses consisted of applying the Mann-Kendall test for trends to the annual-flood data and comparing box plots of these data. These analyses indicate that there has been an upward trend in the flood-frequency distributions at all three sites. It should be noted that Panther Creek basin contains almost no surface disturbance due to mining.

Analyses were then made to determine if trends existed in the number of times each year that floods exceeded certain base flows at the three sites. Analyses were made graphically utilizing box plots of exceedance frequencies and mathematically by computing log-likelihood ratios. These analyses provided no strong evidence of a trend in any of these partial-duration series. There were, however, weak indications of a possible upwards trend in frequency of larger floods at Litwar and Kermit.

The third series of analyses utilized multiple regression to investigate possible causes of changes--meteorological changes or changes in the hydrologic response. Floods at Kermit and Litwar were statistically related to rainfall and a factor times the flood at Panther. This factor was then investigated to determine if it changed with time. There was some statistical indication that it did, but the evidence was not overwhelming using available data.

An analysis was also made of existing data to determine if the flow-carrying capacity of the stream channel had significantly changed with time at the three sites. Some changes that had taken place were attributable to specific high-flow events and no general trend could be identified. Detailed land-use and land-cover data were not available for these analyses. As part of the continuing investigation of flooding in the Tug Fork basin, detailed mapping and quantification of land-use representing 1950, 1960, 1975, and 1980 is being completed. When a detailed quantitative history of land use in the basin becomes available, it will be possible to determine the extent to which the indicated trends may be related changes in land use in the Tug Fork basin.

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APPENDIX

A-1.--Data set for the Tug Fork at Litwar, W. Va. The years are water years. Q is the annual flood peak at the Litwar gage, R is the associated maximum 2-day rainfall at Gary, W. Va., P is the associated flood peak at the Panther Creek near Panther, W. Va. gage. KCFS is thousands of cubic feet per second.

year	Q in KCFS	R in inches	P in KCFS	date
1941	7.31	0.90	--	03/11
1942	5.49	2.08	--	06/20
1943	14.00	1.86	--	03/13
1944	15.80	1.90	--	02/18
1945	19.40	1.96	--	02/17
1946	19.80	2.76	--	01/07
1947	7.93	1.68	0.576	01/16
1948	12.90	1.08	1.700	02/13
1949	8.93	2.38	0.927	12/04
1950	20.50	2.08	1.350	02/02
1951	6.72	1.10	--	12/08
1952	12.70	2.42	1.260	04/28
1953	16.50	2.17	1.260	05/19
1954	14.20	4.36	--	07/21
1955	23.00	2.22	4.200	03/06
1956	13.50	2.32	1.670	04/16
1957	35.70	--	3.600	01/29
1958	16.10	2.35	1.280	08/25
1959	8.70	1.10	1.180	04/12
1960	4.66	1.22	0.798	11/28
1961	8.90	0.74	1.460	02/25
1962	10.20	1.39	1.120	02/28
1963	28.30	2.66	4.570	03/12
1964	7.58	1.47	0.836	03/09
1965	16.30	2.78	1.510	03/26
1966	8.96	2.20	1.050	05/02
1967	20.70	2.04	4.600	03/07
1968	13.30	1.56	1.060	05/27
1969	2.23	0.78	0.308	01/21
1970	11.50	1.49	1.820	02/16
1971	13.50	2.75	1.480	05/07
1972	17.30	2.22	1.340	01/21
1973	18.70	2.64	2.510	03/17
1974	18.60	1.81	1.790	01/11
1975	18.20	2.11	1.450	03/14
1976	5.43	1.48	0.452	01/01
1977	54.50	4.66	5.140	04/04
1978	25.80	1.36	3.210	01/26
1979	13.80	--	1.160	01/21

A-2.--The augmented data set for the Tug Fork at Litwar, W. Va. The years are water years. Q is the annual flood peak at the Litwar gage, R is the associated maximum 2-day rainfall at Gary, W. Va. If the Gary value is missing, the Hurley, Va. rainfall is used. P is the associated flood peak at the Panther Creek near Panther, W. Va. gage. If it is missing, it is estimated from the regression relationship of 2-day maximum precipitation at Hurley, W. Va. and Panther Creek peak discharge. KCFS is thousands of cubic feet per second.

year	Q in KCFS	R in inches	P in KCFS	date
1941	7.31	0.90	0.770	03/11
1942	5.49	2.08	3.497	06/20
1943	14.00	1.86	0.704	03/13
1944	15.80	1.90	1.281	02/18
1945	19.40	1.96	1.307	02/17
1946	19.80	2.76	--	01/07
1947	7.93	1.68	0.576	01/16
1948	12.90	1.08	1.700	02/13
1949	8.93	2.38	0.927	12/04
1950	20.50	2.08	1.350	02/02
1951	6.72	1.10	0.206	12/08
1952	12.70	2.42	1.260	04/28
1953	16.50	2.17	1.260	05/19
1954	14.20	4.36	2.278	07/21
1955	23.00	2.22	4.200	03/06
1956	13.50	2.32	1.670	04/16
1957	35.70	3.25	3.600	01/29
1958	16.10	2.35	1.280	08/25
1959	8.70	1.10	1.180	04/12
1960	4.66	1.22	0.798	11/28
1961	8.90	0.74	1.460	02/25
1962	10.20	1.39	1.120	02/28
1963	23.30	2.66	4.570	03/12
1964	7.58	1.47	0.836	03/09
1965	16.30	2.78	1.510	03/26
1966	3.96	2.20	1.050	05/02
1967	20.70	2.04	4.600	03/07
1968	13.80	1.56	1.060	05/27
1969	2.23	0.78	0.308	01/21
1970	11.50	1.49	1.320	02/16
1971	13.50	2.75	1.480	05/07
1972	17.30	2.22	1.340	01/21
1973	18.70	2.64	2.510	03/17
1974	18.60	1.81	1.790	01/11
1975	18.20	2.11	1.450	03/14
1976	5.43	1.48	0.452	01/01
1977	54.50	4.66	5.140	04/04
1978	25.80	1.36	3.210	01/26
1979	13.80	--	1.160	01/21

A-3.--Data set for the Tug Fork near Kermit, W. Va. The years are water years. Q is the annual flood peak at the Kermit gage, R is the associated maximum 2-day rainfall at Davella, Ky., P is the associated flood peak at the Panther Creek near Panther W. Va. gage. KCFS is thousands of cubic feet per second.

year	Q in KCFS	R in inches	P in KCFS	date
1940	7.37	1.58	--	04/20
1941	8.72	0.49	--	03/12
1942	12.80	2.26	--	08/05
1943	27.00	2.07	--	12/30
1944	17.30	2.16	--	04/12
1945	24.00	1.71	--	03/06
1946	31.40	2.55	--	01/08
1947	12.20	1.21	0.576	01/21
1948	31.10	1.80	1.700	02/14
1949	14.50	1.28	0.948	03/19
1950	31.80	2.75	1.350	02/02
1951	27.20	3.72	0.906	02/01
1952	26.50	3.25	1.170	03/23
1953	19.50	1.53	1.260	05/20
1954	14.40	1.10	--	07/22
1955	44.60	2.37	3.570	02/28
1956	30.00	2.74	1.670	04/15
1957	61.30	2.39	3.600	01/30
1958	46.80	1.91	1.350	05/07
1959	14.60	1.26	1.180	04/13
1960	8.90	--	0.798	11/29
1961	17.00	1.01	1.460	02/26
1962	39.50	4.57	1.120	02/27
1963	69.60	2.57	4.570	03/13
1964	13.70	1.80	0.836	03/09
1965	28.20	--	1.510	03/27
1966	19.00	1.69	1.050	05/02
1967	59.00	3.35	4.600	03/07
1968	19.60	1.37	1.060	05/28
1969	6.76	1.03	0.308	01/21
1970	32.20	3.72	1.390	12/31
1971	27.00	--	1.480	05/08
1972	46.80	--	1.510	02/26
1973	34.60	1.35	2.510	03/17
1974	53.00	2.86	1.790	01/11
1975	31.20	2.60	1.450	03/15
1976	11.20	--	0.452	01/01
1977	104.00	2.57	5.140	04/06
1978	44.30	--	3.210	01/27
1979	39.10	--	1.180	12/09

A-4.--The augmented data set for the Tug Fork near Kermit, W. Va. The years are water years. Q is the annual flood peak at the Kermit gage, R is the associated maximum 2-day rainfall at Davella, Ky. If the Davella value is missing, the Pikeville, Ky. rainfall is used. P is the associated flood peak at the Panther Creek near Panther W. Va. gage. If it is missing, it is estimated from the regression relationship of 2-day maximum precipitation at Hurley, W. Va. and Panther Creek peak discharge. KCFS is thousands of cubic feet per second.

year	Q in KCFS	R in inches	P in KCFS	date
1940	7.37	1.58	--	04/20
1941	8.72	0.49	0.770	03/12
1942	12.80	2.26	0.901	08/05
1943	27.00	2.07	--	12/30
1944	17.30	2.16	1.425	04/12
1945	24.00	1.71	1.635	03/06
1946	31.40	2.55	--	01/08
1947	12.20	1.21	0.576	01/21
1948	31.10	1.80	1.700	02/14
1949	14.50	1.28	0.948	03/19
1950	31.80	2.75	1.350	02/02
1951	27.20	3.72	0.906	02/01
1952	26.50	3.25	1.170	03/23
1953	19.50	1.53	1.260	05/20
1954	14.40	1.10	2.278	07/22
1955	44.60	2.37	3.570	02/28
1956	30.00	2.74	1.670	04/15
1957	61.30	2.39	3.600	01/30
1958	46.80	1.91	1.350	05/07
1959	14.60	1.26	1.180	04/13
1960	8.90	1.60	0.798	11/29
1961	17.00	1.01	1.460	02/26
1962	39.50	4.57	1.120	02/27
1963	69.60	2.57	4.570	03/13
1964	13.70	1.80	0.336	03/09
1965	28.20	1.36	1.510	03/27
1966	19.00	1.69	1.050	05/02
1967	59.00	3.35	4.600	03/07
1968	19.60	1.37	1.060	05/28
1969	6.76	1.03	0.308	01/21
1970	32.20	3.72	1.390	12/31
1971	27.00	3.76	1.480	05/08
1972	46.80	1.92	1.510	02/26
1973	34.60	1.35	2.510	03/17
1974	53.00	2.86	1.790	01/11
1975	31.20	2.60	1.450	03/15
1976	11.20	0.64	0.452	01/01
1977	104.00	2.57	5.140	04/06
1978	44.30	0.93	3.210	01/27
1979	39.10	2.10	1.180	12/09

A-5.--Data set for Panther Creek near Panther, W. Va. The years are water years. P is the annual flood discharge at the Panther Creek gage, R is the associated maximum 2-day rainfall at the Hurley, Va. rain gage. KCFS is thousands of cubic feet per second.

year	P in KCFS	R in inches	date
1947	0.576	--	01/20
1948	1.700	1.91	02/13
1949	0.948	1.40	03/18
1950	1.350	2.32	03/02
1951	0.906	1.17	02/01
1952	1.260	1.85	04/28
1953	1.260	1.73	05/19
1954	0.492	1.43	01/22
1955	4.200	2.60	03/06
1956	1.670	2.65	04/15
1957	3.600	3.25	01/29
1958	1.350	--	05/07
1959	1.660	1.73	01/22
1960	0.798	--	11/28
1961	1.810	1.61	05/12
1962	1.120	1.55	02/28
1963	4.570	--	03/12
1964	0.836	--	03/08
1965	1.890	2.42	01/10
1966	1.920	2.45	09/27
1967	4.600	3.62	03/07
1968	1.060	2.30	05/27
1969	0.308	1.30	01/20
1970	1.820	--	02/15
1971	1.480	1.65	05/06
1972	1.510	2.52	02/24
1973	2.510	2.79	03/16
1974	1.790	--	01/11
1975	2.130	1.40	04/25
1976	0.452	--	12/31
1977	5.140	4.60	04/04
1978	3.210	2.30	01/26
1979	2.630	--	06/22