MINE DRAINAGE

Susquehanna River Basin

MINE DRAINAGE IN THE SUSQUEHANNA RIVER BASIN

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FOREWORD

This mine drainage study was undertaken by the Federal Water Pollution Control Administration (FWPCA) in 1962 in cooperation with State and other Federal agencies and was completed in 1968. The work was done by the staff of the Susquehanna Field Station, an arm of the comprehensive program of the Middle Atlantic Region. It was carried out in conjunction with comprehensive survey of water quality and pollution problems throughout the Susquehanna Basin, initiated by the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.).

The reason for creating a separate report concerning mine drainage alone is because mine drainage is the major pollution problem of the Susquehanna River Basin both in terms of water quality degradation and in terms of costs of cleaning it up. Abatement measures, according to the priority system, will cost approximately 226 million dollars for initial measures including both preventive measures, such as stream diversion, and chemical treatment of the acid flows unaffected by preventive measures. It is estimated that the annual maintenance costs of all measures to control mine drainage pollution will amount to 35 million dollars. These figures are enormous in comparison with the tangible damages resulting from mine drainage. It is estimated that there are at least four million dollars in damages to water uses every year. The intangible damages, such as losses of recreation potential, are difficult if not impossible to assess.

During the study, mine drainage sources were located throughout the Susquehanna Basin generally. Each discharge was sampled for volume and quality. In addition, the biological and chemical quality of the receiving streams were also determined.

Cooperating agencies:

1. Bureau of Mines
2. Geological Survey
3. Soil Conservation Service
4. Fish and Wildlife Service
5. Bureau of Outdoor Recreation
6. Corps of Engineers
7. Forest Service
8. Pennsylvania Department of Health
9. Department of Forests and Waters of Pennsylvania
10. Pennsylvania Department of Mines and Mineral Industries
11. Pennsylvania Fish Commission

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INTRODUCTION

The water pollution problems associated with mine drainage pollution are not new. They are associated not only with coal operations but arise as a difficult problem in mining for other minerals as well. Moreover, mine drainage constituents are occasionally found in ground water flowing from mineral deposits to the surface through natural faults and fissures and undoubtedly have always displayed mine drainage characteristics. Long before the first commercial coal mine was opened, the Indians of Pennsylvania were aware of the "black stone" that burned, and they used the many-hued mud deposits of streams carrying mine drainage as a source of pigment.

Although mine drainage occurs naturally, the growth of the commercial mining industry has greatly accelerated the production of mine drainage discharges that are deleterious to receiving streams. Since the first coal mine was opened more than 150 years ago, the harmful effects of mine drainage have become increasingly significant. What was a localized problem in the early days of the industry is now widespread. Today, after the production of over one billion tons of bituminous coal and five billion tons of anthracite, more than 1200 miles of streams in the Susquehanna River Basin are rendered acid by mine drainage and many more miles are unfit for some uses.

Increasingly stringent regulatory control has been placed on the mining industry by the state water pollution control agencies and, due to this, pollution caused by active mines is expected to diminish. Most of the mine drainage entering the streams of the study area, however, originates in abandoned mines. Responsibility for abating pollution from this source has fallen to state, local, and federal agencies. A rational and efficient approach to the solution of the problem as a basin-wide effort involves identifying pollution sources, assessing their effect on stream quality, and developing a comprehensive abatement program based upon costs and benefits. This report is intended as a first step toward developing such a plan.

The coal fields to be discussed are shown in Appendix A, Figures 1-A through 1-D.

Areas containing coal and allied deposits in the basin are listed here.

Anthracite - Northern Field, Western Middle Field, Eastern Middle Field and Southern Field	484 sq mi
Semi-anthracite - Mehoopany, Towanda, Pine, and Loyalsock Creek Basins	55 sq mi
Bituminous - Broad Top-Juniata Basin	81 sq mi
West Branch Susquehanna River Basin	3606 sq mi
Tioga River Basin	59 sq mi

Purpose and Scope

This report provides background to be used in developing a program for eliminating or reducing mine drainage pollution in the Susquehanna River Basin. The principal objective is to identify and characterize the watersheds in the sub-basins responsible for mine drainage pollution and to suggest measures to abate or alleviate the effects. To do this, the quality and flow volume of each located discharge were characterized, as well as the relationship of each to the quality of the main stem of the receiving stream. Estimates of pollution abatement costs and damages associated with mine drainage pollution were also developed.

Significant pollution is caused by silt from coal mining and processing operations in the basin. However, silt pollution is not peculiar to mining, and its solutions are not necessarily related to the mine drainage problem; therefore, it will not be thoroughly discussed in this report.

Although most of the pollution problems are still very much as described here, it should be kept in mind that some of the situations may have gone through changes since the study was completed.

SUMMARY AND CONCLUSIONS

Summary

From 1962 through 1968, the Chesapeake Bay-Susquehanna River Basins Project (CB-SRBP) conducted a comprehensive water pollution control study in the Susquehanna River Basin. Studies designed to find sources of mine drainage and to assess the stream quality effects and the estimated costs of pollution abatement were carried out as a part of the study. At the same time, the FWPCA chaired the Mine Drainage Work Group, a part of the Corps of Engineers' Interagency Water Resources Study on the Susquehanna River Basin.

Data have been compiled on the extent and causes of mine drainage pollution in the Susquehanna Valley. For this report, the basin has been divided into subareas: the West Branch of the Susquehanna River, the Juniata River Basin, the Tioga River Basin, and the portion of the Susquehanna itself that lies in the anthracite coal region. Sub-basins within these areas are described on a hydrologic basis, beginning in the headwaters.

An estimated 5,000 mining operations have been active in the bituminous coal fields in the period from 1800 to the present. About one billion tons of coal have been produced. About 1,000 major mining operations in the anthracite region have produced five billion tons of coal.

Of the 1,150 major mine drainage discharges located in the entire basin, 970 (about 85 percent) were found to originate at inactive mines. These mines release 820,000 lb/day, or 75 percent of the total acid loading. About 714,000 lb/day come from deep mines. Discharges from inactive deep mines in the anthracite area are responsible for about 387,000 lb/day total acidity coming from that region.

Mine drainage causes gross water quality degradation in 715 miles of major streams in the basin; the water area affected is estimated at 20,000 acres. Another 500 miles of tributaries are perennially degraded by drainage. There is also less severe and intermittent damage on many more miles of streams.

Conclusions

Abandoned mines are a more significant source of acid than active mines in both the anthracite and bituminous coal fields. Strip mines in the anthracite field are not a significant, direct source of pollution, but in the bituminous region they are. Discharges from deep mines in both areas constitute by far the greater source. Strip mines can augment the discharge volume from deep mines by serving as a reservoir for seepage through the ground into the deep mines.

In small watersheds, discharges from coal refuse piles may be extremely significant, but information is not available to make a general statement on their effect upon an entire basin.

State agencies as well as the mining industry have done a great deal of work to seek and apply methods for abating and preventing mine drainage pollution. Funds are not available at the state level to complete abatement from inactive mines on a comprehensive basis. A bond issue recently passed in Pennsylvania will make approximately 150 million dollars available for abatement and control activities over a ten-year period.

The restoration of surface drainage patterns disturbed by mining, as well as other activities to prevent mine drainage, will improve stream quality. It is doubtful, however, that such work alone will completely abate mine drainage pollution. A private consultant (13) studied five areas representative of portions subject to mine drainage. Preventive measures considered to be economically feasible effected an acid reduction of 20 to 70 percent. The reduction methods were applied to the extent considered to be economically feasible. Mine drainage treatment facilities and/or flow regulation for water quality control will be needed in most if not all areas. Additional studies for each basin are needed to evaluate the most economically feasible approach.

It is possible to develop meaningful priority rankings for mine drainage pollution abatement based upon available estimates of costs and benefits associated with pollution abatement. Rankings vary greatly depending upon the method of estimating benefits, availability of funds for construction and operation, and other constraints. Comparison of several alternate ranking methods indicate, however, that particular sub-basins fall near the top of the list and others fall near the bottom under all ranking methods. The first steps in pollution abatement should be taken on the ten watersheds listed below. In all the ranking systems used, these ten consistently fell near the top; however, the order of undertaking pollution abatement projects should be determined after considering constraints operating when the project is to be undertaken.

Based on 1967 dollars, it is estimated that acid mine drainage costs four million dollars annually in damages to water uses. Basic data are not adequate to quantitatively describe pollution abatement benefits in monetary terms for all water uses and all streams influenced by mine drainage.

Restoration of streams polluted with mine drainage will cost 226 million dollars initially and 35 million dollars annually. The costs are based on a pollution abatement program that employs preventive measures to the greatest extent considered economically feasible and then providing lime neutralization to meet water quality objectives.

Benefits will be counted in terms of money saved to all users of mine drainage waters. Waters from this source corrode water pipelines and disrupt all kinds of municipal and industrial uses, as well as interfering with waste treatment processes. Many benefits are attributable to savings in treatment costs necessary to ameliorate the low pH and other adverse chemical constituents of mine drainage water, in restoring the quality of the water desirable uses. Other benefits will be realized in waste treatment system economies as well. These operations presently suffer from the inhibition of biological treatment due to the adversely low pH.

The benefits to recreation are not presently definable. It is suspected that many small streams that are presently devoid of a desirable ecology will once again be able to support a thriving sport fishery environment. Water contact recreation also suffers. The low pH is far below the desirable 6.5 recommended for swimming. Furthermore, boating is not possible on waters of low pH because of corrosion possibilities. Altogether, the intangible benefits to be realized from mine drainage abatement will far exceed the tangible ones.

Sub-basin	First Cost (millions)	Annual Cost (millions)
Sinnemahoning Creek	5.5	0.8
Lackawanna River	14.0	2.3
Wyoming Valley	12.0	2.1
Upper West Branch	18.3	2.0
Chest Creek	2.8	0.4
Tioga River	6.8	0.7
Clearfield Creek	10.0	1.6
Swatara Creek	4.7	0.7
Mahantango Creek	2.3	0.3
Beech Creek	4.0	0.5
Total	80.4	11.4

FORMATION AND SOURCES OF MINE DRAINAGE

Formation

Over the past 20 years, researchers have studied the formation and chemistry of acid drainage; however, areas of disagreement and uncertainty still exist. A detailed treatment of the subject is beyond the scope of this report. The material presented here is intended to describe briefly the mechanics of acid formation as it relates to the mine drainage pollution problem and its solutions.

During coal mining, iron sulfide minerals are oxidized through exposure to air and water. Water flowing through the mine leaches away the oxidation products and aids in the formation of acid mine waters. One of the more common systems yielding ferrous hydroxide and acid is represented by the following reactions:

$$2FeS_2 + 7O_2 + 2HOH \rightleftarrows 2FeSO_4 + 2H_2SO_4;$$

$$FeSO_4 + 2HOH \rightleftarrows Fe(OH)_2 + SO_4^{=} + 2H^+;$$

$$Fe(OH)_2 + HOH \rightleftarrows Fe(OH)_3 + H^+$$

The concentration of soluble metallic salts in mine drainage is a function of the amount of minerals, air, and water present. Other factors are the length of contact time among precursors, temperature, and catalytic agents present. Also, the crystallography, particle size, and purity of the iron sulfide minerals have been found to play a very important role in reactivity.

Geology also plays an important part in acid mine formation. Formations vary significantly from place to place even within a given coal seam; and this variation is due, in part, to differences in the occurrence and form of iron sulfide minerals associated with the coal. These minerals occur in varying amounts both in the seam and in the strata above and below the coal. They occur in distinctly different forms which are commonly described as sulfur balls, lenses, veins, and finely divided particles or crystals.

When the coal is mined, some of the iron sulfide minerals are separated from the coal and deposited inside the mine or on the ground surface in refuse piles. Thus, the sulfides are exposed to oxidation and natural leaching by ground or surface water.

Iron sulfide minerals found in the strata above and below the coal are exposed during the course of mining and, when the location is depleted of coal, the acid forming minerals remain in the roof and sides. Additional oxidation surfaces may continue to be exposed through upheaving, spalling, and roof falls after the mine has been abandoned.

In addition to vertical variations in occurrence through geologic formations containing coal, the amount of iron sulfide minerals present also varies horizontally within a formation. Investigations at the Pennsylvania State University (8, 9) determined a definite correlation between the amount of iron sulfide minerals present and the paleoenvironment. It was shown that coals associated with marine (saline water) deposits had greater iron sulfide content than coals associated with continental (fresh water) deposits. Since the amount of acid mine drainage produced depends in part upon the amount of iron sulfide minerals present, it was concluded that mines in the bituminous coal field extracting coals from strata of a marine paleoenvironment should present a more serious mine drainage pollution threat than those extracting coal from strata of a continental paleoenvironment. Summaries of records maintained by the Pennsylvania Department of Health (10) support this conclusion. One of the most clear-cut examples of this phenomenon is the tendency of mines in the portion of the Lower Freeport coal seam, which underlies the headwaters of the West Branch Susquehanna River, to produce alkaline drainage. The tendency for mines in this seam to produce acid discharges increases to the southwest and northwest. Some seams, notably Clarion and Brookville, are considered much more likely to have significant acid discharges than other seams in the basin.

It is suspected that bacteria act as catalysts in the formation of acid mine drainage. Three specific organisms that have been associated with mine drainage are: *Thiobacillus thiooxidans*, *Ferrobacillus ferroxidans* (sulfur-oxidizing bacteria), and *Thiobacillus ferrooxidans* (ferrous-oxidizing bacteria). The extent to which they play a significant role is not known; however, research is being continued in this area.

Sources

Coal mining operations are carried out in a variety of ways, depending upon the location and configuration of the coal deposit. Development and operation of the mine has a profound effect on the quality and quantity of mine drainage produced.

Mine development. Mines are developed either as "deep mines" or "surface mines." Deep mines are further classified as "shaft," "slope," or "drift" mines. A shaft mine is driven downward vertically into a coal seam which may not outcrop at the point of development. Coal mined by this method often lies beneath the ground-water table. Coal is removed from a slope mine through an entry which slopes downward to intercept the coal seam. A drift mine has its opening driven into the outcropping of a coal seam that is essentially flat-lying.

While shaft and slope mines are active, water that seeps in must be pumped out. Drainage from a drift mine, on the other hand, is accomplished by gravity through open channels. Occasional pools, caused by dips in the strata, may, however, be dewatered by siphoning or pumping. Drift mines are a major source of mine drainage in the basin because, when abandoned, they do not fill with water and tend to continue discharging mine drainage with a quality equal to or worse than that discharged while the mine was active.

When shaft and slope mines are abandoned, infiltrating ground water fills the mines to the natural level of the ground-water table in the area or to a level in the mine at which the water can find its way to the surface by gravity. In some cases, this "natural" inundation of iron sulfide minerals has been beneficial to the quality of drainage from mines.

Surface mines may be drained either by gravity or pumping, depending upon the elevation of surface drainage in the area. In addition to removing ground water which enters surface mines, steps must be taken to divert surface drainage so that it does not enter the mine workings. Surface mines may be sub-divided into "strip" and "auger" mines.

A strip mine is an open pit where the coal is mined after the overlying strata have been removed. Auger mining is usually associated with some form of strip mining. The coal is extracted by boring horizontally into the exposed coal seam. This method is also used to extract coal near the outcrop left behind by previous deep mine operations or where underground mining is not feasible.

Over the years, most of the basin's coal production has been from deep mines. Since 1945, however, use of strip mining techniques has steadily increased until today it accounts for approximately 60 percent of the total annual production.

Mine drainage production. The quality and quantity of mine drainage depends upon a number of factors:

1) Hydrologic and geologic features of the surrounding terrain.
2) Availability of acid precursors (air, water, and iron sulfide minerals).
3) Length of contact time of the required precursors.
4) The type of mining methods used.
5) The operating status of the mine, i.e., active or inactive.

The production of mine drainage from a mining operation may be either continuous or intermittent. Underground mines developed below the ground-water table usually "make" mine drainage on a continuous basis. The concentration of the pollutants varies as a function of the volume of water entering the mine, contact time, and available minerals; underground mines are generally continuous producers. The quality and quantity of the discharge may vary greatly in cases where the water table is below the mine level for only a portion of the time. Quality and quantity will also vary when the mine receives direct surface water contribution. Discharges from surface mines are often intermittent, generally occurring during and immediately after periods of precipitation. In areas disturbed by surface mining, runoff may be trapped by inadequately restored trenches or pits formed during the stripping operation. These pools contain high concentrations of mine drainage indicators and are reservoirs of potential mine drainage pollution. During periods of high runoff, they may overflow and release concentrated "slugs" of mine drainage pollution to receiving streams. Many drain slowly into the bottom and sides of the pool to emerge as mine drainage seepages down the slope from the stripping operation. They may also drain into deep mines underlying the stripped area, thus increasing the mine drainage flow.

Mine drainage may continue to flow from mines long after they have been "worked out" and abandoned. As long as air, water, and iron sulfide minerals are present, the mine will produce acid mine drainage.

Pollution with mine drainage characteristics may also originate at refuse piles associated with mining operations. The refuse piles are made up of impurities removed from the mined coal. Mine refuse piles are subject to the same mechanisms of acid water formation as mines. The pollution coming from these piles is usually intermittent, occurring only during and immediately after periods of precipitation. Several cases exist in the basin, however, where the piles interrupt surface drainage. The water passing through the refuse thus constitutes a vehicle for transport of soluble salts, thereby forming a continuous mine drainage discharge. Although discharges from refuse piles may be extremely significant, particularly in small watersheds, no information is available to permit a general statement on the effect of spoil piles on water quality over an entire basin.

Both surface and deep mining operations contribute to the heavy silt load carried by many of the streams in the basin. During surface mining operations, large tracts of land are completely denuded, exposing the soil to erosion by surface runoff and wind. Coal silt from processing operations and runoff from piles of refuse are a significant source of suspended solids in many streams, particularly in the anthracite area. Silt pollution, although associated with mining, is not peculiar to mining and is not directly related to the mine drainage pollution problem or its solutions. It will not be thoroughly discussed in this report.

From 1964 through 1968, studies were conducted by the FWPCA to locate major mine drainage discharges. The number of discharges located was considerably smaller than the total number of mining operations reported within the basin area. Some of the reasons for this difference are:

1. Studies were conducted during summer low-flow periods when mine drainage flow is expected to be at a minimum. Thus, mines that discharge only during wet weather periods were not located.
2. In many cases, interconnection of mine workings, both intentionally and unintentionally, has consolidated drainage from many mines into one discharge. In the anthracite area particularly, many shaft and slope mines are kept dewatered by a system of drainage tunnels driven expressly for this purpose.
3. Problems in identifying mine drainage discharges arose from mine sealing which results from (a) intentional efforts by man; (b) from the natural deterioration of

mine supports; and (c) from the disruption of drainage patterns by surface mining. These sealings handicapped the inventory process because the quality of discharge water was often improved; another problem arose as a result of mine flooding which often eliminates discrete discharges. All these occurrences make it more difficult to locate and characterize specific discharges.

4. Some abandoned mines do not produce discharge water with the characteristics of mine drainage. There are two reasons for this: first, when a mine is filled with water, the flooding interrupts interaction among the acid precursors; and, secondly, some mines simply have naturally alkaline discharges.

The number of major mine drainage sources located through 1968, as well as the acid contribution of each, are summarized by source category in the following table. Data in the table were developed from records of discharge location-characterization studies conducted during summer low-flow periods. In some cases, the high flow contribution could be many times that recorded. Neither table includes data for discharges to a number of small tributaries to the West Branch which have not as yet been surveyed.

Although the data in the tables do not represent a complete inventory of all basin mine drainage discharges under average flow conditions, they can be used as the basis for several general conclusions.

1. Discharges in the anthracite field are much less numerous, but contribute a much larger acid loading than those in the bituminous field.
2. In both fields, abandoned mines are a more significant source of acid than active mines.
3. In the anthracite field, strip mines are not a significant, primary source of acid mine drainage.
4. In the bituminous field, strip mines are a significant source of acid, but are not collectively as significant as deep mines.

These conclusions are made in the basin-wide context to provide the reader with a better appreciation for the relative influence on various types of mines. They do not necessarily hold true in specific sub-basins. A detailed discussion of sources of mine drainage and their effects on stream quality may be found in the section concerning the individual sub-basins.

SUSQUEHANNA RIVER BASIN

MAJOR MINE DRAINAGE SOURCES

SUB-BASIN	Active Operations				Inactive Operations				Unclassified		Total	
	Deep Mines		Strip Mines		Deep Mines		Strip Mines		Deep & Strip			
	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day
WEST BR. SUSQUEHANNA R.												
West Branch (upstream from Chest Cr.)	5	5000	2	100	97	22500	31	1900	7[1]	24000	142	53500
Chest Creek	4	100	5	500	48	7100	23	1100	4	100	84	8900
Anderson Creek			3	500	13	2700	14	4200			30	7400
Clearfield Creek	1	100	2	200	50	19200	20	15000	22	2400	95	36900
Moshannon Creek					89	80600	49	50600	20	4800	158	136000
Sinnemahoning Creek	3	3600			82	27100	12	2200	3	100	100	33000
Beech Creek	1	0	5	1200	35	8000	51	12000	21	800	113	22000
Pine Creek					22	11500	4	3100			26	14600
West Branch Minor Tributaries Chest Cr. to Sinnemahoning Cr.	5	4000			54	29300	57	12200	26[2]	80300[3]	142	125800
Sinnemahoning Cr. to mouth					70	58600	6	2300	1	0	77	60900
Sub-Total	19	12800	17	2500	560	266600	267	104600	104	112500	967	499000

SUSQUEHANNA RIVER BASIN

MAJOR MINE DRAINAGE SOURCES (Continued)

SUB-BASIN	Active Operations				Inactive Operations				Unclassified		Total	
	Deep Mines		Strip Mines		Deep Mines		Strip Mines		Deep & Strip			
	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day	No. of Disch.	Acid Load #/day
ANTHRACITE AREA												
Lackawanna River					13	83000					13	83000
Wyoming Valley	2	86000			3[4]	142000[4]					5	228000
Nescopeck Creek					4	64800					4	64800
Catawissa Creek					6	27800					6	27800
Shamokin Creek	2	6600			6	27400	1	200			9	34200
Mahanoy Creek	5	28900			13	28900					18	57800
Mahantango Creek	22	2900			10	2200					32	5100
Wiconisco Creek					5	3600					5	3600
Swatara Creek	5	2800			13	7700	2	700	1	100	21	11300
Sub-Total	36	127200			73	387400	3	900	1	100	113	515600
JUNIATA RIVER					44	37900					44	37900
TIOGA RIVER					15	21700	7	2400			22	24100
TOTAL	55	140000	17	2500	692	713600	277	107900	105	112600	1146	1076600

1 Spoil Piles
2 Incomplete - Discharge location work still in progress
3 Estimated contribution from discharges still to be located and characterized
4 Estimated future equilibrium conditions

EFFECT ON WATER USES

When mine drainage enters natural waters, the value of the water for many beneficial uses is reduced. Although the pollutional effects of mine drainage are generally associated with surface waters, there is evidence that the quality of ground water is degraded by mine drainage in some portions of the basin. Data are not available to quantitatively evaluate the effects of mine drainage pollution on ground water. The following discussion is, therefore, limited to mine drainage effects on surface streams.

Significant water quality degradation attributable to mine drainage has been measured in approximately 715 miles of major streams and in 500 miles of small tributaries in the basin. The surface area of the major streams affected is an estimated 20,000 acres. The following table gives the miles of streams in each sub-basin polluted by mine drainage.

The discharge of acid mine drainage to surface water changes its quality by lowering the pH, reducing the alkalinity, increasing the total hardness, and adding varying amounts of iron, manganese, aluminum sulfates, as well as other elements and suspended material. Water quality parameters and uses influenced by mine drainage are discussed in the chapter describing problems in each sub-basin.

Estimates of the dollar value of damages attributable to mine drainage pollution influence on various uses of these streams are listed in Table 1. These data constitute the best estimates of federal and state agencies cooperating on the Susquehanna River Basin Comprehensive Water Resources Study. It does not, as explained in the section describing individual sub-basins, represent all real damages attributable to mine drainage pollution abatement. A detailed breakdown of estimated damages in each sub-basin is in Table 1.

One of the most significant sources of error in estimating damages is the failure to consider the effect of mine drainage on uses of more than 500 miles of tributaries to the "major" streams (Table 1). Analysis of samples collected from these streams, in the course of field survey activities, indicates significant water quality degradation. Data on these streams were not, however, adequate to permit estimation of water use damages. The estimates, however, are utilized in the following calculable damages to various water uses in the basin.

The most pollution-sensitive water use is fishing. Damage to fish and fish food organisms is usually caused by high concentrations of acid, iron, sulfate, and the deposition of a smothering blanket of precipitated iron salts in the streambed. In addition, zinc, copper, and aluminum have been measured in lethal concentrations in some discharges. The toxicities of these elements are compounded by synergism among several of them. Because of the complex nature of mine drainage, it is impossible to accurately measure the toxicity to aquatic life of any single chemical constituent.

SUSQUEHANNA RIVER BASIN
MILES OF STREAM IN WHICH WATER QUALITY
IS SIGNIFICANTLY DEGRADED BY MINE DRAINAGE

Basin	Sub-Basin	Miles of Main Stream	Miles of Tributary Streams	Total
WEST BRANCH SUSQUEHANNA	Headwaters (Upstream from Chest Creek)	31	43	74
	Chest Creek	3	7	10
	Anderson Creek	10	6	16
	Clearfield Creek	61	87	148
	Moshannon Creek	52	57	109
	Sinnemahoning Creek	51	61	112
	Beech Creek	30	25	55
	Babb Creek	16	13	29
	Loyalsock Creek	8	0	8
	West Br. & Minor Tribs. Chest Cr. to Sinnemahoning Cr.	95	70[1]	165
	West Br. & Minor Tribs. Sinnemahoning Cr. to Mouth	70	14	84
	SUB-TOTAL	427	383	810
JUNIATA RIVER	Beaverdam Branch	3	2	5
	Little Juniata	0	1	1
	Raystown Branch	0	24	24
	Aughwick Creek	0	7	7
	SUB-TOTAL	3	34	37

SUSQUEHANNA RIVER BASIN
MILES OF STREAM IN WHICH WATER QUALITY
IS SIGNIFICANTLY DEGRADED BY MINE DRAINAGE (Continued)

Basin	Sub-Basin	Miles of Main Stream	Miles of Tributary Streams	Total
TIOGA RIVER		29	12	41
ANTHRACITE AREA	Lackawanna River	31	2	33
	Nescopeck Creek	18	24	42
	Catawissa Creek	39	8	47
	Shamokin Creek	35	4	39
	Mahanoy Creek	52	5	57
	Mahantango Creek	17	13	30
	Wiconisco Creek	12	0	12
	Swatara Creek	30	7	37
	Susquehanna River & Minor Tribs.	22	10	32
	SUB-TOTAL	256	73	329
SUSQUEHANNA RIVER BASIN	TOTAL	715	502	1217

1 Incomplete - Discharge location work still in progress.

It was estimated in 1967 that a total of 600,000 fishermen days, with a value of about 942,000 dollars, would be gained annually by mine drainage pollution abatement. The greatest benefit would come from pollution abatement in the West Branch Susquehanna River, Sinnemahoning Creek, Clearfield Creek, and Moshannon Creek.

The destruction of aquatic life and the discoloration of the water and bottom by precipitates combine to make the streams and impoundments aesthetically unappealing. Effects of mine drainage make streams and impoundments unattractive for boating, water skiing, bathing, and other forms of recreation. The low pH caused by mine drainage has been associated with bathers' eye irritation (11) and discoloration of the water may present a safety hazard to swimmers by concealing underwater objects.

Loss of recreational value due to mine drainage is estimated to total 2.5 million dollars annually. The greatest damages in monetary terms occur in the West Branch Susquehanna River, Swarata Creek, Clearfield Creek, Moshannon Creek, and the Susquehanna River (Table 1).

By altering the ecology, the stream's ability to stabilize sewage and organic industrial wastes may be retarded. The organic material may thus be at least partially preserved until it is carried to a stream or reach of stream where the mine drainage influence is not significant. Data are not presently available to estimate the monetary value of this effect.

Substantial corrosion may occur to unprotected structures and navigation equipment located in streams polluted by mine drainage. The effect may be minimized by using special concrete mixes for instream structures and frequent maintenance of metal exposed to mine drainage; however, the additional cost of providing this protection cannot be accurately estimated.

Mine drainage has a definite, adverse effect on the use of streams for industrial, municipal, and agricultural water supply. The principal sources of the adverse effect are sulfuric acid, iron, manganese, aluminum, calcium, and magnesium salts.

In water treatment plants, high acidity and low pH may result in adverse effects on chemical coagulation, softening, and corrosion control. Corrosion control is the major problem of most industrial users.

Both iron and manganese create serious problems in public and in some industrial water supplies. Iron and manganese salts stain plumbing fixtures and laundry and interfere with some industrial processes. Iron also supports the growth of filamentous iron bacteria which restrict or even completely stop the flow of water in distribution lines.

Some sulfate compounds and the end products of their reaction with calcium and magnesium carbonate (the principal constituents of the alkalinity of many streams) produce permanent hardness in water. Hardness is objectionable in public supplies, particularly because consumers are forced to use more soap for cleaning purposes. Permanent hardness in boiler feed water forms scale, which cuts down the heat exchange efficiency of boilers.

The undesirable characteristics of mine water can be removed by modern and adequately designed water treatment plants. These additional treatment costs, however, can be a very important consideration to a community developing a new public water supply or to an industry seeking a new location. The estimated monetary damage to municipal and industrial water supply use in the basin is 1,106,000 dollars annually.

The use of mine drainage for crop irrigation tends to increase the acidity of the normally acid soils in the basin. It may also cause a chemical reaction in the soil, adversely affecting its physical properties.

Livestock and wildlife use is also impaired by mine drainage effects. Milk production is reported to decrease when cows are limited to drinking water bearing mine drainage indicators (11).

Mine drainage damages to agricultural water use in the basin total an estimated 65,300 dollars annually. This estimate is based solely on irrigation use and would be slightly higher if stock watering damage were considered.

Calculable Damages from Mine Drainage Pollution*
(Thousands of Dollars)

Area	Recreation	Fishing	Mun. & Indus.	Agric.	Corrosion	Total
Anthracite	414	207	693	13		1327
West Branch	1875	717	336	23		2951
Juniata	3	1	77	0		81
Tioga	210	17	0	29	40	296
TOTAL	2502	942	1106	66	40	4656

* Susquehanna River Basin Water Resource Report. Interagency Study on Susquehanna River Basin Water Resources (Type II).

ABATEMENT MEASURES

Over the many years that mine drainage pollution has been recognized as a problem, numerous methods have been advanced as possible solutions. The methods are categorized as either "preventive" or "control" measures. Prevention measures are intended to reduce the amount of pollutants at the source. Control measures are intended to eliminate or reduce the polluting effects of mine drainage after the pollutants have been formed and have entered the mine discharge or the surface stream.

Studies by Gannett Fleming Corddry and Carpenter (GFCC) (13) for the FWPCA concluded that prevention measures have a high first cost, but a low annual cost compared with treatment measures. Prevention measures are a feasible measure in all the recommended pollution abatement plans in each of the five areas investigated. The amount of prevention work recommended for each area varied as did the estimated pollution abatement benefit. The acidity reduction that is expected from these prevention procedures ranges from 20 percent to 70 percent among the five areas.

The least-cost solution to a given problem could involve any or a combination of available methods. A more thorough treatment of this subject may be found in reports of Stephan and Lorenz (12) and GFCC (13).

The most successful prevention measures are those which preclude the simultaneous contact among the three precursors. Some of these are described here.

(1) Inundation utilizes the technique of immersing iron sulfide in water, which keeps it out of contact with the air, and oxidation is prevented. To be successful the minerals must lie below the level of the pool formed. The ideal inundation situation is where the entire cross-section of the mine is covered by water.

(2) Water control and diversion can significantly reduce the amount of pollutants discharged from both deep and strip mines. Although soluble metallic salts may be formed, flowing water is needed to dissolve and carry the salts from the mine. Reduction in the volume of water entering a mine or reducing the time of contact between the water and the soluble salts may reduce the polluting effect of mine drainage reaching the receiving stream. While the mines are active, water that enters may be conveyed back to a surface water course quickly so that chances for contact among the acid-forming ingredients are minimized. In abandoned mines, where this kind of control is not possible, emphasis must be placed upon preserving surface drainage patterns and minimizing the introduction of surface water to the mines.

Regrading and planting selected areas disturbed by surface mines or deep mine subsidence promotes surface runoff, minimizes percolation of impounded water, and reduces the introduction of water to underground mines which may underlie the area. Restoration of the land to a configuration which makes it more suitable to new uses is an important secondary benefit.

Lining stream channels has been cited (13) as an important measure for control of surface water contribution to deep mines. Interconnections between surface streams and deep mine workings are provided by surface subsidence areas, boreholes, and by cracks and fissures in the strata lying between the streambed and the mine workings.

In cases where it is not possible to locate the plug individual interconnections, it is sometimes necessary to construct an impermeable channel liner of wood, concrete, asphalt, or other material to maintain the stream flow on the surface. Some work of this type has been carried out in the anthracite fields under the provisions of a joint federal-state mine water control program established in 1955 (14). Although some of these liners are in bad condition because of inadequate maintenance and disturbance by surface mining activity, they successfully convey surface water across areas offering access for water to the mine workings.

(3) In some cases, air sealing may prevent oxidation of iron sulfide minerals. The planned collapse of deep mines, called retreat mining, prevents the free movement of both air and water. Unrestored surface mines and refuse piles can be covered with an impervious layer of clay to prevent the iron sulfide minerals from coming into contact with water and air. Unrestored strip mines can be filled with coal mine refuse and the surface regraded; this serves the dual purpose of burying the refuse so that the air and water contact is minimized as well as reducing mine drainage production and erosion on the banks of the strip mine.

It is not always feasible or possible to abate mine drainage pollution with preventive measures above. In these cases, a variety of control measures may be used to eliminate or reduce the adverse effect upon stream quality. Some of these are:

(1) Many types of treament measures have been proposed to remove the pollutants from mine drainage discharges (12). Probably the most widely practiced is the addition of lime, limestone soda ash, caustic soda, or some other alkaline materials to neutralize the acid and induce precipitation of metallic salts. A major disadvantage of this process is the operating costs: it has been

reported to range as high as 1.30 dollars per 1,000 gallons. These large operating expenditures include the chemical costs and the costs of removing the sludge. The precipitate formed in the course of treatment is frequently difficult to dewater to the point where landfill disposal can be used. A second disadvantage is its failure to remove some dissolved mineral constituents and only a portion of the suspended material. Materials added during the process may themselves cause pollution. The hardness of mine drainage, for example, may be raised by lime neutralization.

Other treatment measures proposed involve removal and concentration of pollutants in the water. Some of the processes are also being investigated in conjunction with the federal government's desalination program. These include ion exchange, distillation, reverse osmosis, and electrodialysis. Major problems associated with these methods, however, are high operating costs and disposal of the separate pollutants. No full-scale treatment plants using these principles have as yet been constructed in the basin. The Pennsylvania Coal Research Board, however, has sponsored the design of experimental treatment plants which use evaporation and ion exchange techniques.

There is a need for reliable information on the cost of constructing and operating the various types of treatment facilities under a variety of conditions. Cost data have been derived mainly from bench-scale and pilot plant studies and may not be applicable to many field situations. Research and development programs in progress, as well as operating data from full-scale plants in operation should provide more reliable data on which to base evaluations of alternatives to treatment.

An important consideration in an abatement program utilizing treatment is the cost of conveying the mine drainage from the discharge point to the treatment plant. Development of a least-cost program involves balancing the scaled economies of a large plant against the cost of conveying the mine drainage from remote sources to a treatment plant. Since the range of flows encountered is likely to be great, flow equalization basins will probably be required in most collection systems to minimize the design capacity of both the collection system and treatment plant.

(2) In some situations, benefits may be realized from impounding mine drainage for release at a time when its adverse effect upon water quality will be minimal. The objective here is to utilize the assimilative capacity of the stream to the greatest possible extent. Impoundment per se has no appreciable effect upon the quality of mine drainage (15).

(3) Streamflow regulation is closely related to impoundment and the controlled release of mine drainage. The objective here is to impound good quality water for release during periods of minimum stream assimilative capacity. This increases the assimilative capacity; however, the impounded water should be high in alkalinity and low in mine drainage, so that the release will have the dual value of neutralizing acid while diluting concentrations of other mine drainage indicators.

Streamflow regulation is applicable only in situations where the stream's natural assimilative capacity is adequate to prevent pollution under most conditions. The releases act simply as loans of good quality water which are drawn from the stream's total assets. A stream perennially polluted by mine drainage cannot be reclaimed by flow regulation alone.

A technique has been developed for predicting net alkalinity. It is based on the analysis of blends of mine drainage with natural waters of varying qualities from widely separated geographic locations. By using this technique in a river basin where the acid and alkaline loading of input streams can be determined, it should be possible to predict the net residual alkalinity of the river at any point (15). This technique should be particularly useful to control water quality on streams influenced by mine drainage where it is possible to regulate the flow by using impoundments.

In a few cases, conveyance or diversion of either mine drainage or unpolluted water between adjacent watersheds can play a role in pollution abatement. Diversion of good quality water between watersheds may be feasible in some cases to increase the assimilative capacity of the receiving stream. In contrast to streamflow regulation, inter-watershed diversion could result in a perennial benefit to the quality of a stream regardless of the alkalinity of its watershed.

As in the case of streamflow regulation, it is necessary to predict the quality resulting from mixing mine drainage water with unpolluted water.

ABATEMENT COSTS AND PRIORITIES

Estimation of Mine Drainage Pollution Abatement Costs

Limitation prevented a detailed consideration of each source in estimating abatement costs for the entire basin. Some of these limitations were a lack of detailed, long-term study data on all mine drainage sources, the lack of completely reliable information on the costs of construction and operation, and the lack of costs for pollution abatement measures in general.

To overcome some of these limitations and to develop basic data for estimating costs in the entire basin, the firm of Gannett Fleming Corddry and Carpenter, Incorporated (GFCC) conducted feasibility type investigations in five small watersheds. Each watershed chosen was representative of some portion of the Susquehanna River Basin influenced by mine drainage. In each area, a number of alternate abatement plans were studied. Each plan involves various combinations of abatement measures, and all are intended to meet the same objective: compliance with the requirements presently imposed by the Pennsylvania Sanitary Water Board on active coal mines. These requirements are intended to insure that no polluting discharges enter surface streams.

Although each plan differs from every other plan, each has the following elements. (1) Prevention measures: reclamation measures such as restoration of surface drainage courses, mine sealing, etc., which are intended to reduce the flow or polluting characteristics of the mine drainage. (2) Collection and impoundment: these facilities are designed to collect the mine drainage escaping, after preventive measures are operating, and to convey it to a treatment plant. Their capacity is the difference between the design capacity of the treatment plant and the flow of mine drainage following the one day of maximum rainfall occurring once every 20 years. (3) Treatment: facilities for lime neutralization treatment were designed to treat the mine drainage remaining after recommended preventive measures were completed. Plants were designed to produce an effluent that conforms to the requirements of the Sanitary Water Board for mine drainage discharges.

From each set of alternate plans developed, one recommended plan was chosen. Major considerations in choosing the plan were long-term annual cost, first cost, and technical feasibility. Additional details may be found in "Acid Mine Drainage Abatement Measures for Selected Areas Within the Susquehanna River Basin" (13).

To use the results of the GFCC study, a number of assumptions are made. The most important is the assumption that each watershed influenced by mine drainage can be categorized and equated to one of the five model areas studied by GFCC. That is, the mine drainage abatement plan and associated costs applicable to one of the model GFCC areas can be adjusted and applied to a watershed with similar characteristics. The second assumption is that the mine drainage flow data for the GFCC model areas can be used to establish flow trend lines in the watersheds of the basin affected by mine drainage. This assumption is necessary since most of the FWPCA mine drainage discharge inventory and stream quality studies were conducted during low flow periods. Using observed low flow discharges as a base line, average and high flow values are estimated for all basin watersheds by applying the appropriate model area trend line. Quality variations for averaging high flow conditions are estimated the same way.

The first cost of preventive measures is estimated for each watershed by first expressing the cost in dollars per ton of acidity abated in each GFCC area. This figure is then multiplied by the tons of acid abated per day in the similar watershed. Estimates using this procedure are found in Table 4 at the end of the text. This assumes that if the watersheds are similar, then the type of preventive measures applied and the degree of success expected will be similar. The amount of construction work, and thus the cost, will be proportional to the amount of acidity reduced.

The costs for collection and impoundment are estimated by expressing the cost for these facilities in each GFCC area in dollars per mgd of mine drainage entering the stream under high flow conditions after all applicable preventive measures are operative. These figures are then multiplied by the corresponding flow in each similar watershed. The effect of these deficiencies is minimized by maintaining the size of each watershed at approximately the same size as the corresponding GFCC area. It is then assumed that the collection systems are of equal length. The lack of maximum flow data is overcome by assuming high flow to be proportional to maximum flows.

The cost of treatment facilities is estimated using preliminary design curves developed by GFCC relating the cost of facilities to flow, acid, and iron content of the mine drainage to be treated.

The annual cost of mine drainage pollution abatement work includes amortization of the first cost over 30 years at four percent interest, replacement of major facilities periodically as a result of normal wear, as well as operating and maintenance costs. The annual cost of amortization and maintenance of pollution abatement facilities was based on a ratio of the annual cost to the first cost for areas studied by GFCC. The estimated operating cost of treatment facilities is based on curves developed by GFCC relating operating cost to flow, acid, and iron content of the mine drainage to be treated. A summary of estimated abatement costs for each sub-basin significantly influenced by mine drainage is included in Table 4.

It should be noted that the first cost constitutes only a fraction of the sum of the total annual costs for each year of a project with a life of about 30 years. Operation, maintenance, and amortization costs greatly exceed the first cost over the minimum life of a project.

If the recommended work is undertaken under the provisions of a grant, the amortization costs will not apply.

Regardless of the method of financing, however, it may be seen that the annual cost for the entire basin constitutes a very significant sum; one that should be considered in planning any future mine drainage pollution abatement program.

Water Use Damages Resulting from Mine Drainage Pollution

Mine drainage pollution abatement is costly. Although future technological advances may substantially reduce the costs, it is probable that for the immediate future only those projects with high pollution abatement benefit potential can be undertaken. Determining the order of projects to be undertaken involves consideration of: (1) the first cost of the necessary construction work and (2) the benefits to be realized from each unit of work. No quantitative estimate of all the potential benefits associated with mine drainage abatement has ever been made for the Susquehanna River Basin.

In the absence of existing data for all benefits, procedures were developed to estimate present damages throughout the basin. Estimates were made in two ways based on: (1) the dollar value of damages, and (2) a point system weighted to reflect the stream area to benefit from mine drainage pollution abatement. Dollar estimates are the total of estimates made under four categories: recreation and aesthetics, municipal and industrial water supply, fish and wildlife, and agricultural water use. They were made by the federal agency members of the work group considered to be best qualified to make estimates for specific water use categories. The estimates were modified slightly in accordance with the consensus of opinion among members of the Mine Drainage Work Group. Factors considered in making the estimates were the natural, physical, and chemical characteristics of the streams; the geographic location; and the extent and degree of pollution (Table 1).

In making dollar estimates of damages, it was recognized that the procedure does not adequately consider all significant benefits. Some of the shortcomings of the dollar estimates are: (1) all potential water uses were not considered; (2) secondary benefits associated with water quality improvement were not considered (these are such benefits as increase in property value or stimulation of service-type enterprises); (3) value factors assigned to the various water uses may not be accurate; and (4) increases in land values resulting from completing reclamation measures intended to prevent formation of mine drainage were not considered.

A procedure involving assignment of dimensionless value points was developed to include damages assignable to all significant water uses. The basis for this procedure is the assignment of value point totals for each water use to reflect the degree of damage attributable to mine drainage in the stream or reach in question. The point totals from which a "value point" assignment was made for each water use category are listed here.

Damages Attributable to Mine Drainage Pollution

Water Uses	Point Assignment		
	Slight	Moderate	Great
1. Water-oriented recreation and aesthetics	8	16	24
2. Municipal and industrial water supply	10	20	30
3. Fish and wildlife	8	16	24
4. Agriculture	8	9	12
5. Treated waste assimilation and transport	1	2	3
6. In-stream corrosion	1	3	5

To reflect the extent to which pollution abatement affects water uses, the value points assigned were weighted by multiplying the area of stream in acres and the streamflow in cfs. "Best judgment" was used, therefore, in the weighted value point totals for the six water uses in the table. The weighted value totals for all water uses were then totaled to give a measure of the total benefit to be enjoyed in the streams or reaches influenced by mine drainage.

The totals developed by both methods, i.e., estimated dollar value and weighted points did not, in many cases, reflect the potential benefits to be realized from a comprehensive pollution abatement program. Such a program would involve abatement in more than one tributary and would result in pollution abatement in a significant reach of the main stream. This effect is particularly significant in the West Branch Susquehanna River Basin. Damages calculated in the main streams were related to tributary watersheds. Thus, it was possible to estimate the value of pollution abatement in a given watershed as a part of a comprehensive, basin-wide pollution abatement program. There are four steps to the procedure used:

(1) The influence of acid loading from each tributary was calculated for its affect on the receiving reach of the main stream (Table 2).

(2) Estimated damages for the main streams were developed following the procedure described previously for tributary streams (Table 1).

(3) Damages on the main stream were related back to the tributary streams using the ratios shown in Table 2.

(4) The proportioned main stream damages were added to the damages within individual tributary watersheds to get a measure of total benefits expected from a comprehensive program (Table 3).

Pollution Abatement Priority Ranking

Using the damages and cost estimates previously described, benefit-cost ratios have been calculated. Estimated annual dollar benefits to be realized from both individual sub-basin programs and a comprehensive program were divided by estimated annual pollution abatement costs to get an indication of the economic feasibility of pollution abatement. Under the two conditions, projects with a benefit-cost ratio of greater than 1.0 are generally considered to be economically feasible.

Another measure of pollution abatement desirability was obtained by dividing the annual cost by the weighted value points assigned as described previously. This was done for both an individual program and a comprehensive program. The smaller the ratio obtained, the more desirable the program.

The benefit-cost ratios, computed considering all four conditions, and rankings computed for each condition are listed in Table 3. It may be seen that the dollar benefit-cost ratio in most cases does not approach 1.0. This, however, is considered to be an indication of the inability to accurately estimate dollar benefits and not a direct reflection of the economic feasibility of the project. Despite the apparent limitations concerning benefits, estimates are considered consistent among the sub-basins; thus, comparisons are valid. Utilizing these ratios, then it is possible to rank, in a rough way, the watersheds in order of "pollution abatement desirability."

The four rankings , shown on Table 3, differ for various reasons but indicate particular watersheds which have a high benefit-cost ratio under all ranking methods and those which have a low benefit-cost ratio under all ranking methods. Others have a fairly wide range of potential ranking positions. The order in which pollution abatement work is finally carried out may well be influenced by factors not considered in this analysis. Strong social, political, or economic forces in individual watersheds may cause significant changes within the priority framework developed here.

The most significant determinant of the final priority ranking is, of course, the type of pollution abatement program plan to be implemented. Rankings listed under "individual program" (Table 3) would be most applicable in a program in which funds were limited and a comprehensive program could not be undertaken. Rankings listed under "comprehensive program" (Table 3) would apply to a basin-wide pollution abatement program.

PENNSYLVANIA ABATEMENT PROGRAM

Pennsylvania's program to control pollution from active mines began in 1945 with an amendment to the state "Clean Streams Law" giving the State Sanitary Water Board limited authority over acid mine drainage. Coal mine operators were required to obtain Board approval of a plan of drainage before a mine could be opened, reopened, or continued in operation. The Act prohibited the discharge of acid mine drainage into "clean waters." They were defined as waters which were unpolluted and free from industrial waste and authorized sewage discharges at the effective date of the Act. The Act also authorized the Board to provide the necessary diversion works to carry acid mine drainage away from clean waters for discharge to polluted or "unclean waters."

Provisions of this 1945 amendment tended to prevent pollution of streams which were unpolluted on the effective date of the Act. They did not, however, provide for effective control of discharges to streams which did not fall within the rather narrow definition of streams to be protected.

In 1965 the "Clean Streams Law" was again amended, removing all exemptions in the law relating to mine drainage. Under the provisions of the 1965 amendment which became effective on January 1, 1966, mine drainage is subject to the same controls as sewage and industrial waste. Discharges may not cause pollution. The intent of the amended law is to "restore to a clean, unpolluted condition all waters of the Commonwealth." Regulations adopted by the Board to implement the most recent amendment to the Law include the provision that discharges from active mines have residual alkalinity and a maximum of 7 mg/l iron.

In addition to making water pollution control laws more stringent, the Pennsylvania Legislature has, over the years, progressively increased requirements concerning the backfilling and restoration of areas disturbed by surface mining. Present requirements, which are administered by the Department of Mines and Mineral Industries, demand prompt and, in some cases, complete restoration of the disturbed area. Regulations have been adopted to prevent acid drainage and soil erosion from areas disturbed by strip mining, both during and following the active mining phase.

State mine drainage pollution control and strip mining reclamation regulatory authority appears to be adequate to prevent additional stream quality degradation resulting from future mining activities. Stream quality degradation from future mining will depend largely upon the extent to which the existing legislation can be enforced in the face of technical and economic obstacles.

In addition to the enforcement activities described above, considerable effort is expended to discover and demonstrate new methods of abating mine drainage pollution. Both the Sanitary Water Board and the Coal Research Board, an administrative arm of the

Department of Mines and Mineral Industries, are involved in these activities. The work is intended to demonstrate ways of preventing pollution from active operations as well as determining methods of abating pollution from the thousands of abandoned mines already causing pollution.

In early 1967, the Pennsylvania Legislature adopted a 500 million dollar conservation bond issue which will make approximately 100 million dollars available to the Department of Mines and Mineral Industries for the reclamation of areas disturbed by mining and for the abatement of mine drainage pollution. The funds are to be expended over a ten-year period.

STUDY PROCEDURES

Field investigations, sampling programs, and laboratory analyses were conducted by personnel of the Chesapeake Bay-Susquehanna River Basins Project primarily during the periods of June through October in the years 1964 through 1967.

The field investigations were conducted in two phases--"reconnaissance" and "control sampling." During the reconnaissance phase of the survey, primary effort was directed toward identifying watersheds which contribute significant amounts of mine drainage pollution. Existing federal, state, and industry data were reviewed. To the extent possible, streams affected by mine drainage pollution and sources of the pollution were identified and located. Where the existing data were inadequate to characterize mine drainage pollution, survey crews made field determinations on pH, alkalinity, acidity, conductivity, and flow. The crews also located and identified point sources of mine drainage pollution not recorded by other agencies.

Results of stream biological surveys conducted during the course of the Chesapeake Bay-Susquehanna River Basins Project study were used as an aid in determining the streams affected by mine drainage pollution.

Based on existing data and results of the reconnaissance survey, control sampling stations were established on all streams significantly affected by mine drainage pollution. Six to eight samples were normally taken at each station ever a six- to ten-week period. Samples taken were iced and transported to the laboratory for physical and chemical analyses. Time in transit from the field to the laboratory usually varied from six to 24 hours. At the time of the sampling, field determinations were made of the flow, pH, and specific conductivity. During this phase of the study, every effort was made to locate and characterize every significant discharge. Detailed investigations in watersheds of some minor tributaries to the West Branch Susquehanna River Basin, as well as in minor watersheds in the anthracite and semi-anthracite areas, are yet to be completed.

Field sampling activities were generally conducted only during the summer months; therefore, data presented here represent, for the most part, summer low flow conditions. Limited sampling over a range of flow conditions in several sub-basins indicates that mine drainage indicator loadings may vary as much as two orders of magnitude or more in response to variations in surface runoff and ground water flow. Loadings quoted in the descriptive sections of this report are thus utilized for comparative purposes only and should not be considered to represent a static or a statistically significant value.

Considerable information on major mine drainage discharges and their effects on stream quality is still needed. Activities planned and in progress by several state and federal agencies should add significantly to the basic data presently available.

Mine drainage pollution is generally characterized by increased concentrations of specific indicators above usually accepted levels or by the presence of ions of elements considered unique to mine drainage discharges.

In the course of the Mine Drainage Study efforts, samples of both discharges and receiving streams were analyzed for the following indicators:

Physical	Chemical
1. pH	1. Acidity
2. Conductivity	2. Alkalinity
3. Solids	3. Iron (Ferrous and Total)
4. Temperature	4. Hardness
	5. Calcium
	6. Magnesium
	7. Manganese
	8. Aluminum
	9. Sulfate

Methods used and significance of the individual analyses are discussed below.

pH in the range of 6.0 to 9.0 is usually exhibited by natural waters. Generally, acid mine drainage will vary from pH 2.5 to 6.0. Alkaline mine drainage occurs with pH in the order of 6.0 to 8.0. The pH of the receiving stream varies according to the amount of pollution and the buffering capacity of the stream waters.

Conductivity is measured by Conductivity Bridge in both laboratory and field. It is expressed in mhos, the reciprocal of resistance, and is a measure of the electrical conducting power of the system and is related to the dissolved matter (dissolved solids) in solution. Waters uncontaminated by mine drainage exhibit conductivities in the order of 100 micromho. The conductivity of mine drainage discharges varies generally from 500 to 8,000 micromho.

Nonfilterable (suspended) solids were determined by filtration of a standard volume (250 ml) and dried to constant weight at 105° C

(Standard Methods, 12th Edition). This measurement determines the fraction of suspended matter in the sample.

Filterable (dissolved) solids were measured by evaporating the filtrate from the nonfilterable solids test and drying the residue to constant weight at 105° C. Measurement of filterable solids indicates the concentration of dissolved materials. The total solids measure is the sum of the nonfilterable and filterable solids.

Cold Acidity is measured by titration to pH 8.3 (modification of Standard Methods, 12th Edition). Laboratory analyses were conducted potentiometrically. Field analyses were conducted either potentiometrically or colorimetrically. This procedure measures the titratable acidity, including volatile acidity which can be made to combine with a base. It is a measure of the uncombined hydrogen ion immediately present and that which can be available from all potential sources under the titration conditions. In samples containing high concentrations of acid precursors, the total potential acidity may not become available under test conditions. Therefore, pre-oxidation by addition of ozone, peroxide, or by heating is required to measure total acidity.

Hot Acidity is determined by potentiometric titration to a pH 8.3 end point (modification of Standard Methods, 12th Edition). This procedure measures the titratable acidity (hydrogen ion) which is available in the sample and that which is made available by heating the sample to boiling with the addition of hydrogen peroxide. The method determines the acidity made available from the potential sources. It does not measure any contribution to acidity of volatile constituents either present initially or produced by subsequent reactions. This determination is applicable to relative measurements such as the effect of an abatement procedure or the characterization of a discharge. However, it may not be useful in stream analysis, since it does not measure all of the acidity originally present; results are reported in mg/l, $CaCO_3$.

Alkalinity is also measured by the potentiometric method of titration to pH 4.5 (Standard Methods, 12th Edition). Field analyses were conducted potentiometrically or colorimetrically. These procedures measure the titratable alkalinity of a system which, in most waters of this Basin, is essentially bicarbonate or carbonate in origin.

Under the conditions of the determination, alkaline mine drainage exhibits a final, positive alkalinity when the acidity produced in the course of the titration does not exceed the available alkalinity. It is, therefore, essential that reactions yielding acidity be completed before the alkalinity determination is attempted.

Net or residual alkalinity is determined by calculation. It is the difference between the alkalinity and acidity determined by cold titration on a given sample. For purposes of calculation, acidity is considered to be equivalent to negative alkalinity.

Sulfate is measured by precipitation with benzidine-dihydrochloride. This procedure measures the concentration of sulfate in the sample and is an indicator of mine drainage pollution. Unpolluted waters of the Basin contain low levels of the indicator, being derived from leaching of soils, rock, etc.

Whereas relatively unpolluted waters contain concentrations normally below 50 mg/l, mine drainage discharges often exhibit concentrations in the range of 300 to 10,000 mg/l.

Hardness is determined by EDTA titration with hydroxy napthol blue indicator. This procedure measures the total concentration of such ions as calcium, magnesium, lithium, etc. It does not differentiate among species. Unpolluted waters in the portion of the Basin influenced by mine drainage usually exhibit hardness concentrations less than 100 mg/l as $CaCO_3$. Concentrations of 500 to 2,000 mg/l as $CaCO_3$ are common in mine drainage.

Calcium is determined either by EDTA titration with Eriochrome Black T Indicator or by atomic adsorption spectrophotometry. This procedure measures only the concentration of calcium, a component of hardness. Concentrations of this indicator in unpolluted waters are from 15 to 30 mg/l.

Magnesium is done by atomic adsorption spectrophotometry. Only the concentration of magnesium is measured, which is also a component of hardness. Concentrations of this indicator in unpolluted water are in the order to 10 to 20 mg/l.

Manganese is also measured by atomic adsorption spectrophotometry. This procedure measures the concentration of manganese, normally an acidic precursor. Concentrations in natural streams do not usually exceed 0.05 mg/l. Concentrations in the order of 5 mg/l to 20 mg/l are not uncommon in mine drainage.

Aluminum is done by atomic adsorption. This indicator, a potential acidic precursor, is usually present in rather low concentrations in unpolluted water. High concentrations are usually found as a result of acid mine drainage leaching clay deposits associated with the coal bearing strata.

Iron is measured in both the ferrous and total states by 1.10 phenanthroline (Standard Methods, 12th Edition) or by atomic adsorption.

Generally, mine drainage pollution contains iron in both the ferrous and ferric states. Ferric iron does not contribute to acidity. Ferrous iron, a major contributor to acidity, is usually present in high concentrations in deep mine discharges, and its presence in a receiving stream usually indicates recent mine drainage discharges.

Unpolluted streams in the Basin have total iron concentrations of frequently less than 0.3 mg/l. Mine drainage influence may raise iron to concentrations in excess of 100 mg/l.

WEST BRANCH
SUSQUEHANNA RIVER

AREA DESCRIPTION

The West Branch Susquehanna River drains an area of 6900 square miles in the west central portion of the Susquehanna River Basin. The sub-basin lies entirely within Pennsylvania and is bounded on the north by the Genesee and Chemung River Basins, on the south by the Juniata River Basin, on the east by the Susquehanna River Basin, and on the west by the Allegheny River Basin.

The West Branch Susquehanna River has its source in northwestern Cambria County and flows a distance of 240 miles to its confluence with the Susquehanna River at Northumberland, 123.5 miles upstream from the Chesapeake Bay. The upper portion of the sub-basin lies within the high tablelands of the Appalachian Plateau Province. At Lock Haven, the river breaks through the Allegheny Front, the escarpment which divides the Appalachian Plateau Province from the Ridge and Valley Province, then flows approximately 70 miles through the Ridge and Valley Province to its confluence with the Susquehanna River. The sub-basin is approximately equally divided between the Appalachian Plateau and the Ridge and Valley Provinces. In the Appalachian Plateau Province, stream valleys are narrow and flanked by high, steep hills. In the Ridge and Valley Province, valleys are generally broad and fertile and bounded by rugged, forested mountains. Moderate to steep gradients of streams in the Appalachian Plateau Province provide considerable turbulence and excellent mixing. The combination of low gradient and a wide, shallow channel configuration combine to produce poor mixing in the Ridge and Valley Province.

Major tributaries of the West Branch, their drainage area, and the mile points of confluence with the main stream are tabulated in the following table. (Also see Figure 1-A, a map of the West Branch Susquehanna River sub-basin, illustrating major tributaries and other pertinent physical features.)

Name	Drainage Area (square miles)	Mile Point of Confluence
Loyalsock Creek	493	35
Lycoming Creek	276	41
Pine Creek	973	67
North Bald Eagle Creek	782	68
Kettle Creek	239	104
Sinnemahoning Creek	1033	110
Moshannon Creek	288	136
Clearfield Creek	396	172
Chest Creek	132	205

Geology: Consolidated rocks which outcrop in the area are all of the Paleozoic era and generally of the Pennsylvanian and Mississippian systems. In descending order from youngest to oldest,

the specific rock formations are identified as Conemaugh, Allegheny, Pottsville, Mauch Chunk Shale, Pocono, Oswago, and Catskill. Of these, only the Conemaugh and the Allegheny formations contain coal beds of economic significance.

A portion of the main Pennsylvania bituminous field lies within the basin beneath all or a portion of Clearfield, Cameron, Clinton, Centre, Lycoming, Potter, Cambria, Indiana, McKean, and Elk Counties. The bituminous coal beds lie within the Appalachian Plateau Province in the western part of the basin (see Figure 1-A). Other coal deposits underlie portions of Bradford, Tioga, and Sullivan Counties.

Economy: The rich bituminous coal deposits of the Pennsylvanian system have played a dominant role in the area's economy. It is estimated that approximately 4400 mines have been opened in the basin, most of which have long since been abandoned. Estimates by watershed as of 1962 indicate the opening of about 830 mines in the Moshannon Creek watershed, 1150 in the Clearfield Creek watershed, 330 in the Bennett Branch Sinnemahoning Creek watershed, and 180 in the Beech Creek watershed (2). The remaining mines were opened in the watersheds of minor tributaries to the West Branch upstream from the mouth of Loyalsock Creek.

Of the original bituminous coal reserves in the West Branch sub-basin, estimated to be 4140 million tons in 1928 (3), about 2535 million tons still remained as "recoverable reserves" in January 1963 (4). About 431 million tons of the depletion of the reserves is attributable to production (5). The remainder is considered "loss in mining" (pillers, fines, unminable coal, etc.). An estimated 1334 million tons, more than half of the recoverable reserves, underlie Clearfield County (4). Coal production in the sub-basin has been relatively stable, averaging about nine million tons per year since 1945. Within the last decade, Clearfield and Centre Counties have accounted for about 80 percent of the production in the basin (6).

Prior to 1945, deep mines accounted for most of the coal production in the basin; however, development of large earth-moving equipment during World War II greatly stimulated surface mining activity. Strip mining accounted for 45 percent of the Susquehanna River Basin's production in 1945 and 77 percent in 1955 (6). Of the 8,650,000 tons of coal produced in 1962, about 84 percent was mined at strip operations. Clearfield County produced 83 percent of its total from strip mines (2). Strip mine production exceeded 90 percent of the total production in the remaining coal producing counties.

Coal production for 1970 is projected at about 8,040,000 short tons. A gradual increase in production to 13,380,000 short tons in 2020 is expected. The following table lists projected bituminous coal production for the West Branch Susquehanna River Basin.

Projected Production of Bituminous Coal
by Economic Subregion (6)

Economic Subregion	(thousands of short tons) 1970	1985	2020
Clinton Centre } Lycoming	960	530	450
Cameron Clearfield }	7080	8610	12,930
Total	8040	9140	13,380

In this sub-basin description as well as in those following, the presentation is organized by minor watersheds and arranged in order of hydrological sequence. Each contains summaries of the data collected on mine drainage sources, the effects on stream quality, and the potential abatement measures.

West Branch Susquehanna River--Upstream from Chest Creek

A total of 166 mine drainage discharges have been located in this watershed, contributing approximately 54,000 lb/day net acidity. Most of the mine drainage originates in abandoned deep mines discharging into a nine-mile portion at the head of the 35-mile reach of the West Branch within this watershed. In the downstream portion of the sub-basin, considerable mining has been carried out, and numerous mine drainage discharges exist. For reasons described in the Chapter on Formation and Sources of Mine Drainage, most of the discharges are alkaline and contribute to the neutralization of acid mine drainage discharged to the extreme headwaters.

The first major addition of mine drainage in this watershed is a pumped discharge from an active, deep mine operated by the Barnes and Tucker Coal Company. The discharge contributes a loading of 4100 lb/day net acidity. This is primarily responsible for the mean acidity concentration of 450 mg/l and an associated loading of 4800 lb/day net acidity at a sampling point about two miles downstream (Figures 2A and 2B).

Within the next seven miles, the river gains an additional 14,000 lb/day net acidity; however, the net acidity declines to 200 mg/l. Major mine drainage contributors to the reach include two spoil piles and four abandoned deep mines. Their total contribution is 26,000 lb/day net acidity, or about 82 percent of the total acid loading in the reach. The spoil piles are responsible for about 30 percent of this total.

Between Mile 229 and 220, the acid load in the West Branch is reduced by about 10,000 lb/day, and the acidity concentration declines to 50 mg/l. This reduction is the result of the neutralizing effect of naturally alkaline tributaries and alkaline mine drainage discharges.

Several of the tributaries have alkalinities in excess of 150 mg/l. A major source of alkalinity to the West Branch is Beaver Run which contributes 7600 lb/day net alkalinity. About half of this originates in a discharge from the abandoned Barnes and Tucker #12 deep mine.

From Mile 220 to the confluence with Chest Creek, at mile 205, the West Branch does not exhibit a significant change in alkalinity, although a slight increase in other mine drainage indicators is noted.

One discharge to Cush Creek, originating from a coal refuse pile near Hooverhurst, contributes almost 12,000 lb/day net acidity. Although this discharge constitutes the largest single acid contributor to the sub-basin, the alkalinity resources of Cush Creek are adequate to overcome the acidity to the extent that Cush Creek contributes 350 lb/day net alkalinity to the West Branch.

In general, concentrations of mine drainage indicators decline throughout the length of the reach from the headwaters to Chest Creek. Mean iron and manganese concentrations, which are 120 and 3.6 mg/l, respectively, at the head of the reach, decline to 1.1 and 2.5 mg/l, respectively. Sulfates decline from 1300 mg/l to 350 mg/l (Figure 4B).

* * *

Abatement of mine drainage pollution in the sub-basin will involve three primary efforts: (1) measures intended to minimize surface water contribution to deep mine discharges; (2) restoration of drainage presently impeded by refuse banks and areas disturbed by surface mining; and (3) treatment of the residual mine drainage remaining after preventive measures are carried out.

Diversion of streams presently seeping through refuse, or otherwise preventing mine drainage-type discharges from refuse piles, appears to be the most immediately effective and least costly abatement activity in this sub-basin. This could be expected to reduce the acid loading in this reach by almost 50 percent.

A comprehensive program to abate mine drainage pollution in the entire sub-basin is estimated to cost 18 million dollars initially and have an annual cost of two million.* Considerable benefit could be realized at a reduced cost by completing applicable prevention measures in the entire sub-basin and by treating the residual mine drainage loading from one active and four abandoned deep mines in the headwaters.

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* The initial cost referred to hereafter in the text is the construction cost. Annual costs account for amortization, maintenance, and operation.

Chest Creek

Chest Creek contributes approximately 2500 lb/day net alkalinity to the West Branch. Although the stream is alkaline at its mouth (Figures 4A and 4B), a three-mile reach about 11 miles from the mouth is degraded by mine drainage originating in the watershed of Brubaker Run. Acid loads are on the order of 4,000 lb/day and degrade the quality of Chest Creek from its confluence with Brubaker Run to Westover. At Westover, a large alkaline discharge from a tannery overcomes the acid and renders the stream alkaline.

Surface mining has created a number of acid discharges in watersheds of tributaries of Chest Creek downstream from Brubaker Run. Most of the discharges are neutralized by lime neutralization facilities in accordance with Sanitary Water Board regulations. Although Chest Creek is alkaline downstream from Westover, significantly high levels of other mine drainage indicators are present.

A total of 83 mile drainage discharges were located in the Chest Creek watershed, contributing a total of 8300 lb/day net acidity. As in the case of the watershed in the West Branch upstream from Chest Creek, many of the discharges are alkaline. Of the 29 discharges that are alkaline, most are located in the portion of the sub-basin downstream from Brubaker Run. One discharge contributes 3200 lb/day net alkalinity to Kings Run, a tributary of Chest Creek, downstream from Westover.

Substantial curtailment of mining operations in the Brubaker Run watershed during the time field operations were in progress may have influenced the location and quality of some discharges; however, the data collected indicate 42 discharges contribute 6400 lb/day net acidity. This loading constitutes about 75 percent of the acid loading to the Chest Creek watershed. About 85 percent of the acid loading to Brubaker Run originates in five discharges. Most of the mine drainage originates from inactive deep mines; however, surface mines and coal refuse piles also contribute significant quantities of mine drainage. Although the tannery discharge limits acid conditions in Chest Creek to a three-mile reach, elimination of this source of alkalinity would extend the acid zone downstream probably an additional three miles to the mouth of Pine Run.

The ultimate effect of mine drainage discharges on stream quality cannot be precisely assessed. This is due to extensive surface mining activity in the portion of the sub-basin downstream from Brubaker Run and attendant neutralization of mine drainage discharges. There is a strong possibility, however, that if operation of all lime neutralization plants were suspended and the alkaline tannery discharge abated, acid conditions would prevail throughout most of the length of Chest Creek. A detailed study of this watershed is presently being conducted by personnel in the Pennsylvania Department of Mines to determine the effect of mine drainage discharges.

* * *

It is conservatively estimated that a comprehensive mine drainage pollution abatement program in the Chest Creek watershed would cost 2.9 million dollars initially and 400,000 dollars annually. About two-thirds of this cost would be required in the Brubaker Run watershed. Uncertainty concerning locations and strengths of sources and their effects on stream quality, however, makes the estimation of abatement costs difficult.

Pollution abatement in the Brubaker Run watershed will primarily involve reducing surface water contribution to mine water flows, possibly the flooding of deep mines, burial of acid-forming refuse, and back filling of some surface mines. The watershed involved is small (12 square miles) compared with the 132 square-mile watershed of Chest Creek. It would, therefore, appear that pollution abatement in the small watershed to prevent pollution in the main stream is feasible. Pollution abatement in the remainder of the watershed will involve restoration of surface mines and possibly collecting and treating residual mine drainage.

The state regulatory agencies should give careful consideration to future applications for mine drainage discharge permits in this watershed. Additional surface mining without proper safeguards could result in extensive stream quality degradation.

West Branch Susquehanna River--Chest Creek to Clearfield Creek

This part of the discussion considers all of the tributaries of the West Branch except Anderson Creek. This Creek is left out because it constitutes a major mine drainage problem in itself and is handled later in a section of its own.

A total of 50 mine drainage discharges contribute a total of 7,000 lb/day net acidity in this watershed. Although discharges are distributed rather uniformly throughout the watershed, the large discharges are located in the portion of the watershed downstream from Anderson Creek. Seven of the discharges, all abandoned deep mines, contribute about 70 percent of the acid loading. Most of the remaining discharges release less than 100 lb/day net acidity.

The West Branch Susquehanna River is essentially neutral in the reach from Chest Creek to Anderson Creek. The reach varies between weakly acid to weakly alkaline, depending upon the hydrologic conditions that prevail. The minor tributaries to this reach are influenced by mine drainage, but for the most part contribute alkalinity. Acid contributions originating primarily in the watersheds of Anderson Creek, Montgomery Creek, and Wolf Creek total about 3100 lb/day, but are outweighed by alkaline contributions within the reach (Figure 2A).

Biweekly sampling during the summers of 1966 and 1967 in the Curwensville Reservoir indicate no water quality stratification.

Relatively frequent fluctuations between net acidity and net alkalinity occur in the reservoir as a whole in response to variations in the upstream quality of the West Branch.

The pH of the reach within the sub-basin ranged from 3.1 to 7.6 (Figure 2B). The mean total iron concentration declines from 1.1 mg/l to 0.25 mg/l through the reach. Manganese and sulfate concentrations decline from 2.5 mg/l and 553 mg/l, respectively, to 0.05 mg/l and 270 mg/l, respectively. Fish and other aquatic life have been observed in this reach, most frequently downstream from Curwensville Dam. The aquatic population, however, is somewhat depressed by residual amounts of mine drainage.

* * *

Pollution abatement measures, such as surface water control and diversion, would appear to be most appropriate since most of the mine drainage originates in abandoned deep mines. Residual mine drainage loadings could even then be significant, however, and require treatment.

The estimated cost of abatement in the watershed is 2.8 million dollars, with an annual cost of 500,000 dollars. Measures which might be applied to increase water quality at lower cost might include conveying residual mine drainage directly to the West Branch or to adjacent watersheds so that some or all of the tributary streams will be protected.

The Curwensville Dam can impound water for quality control and might be utilized in a basin-wide pollution abatement program. The impoundment would be particularly valuable if pollution abatement measures were carried out upstream from the reservoir to assure that the impounded water is alkaline at all times.

Anderson Creek

Anderson Creek contributes an average of 1750 lb/day net acidity to the West Branch. Most mining activity has been confined to the lower reaches of the watershed, and stream quality is not seriously impaired by mine drainage upstream from the confluence with Little Anderson Creek. Mine drainage contributed by Little Anderson Creek and minor tributaries downstream combine to render Anderson Creek acid. Mean total iron, manganese, and sulfate concentrations measured at the mouth were 3.9 mg/l, 3.4 mg/l, and 150 mg/l, respectively.

Most of the mine drainage in the watershed originates in abandoned surface clay mines, some of which have intercepted deep mines. Although 30 discharges were observed, about 70 percent of the acid load measured originates at six discharges.

* * *

Abatement will involve primarily surface reclamation measures such as surface water diversion and control and back filling of surface mines. Treatment of residual mine drainage will probably be necessary particularly in the Little Anderson Creek watershed where most of the mine drainage originates. Concentrating abatement in the Little Anderson Creek watershed would be particularly desirable since abatement in a six-mile reach of Little Anderson Creek would probably abate pollution in a ten-mile reach of Anderson Creek when accompanied by relatively minor work at other discharge points.

The estimated first cost of pollution abatement in the subbasin is 1.1 million dollars. The annual cost of the program would be 160,000 dollars.

Clearfield Creek

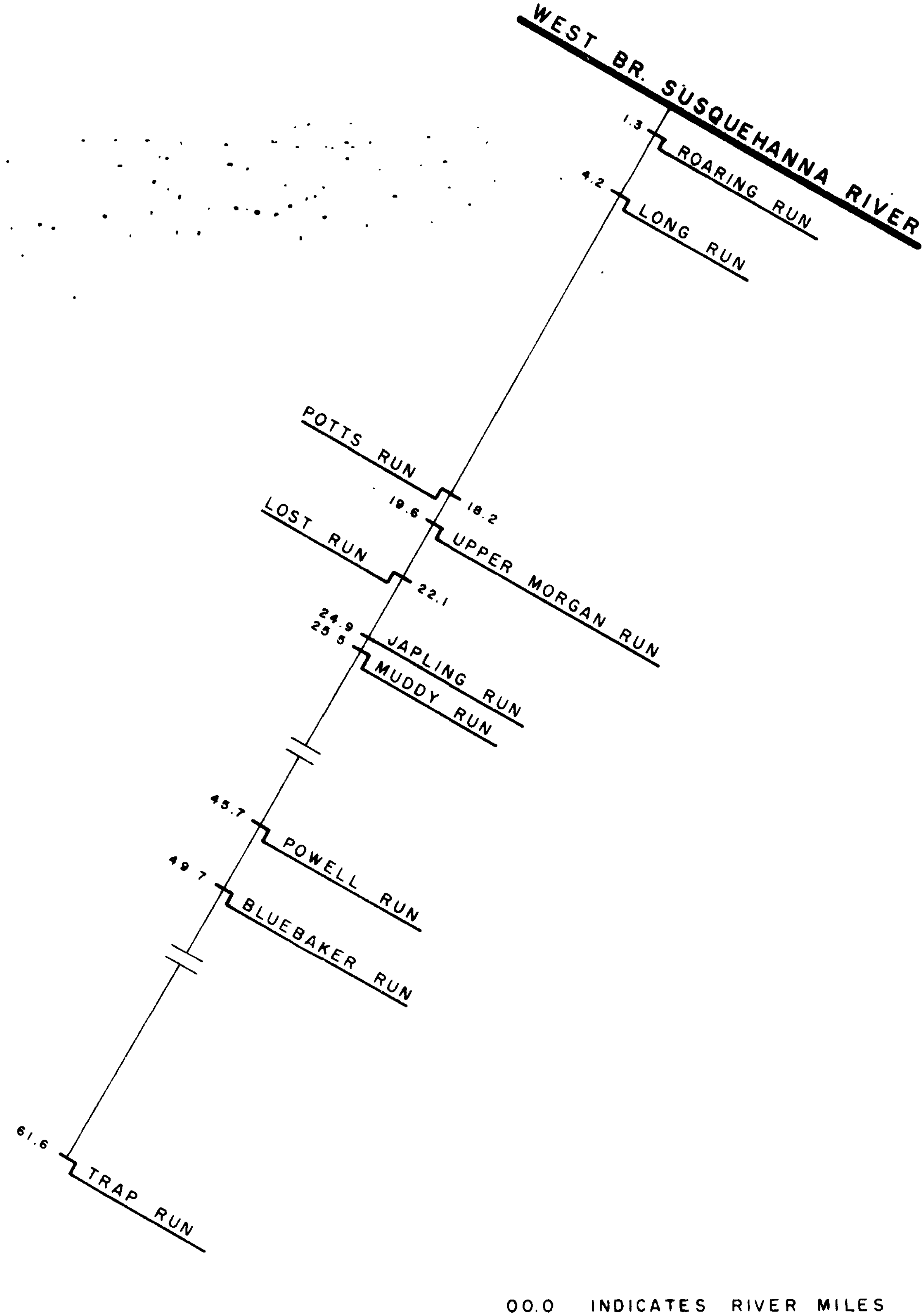
Clearfield Creek is rendered acid by mine drainage from source to mouth. During an eight-week intensive survey in 1966, the stream contributed an average of 57,000 lb/day acidity to the West Branch. At the mouth, mean net acidity concentrations of 115 mg/l were measured. Total iron concentrations were relatively low (1.4 mg/l); however, other mine drainage indicators were present in high concentrations.

As indicated by the results of sampling and analysis conducted in 1967 (Figures 5A and 5B), acidity concentrations upstream from Mile 31 are relatively low. Mine drainage is discharging directly to Clearfield Creek as well as to several tributaries, and severely degrades stream quality from Mile 25 to the mouth.

Although mining activity has been very extensive throughout most of the watershed, about 45 percent of the acid load in Clearfield Creek originates in ten tributaries. These have a combined drainage area of 95 square miles which is about 25 percent of the area within the Clearfield Creek watershed.

The streams responsible for most of the acid load in Clearfield Creek are shown in the following schematic diagram and tabulation.

Ninety-seven major mine drainage discharges were located in the watershed, and their total contribution is about 45,000 lb/day acidity. Discharges were found to be scattered rather uniformly over the watershed, with the number of discharges found upstream from Muddy Creek about equal to the number found downstream. Discharges found in the lower part of the watershed, however, contribute about three times as much acid as those located upstream from Muddy Creek. As shown on the schematic diagram, all of the streams responsible for major mine drainage discharges enter Clearfield Creek from the east, except Potts Run and Lost Run. Little Clearfield Creek is the largest tributary of Clearfield Creek and drains 45 square miles in the western part of the watershed. It is stocked by the Pennsylvania Fish Commission and maintains relatively good quality despite strip



CLEARFIELD CREEK

SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY MINE DRAINAGE POLLUTION

Principal Mine Drainage Contributors - Clearfield Creek

Streams	Stream Mile (on Clearfield Creek)	Drainage Area (sq. mi.)	Net Acid Contribution (lb/day)
Roaring Run	1.3	12.2	2,000
Long Run	4.2	4.0	2,000
Potts Run	18.2	15.4	3,200
Upper Morgan Run	19.6	12.2	2,900
Lost Run	22.1	2.5	4,000
Japling Run	24.9	3.2	5,000
Muddy Run	25.5	30.6	27,000
Powell Run	45.7	11.2	2,600
Bluebaker Run	49.7	2.5	1,500
Trap Run	61.6	1.5	2,500

mining and several deep mine discharges in the watershed. The concentration of major mine drainage sources in the lower portion of the basin is primarily the result of geologic conditions discussed in the chapter on Formations and Sources of Mine Drainage.

As in the case with other watersheds studied, a small number of large discharges contribute most of the acid loading. Ten discharges contribute more than half of the acid discharges in the sub-basin. Most of the major discharges are recorded as discharges from strip mine areas; however, in many cases they are a combination of drainage from both deep and strip mines. It is particularly difficult in this sub-basin to differentiate between deep and strip mine drainage because so many strip mines have intercepted shallow, deep mines or have crossed deep mine portals. Essentially, all the acid drainage located in the sub-basin is discharged from abandoned mines.

* * *

Extensive disturbed areas, large numbers and varieties of mine drainage sources, and heavy acid loadings combine to make Clearfield Creek one of the most difficult streams in the West Branch Susquehanna River Basin to reclaim. It is estimated that a program of pollution abatement at the source, supplemented by treatment of the residual mine drainage loadings, would have a construction cost of 11 million dollars and an annual cost of 1.6 million. Most of the major mine drainage sources are concentrated in the northeastern portion of the sub-basin, and this may have a significant effect on final pollution abatement costs. This distribution would make it possible to realize considerable benefits from relatively low cost pollution abatement activities in the southern and western portions of the sub-basin. Complete abatement might be accomplished more cheaply than estimated if in-stream impoundments and, possibly facilities to convey mine drainage between sub-basins were provided.

West Branch Susquehanna River--Clearfield Creek to Moshannon Creek

The quality of the West Branch in this reach is seriously degraded by mine drainage from Clearfield Creek and from several minor tributaries within the reach. Acid loadings increase from about 4,000 lb/day net alkalinity at Mile 173, which is upstream from Clearfield Creek, to 53,000 lb/day net acidity at Mile 163, about nine miles downstream from Clearfield Creek. In the vicinity of Mile 144, the acidity increases to 108,000 lb/day as the result of acid tributaries in that portion of the reach. Iron and manganese concentrations are about 6 and 7 mg/l, respectively (Figures 2A and 2B).

The total acid contribution by 13 tributaries is about 53,000 lb/day. Location and characterization of mine drainage discharges in these stream basins have not been completed, but to date, about 25 percent of the area has been covered, and 50 discharges have been located with a total acid contribution of 51,000 lb/day. It is believed that most of the drainage originates in abandoned deep mines, with a lesser amount originating in abandoned strip mines. Completion of field work in this sub-basin may show that it is a source of acidity to the West Branch second only to Moshannon Creek.

Principal Mine Drainage Contributors - West Branch Susquehanna River--Clearfield Creek to Moshannon Creek

Streams	Stream Mile (on West Branch)	Drainage Area (sq. mi.)	Net Acid Loading (lb/day)
Lick Run	165	31	1,000
Trout Run	163	40	2,000
Millstone Run	161	4	4,000
Surveyor Run	158	5	2,000
Murray Run	154	1	1,200
Congress Run	153	1	11,300
Deer Creek	148	19	4,400
Sandy Creek	144	19	4,200
Alder Run	144	22	9,400
Rolling Stone Run	143	4	2,000
Basin Run	142	5	1,000
Rock Run	140	3	5,000
Potter Run	139	4	4,600
Unnamed Tributary	138	2	1,100

* * *

Since source location in this watershed has not been completed, no definite statement on abatement methods can be made. A total abatement cost of 19 million dollars and an annual cost of approximately 2.5 million is inferred from data of the area surveyed to date.

While basic data are incomplete for the watershed, it is certain that the watershed contributes a very significant portion of the mine drainage load to the West Branch. It definitely should be considered in any comprehensive mine drainage pollution abatement program for the West Branch area.

Moshannon Creek

Moshannon Creek is the largest contributor of mine drainage to the West Branch of the Susquehanna River. It brings an average of about 130,000 lb/day net acidity to the river. It is considerably smaller in drainage area than most of the major watersheds mentioned in this report, but intense mining combined with geologic and other conditions have joined to give Moshannon Creek the dubious distinction of being the largest single source of mine drainage to the West Branch.

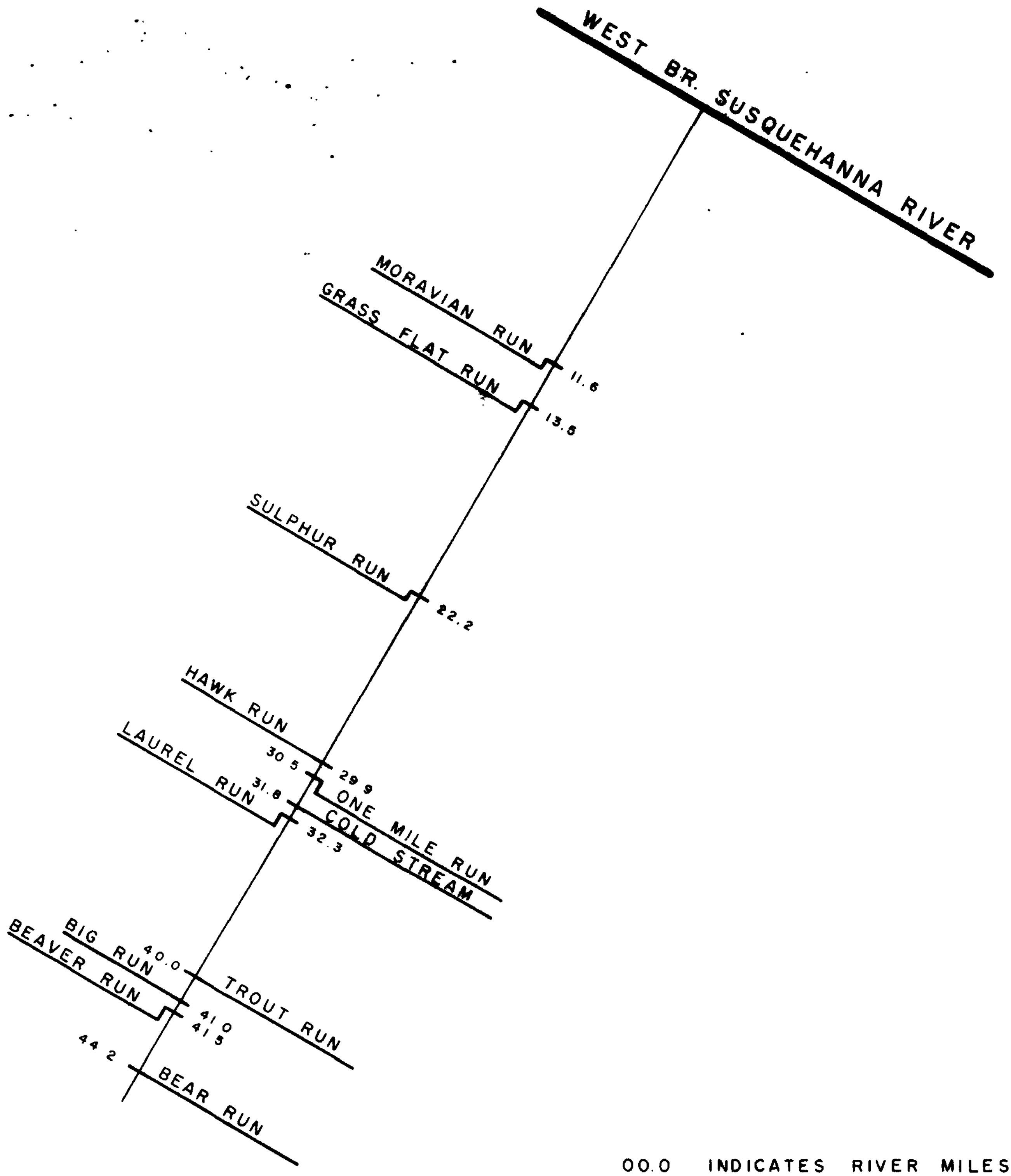
A total of 160 mine drainage discharges have been located, and they contributed a total of 135,000 lb/day net acidity. Most of the mine drainage originates at inactive mines; in many cases, however, strip mines intersect portals of abandoned deep mines, which means that a significant portion of the acidity attributed to strip mines may also come from deep mines. Possibly a problem in ascertaining the source of mine drainage is its tendency to follow bedding planes to where they outcrop on hillsides and stream banks. This has created large seepage swamps for which it is difficult to characterize flow, quality, and source of water.

As in the case with most of the sub-basins studied, a large proportion of the acid originates in a small percentage of the discharges. Twenty-six discharges contribute more than three-quarters of the total acid loading introduced to the Moshannon Creek.

Stream quality in most of the watershed is influenced by mine drainage. The 11 streams listed in the following table are considered the most significant contributors of mine drainage.

Principal Mine Drainage Contributors - Moshannon Creek

Streams	Stream Mile (on Moshannon Creek)	Drainage Area (sq. mi.)	Net Acid Loading (lb/day)
Moravian Run	11.6	2	23,000
Grass Flat Run	13.5	1	65,000
Sulphur Run	22.2	2	20,000
Hawk Run	29.9	2	16,500
One Mile Run	30.5	1	6,100
Cold Stream	31.8	24	12,400
Laurel Run	32.3	20	4,300
Trout Run	40.0	11	8,000
Big Run	41.0	3	3,300
Beaver Run	41.5	19	13,000
Bear Run	44.2	4	5,500



MOSHANNON CREEK

SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY MINE DRAINAGE POLLUTION

A notable exception to the list of tributaries contributing mine drainage is Black Moshannon Creek. It drains a 56 square-mile area outside the coal measures and contributes about 1,000 lb/day net alkalinity and, under some flow conditions, effects a significant improvement in the quality of Moshannon Creek.

Stream quality varies greatly with flow. There is, however, a normal pattern of weak acidity in the headwaters which rapidly increases in concentration downstream from Bear Run (Figures 6A and 6B). It improves gradually to the 150-250 mg/l net acidity range at the mouth. Other mine drainage indicators follow essentially the same pattern. Iron concentrations are normally quite high, ranging from 20-40 mg/l.

* * *

In addition to the obvious problem involved in abating a large number of highly acid mine drainage discharges, other factors combine to make mine drainage pollution abatement in this watershed more difficult and thus more costly than in any other watershed tributary to the West Branch. The factor which influences abatement costs to the greatest extent is the shallow depth of the coal seams below the ground surface. Extensive deep mining in these seams has created cracks and fissures which make for easy entry of water into the mines. Abatement must include costly surface sealing techniques or be supplemented with high capacity treatment plants.

The shallow cover of the coal has also made surface mining very popular. These operations contribute to mine drainage discharges; inadequately restored strip mines offer another avenue of entry by surface water to deep mines.

Abatement in the watershed will involve back filling unrestored strip mines, diverting surface water, sealing surface fissures, and treating discharges. The estimated first cost of such a wide program is 52.6 million dollars, with an annual cost of more than 11.5 million dollars.

Mine drainage sources are quite evenly distributed over the sub-basin, and only one major tributary (Black Moshannon Creek) contains a significant amount of alkalinity. For this reason, flow regulation or conveyance do not appear to be applicable measures.

Concentration of pollution abatement efforts on the relatively small number of large sources could result in a significant improvement in the quality of the Moshannon and abate pollution in the West Branch at a lower cost than that estimated for a complete abatement program in the Moshannon Creek watershed.

West Branch Susquehanna River--Moshannon Creek to Sinnemahoning Creek

Severe water quality degradation is evident in this reach of the West Branch. Discharges within the reach as well as from upstream are responsible. Variations in both acid loadings and concentrations within the reach are slight and not considered significant. Mean net acidity is about 130 mg/l (Figures 3A and 3B). Sulfate concentrations range from 800 to 1,000 mg/l, while iron and manganese concentrations average 3 mg/l and 7 mg/l, respectively. Most of the tributaries are mildly acid or mildly alkaline and have no significant effect on the quality of the West Branch.

The work on mine drainage location and characterization has not been completed in this watershed. It is known, however, that only a limited amount of mining has been done, and that most of the acid drainage originates in abandoned deep mines.

* * *

Minor tributaries in this reach lie in a remote, almost inaccessible area. Abatement would have very little effect on any streams that are of significant public use or on the quality of the West Branch. Estimates of pollution abatement costs are based primarily on stream quality data and information collected by other agencies. The first cost of a complete mine drainage pollution program would be about three million dollars, with an annual cost of about 500,000 dollars.

Sinnemahoning Creek

The Sinnemahoning Creek contributed about 36,000 lb/day net acidity to the West Branch. The stream, with its drainage area of 1032 square miles, has the largest watershed area of any tributary to the West Branch. It is two-thirds as large as all the area upstream from the point where the Sinnemahoning meets the West Branch. Major tributaries include the First Fork, Bennett Branch, and Driftwood Branch.

Although the stream has a large watershed area, topographic and geologic conditions combine to produce "flash" flow characteristics with low drought flows and low natural alkalinity reserves in the stream. These characteristics interact to give it a very poor capacity to assimilate mine drainage discharges.

Although most of the watershed is underlain by coal bearing deposits, mining activity has been restricted almost exclusively to the watersheds of the Bennett Branch Sinnemahoning and Sterling Run, a minor tributary to the Driftwood Branch Sinnemahoning (See Figure 1A). The Bennett Branch is acid essentially from its source to its mouth. In turn, it renders Sinnemahoning Creek acid from their confluence to the point where the Sinnemahoning joins the West Branch. Sterling Run does not overcome the alkalinity reserve in the Driftwood Branch but does add mine drainage indicators.

Water quality in the Bennett Branch varies considerably throughout its length and is weakly alkaline in its headwaters (Figures 7A and 7B). Discharges from Moose Run and Mill Creek raise the acidity concentration to 350 mg/l at Mile 32. The acidity concentration gradually declines at successive stations, but the acid loading remains essentially constant. Concentrations of other indicators vary from station to station, but are generally high except at the mouth.

Although quite acid (136 mg/l net acidity), the Bennett Branch is relatively low in concentrations of other mine drainage indicators at its mouth. The mean total iron and manganese concentrations are, for example, only 1.0 mg/l and 4.1 mg/l, respectively. Concentrations of most indicators at the mouth of the Sinnemahoning Creek are about half of Bennett Branch concentrations, reflecting the diluting effect of water contributed by other tributaries of Sinnemahoning Creek (see following table and schematic).

Principal Mine Drainage Contributors to Bennett Branch
Sinnemahoning Creek

Streams	Stream Mile (on Bennett Branch)	Drainage Area (sq. mi.)	Net Acid Loading (lb/day)
Dents Run	11	36	3800
Trout Run	17	55	1500
Unnamed Tributary at Caledonia	24	4	7300
Kersey Run	27	27	1200
Cherry Run	29	5	1000
Tyler Run	31	8	1200
Mill Run	32	2	5800
Moose Run	34	2	2300

A total of 110 discharges have been located in the Bennett Branch watershed, most of which originate at abandoned deep mines. Strip mining is being carried out on a limited basis. Although few mine drainage discharges are attributable directly to strip mines, they do in a number of cases contribute to the flow of discharges from underground mines. Mine discharges from deep mines (all of which are inactive except one) contribute a total of more than 24,000 lb/day net acidity. This is more than three-quarters of the acid loading contributed by all discharges.

Work on location and characterization of mine drainage discharges has not been completed in the Sterling Run watershed. Most of the mine drainage apparently originates in abandoned deep mines. The flow from the mines, however, is significantly influenced by strip mining operations.

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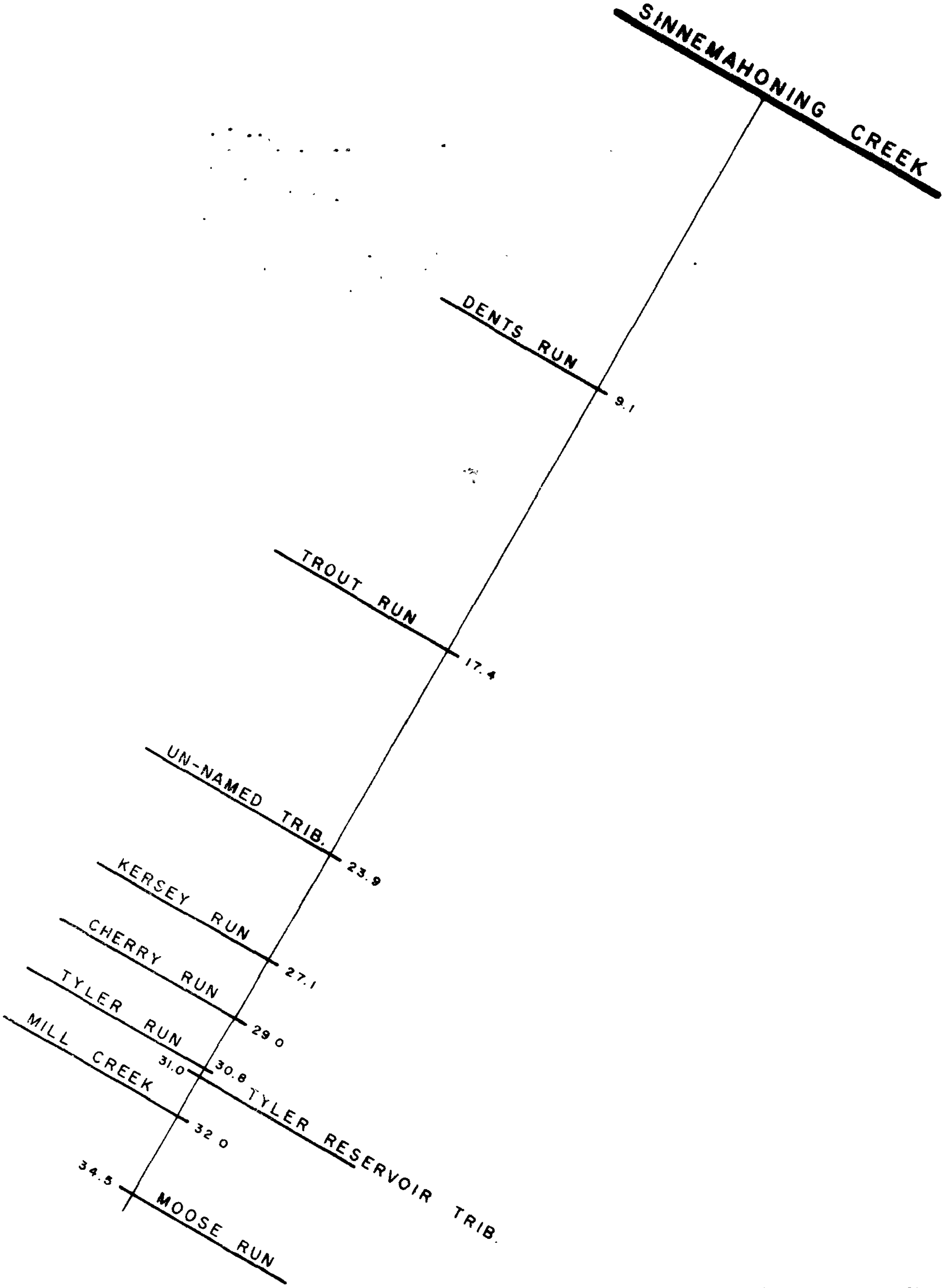

00.0 INDICATES RIVER MILES

BENNETT BRANCH

SCHEMATIC DIAGRAM OF STREAMS AFFECTED BY MINE DRAINAGE POLLUTION

A pollution abatement program would probably be centered around treatment measures similar to those used in other watersheds of the West Branch area. This is for two reasons: (1) the way the mines were developed makes abatement at the source difficult; and (2) the streams have low natural alkalinity which limits assimilative capacity. The estimated cost of a complete mine drainage pollution abatement program is 5.5 million dollars initially, with an annual cost of 800,000 dollars thereafter. There are some measures to consider for supplementing the pollution abatement methods discussed here. Facilities could be constructed to supply flow augmentation during low-flow periods for streams or for streams with excessive mine drainage discharges entering them. The George B. Stevenson Dam, which was constructed for flood control purposes, could serve as a flow augmentation facility as well. The impounded water, however, is low in natural alkalinity, which restricts its usefulness.

West Branch Susquehanna River--Sinnemahoning Creek to Bald Eagle Creek

The quality of the West Branch remains essentially constant in this reach from Sinnemahoning Creek to Bald Eagle Creek. Alkalinity added by numerous small tributaries is offset by mine drainage from a small area of intense mining activity near the mouths of Cooks Run, Milligan Run, and Kettle Creek. Crooks Creek receives mine drainage from Crawley Hollow Run, a major tributary of Cooks Run, about one mile from its mouth. The weak natural alkalinity of Cooks Run is overcome, and it is rendered acid so that about 8,000 lb/day net acidity is brought to the West Branch. Iron and manganese concentrations in Cooks Run are raised from essentially zero to the 20 to 30 mg/l range.

Milligan Run is highly acid (more than 400 mg/l) and bears high concentrations of other mine drainage indicators but has a relatively insignificant effect on the quality of West Branch. This is due to its low flow, which is less than 0.1 cfs during low-flow periods. Mine drainage originating in this watershed probably finds its way underground to the Cooks Run or Kettle Creek watersheds through abandoned deep mines.

Kettle Creek is the largest tributary to the West Branch in this reach, and it is the last downstream, direct source of mine drainage on the West Branch. Throughout most of its length, Kettle Creek flows through heavily forested land and is considered an excellent trout stream. In its lower two miles, its quality is degraded by mine drainage originating in the Two Mile Run watershed and discharges which enter directly.

The mine drainage renders the stream acid, overcoming a net alkalinity of frequently less than 15 mg/l, to produce a net acidity of about 25 mg/l at the mouth. Although this is a low concentration of acidity, it amounts to a loading of more than 30,000 lb/day net acidity under average flow conditions. Iron and manganese concentrations at the mouth are relatively low, which is partially the result of dilution.

A total of 66 discharges were located in the watersheds of the three streams. The area has been extensively mined by deep and surface mining methods. Due to disturbance of the surface by surface mining, it is difficult to determine the exact source of a number of mine drainage discharges and in some cases almost impossible to accurately measure the flow volume. It is probable, however, that most discharges originate in deep mines influenced by surface water diverted underground by surface mines.

The size and distribution of discharges in the area are slightly more uniform than for other sub-basins. Fourteen discharges of more than 1,000 lb/day net acidity each account for almost 30,000 lb/day net acidity, three-fourths of the total acidity from the sub-basin.

* * *

Since only a short reach of accessible tributary is involved, the greatest benefits would be realized if abatement were carried out in conjunction with comprehensive mine drainage abatement throughout the West Branch sub-basin.

The estimated cost of a complete pollution abatement program in the area is 4.1 million dollars initially, and 0.6 million annually. Because of the method in which the mines were developed, a completely effective program will probably include treatment.

The Pennsylvania Department of Forests and Waters is carrying out a limited surface mine restoration program on state forest land in the area. This program, however, will not have a significant effect on the total mine drainage contribution from the area.

North Bald Eagle Creek

North Bald Eagle Creek is responsible for neutralizing most of the acid load in the West Branch. Its contribution of 132,000 lb/day alkalinity is the largest single source of alkalinity; but the lower reaches of North Bald Eagle Creek are influenced by mine drainage from Beech Creek, a major tributary. Beech Creek is acid from its source to its mouth and contributes about 10,000 lb/day net acidity to North Bald Eagle Creek. Analysis of samples collected in 1967 shows dramatically the water quality effect felt from the geographic distribution of major discharges (Figures 8A and 8B). Mine drainage contributed to the North Branch of Beech Creek is partially assimilated by flows from the South Branch of Beech Creek and other smaller tributaries upstream from Sandy Run. Mine drainage originating in the Sandy Run watershed severely degrades stream quality. Downstream tributaries then gradually improve stream quality through the remaining distance to the mouth.

Under most natural flow conditions, the alkalinity in North Bald Eagle Creek is adequate to neutralize the acid contributed by Beech Creek. During periods of unbalanced rainfall and runoff in the sub-basin, high flows from Beech Creek have significantly reduced the alkalinity in North Bald Eagle Creek. Flow regulation by Blanchard Dam (a multi-purpose structure upstream from Beech Creek, to be in operation by the end of 1969) may worsen this condition. Flood control regulation by this dam will impound the high alkalinity water of North Bald Eagle Creek, while the acid-laden water from Beech Creek flows unrestrained into Bald Eagle Creek.

Mining conditions in the Beech Creek watershed are very similar to those in the nearby Clearfield and Moshannon Creek watersheds. Much of the watershed has been mined, both by surface and sub-surface methods. A total of 115 mine drainage discharges have been located in the watershed. Most add relatively small acid loads. Only four discharges with contributions greater than 1,000 lb/day net acidity were located. These discharges accounted for about 6200 lb/day net acidity, which is only about one-fourth of the acid contribution by all discharges located. The total acid contribution is 22,000 lb/day net acidity.

A combination of almost all abatement methods will probably be applicable in this sub-basin. Abatement work should have a high priority, since the reduction of acid loadings is needed to protect the quality of North Bald Eagle Creek during periods of unbalanced stream flow caused by natural conditions and by flow regulation by the Blanchard Dam.

It is estimated that a complete pollution abatement program in the watershed will cost four million dollars and will have an annual cost thereafter of about 500,000 dollars.

The Pennsylvania Department of Mines and Mineral Industries is presently sponsoring a study to develop a least-cost program for pollution abatement in the sub-basin. The Beech Creek watershed is the largest one studied in this detail to date in Pennsylvania. Completion of the work will make the sub-basin a likely site for pollution abatement under the state conservation bond issue.

Blanchard Dam will probably be the key to any program of flow regulation for water quality control in the lower West Branch Susquehanna River, if it is used for this purpose. The high alkalinity of the impounded water (110 mg/l) makes it by far the most promising source of "stored alkalinity" in the basin.

West Branch Susquehanna River--North Bald Eagle Creek to the Mouth of the West Branch

The quality of the West Branch changes significantly in this reach, primarily in response to the alkalinity brought to it by the North Bald Eagle Creek (Figures 3A and 3B). Its 132,000 lb/day net alkalinity loading enters the West Branch at Mile 68 and contributes most of the alkalinity required to neutralize the acid load. Other major alkaline tributaries in the reach between Mile 68 and Mile 40 (Williamsport) include Pine Creek, Larry's Creek, Lycoming Creek, and Antes Creek. There has been some mining on Pine Creek and Loyalsock Creek, but these operations cause only localized pollution problems.

During unusual flow conditions, i.e., when acid loadings in the West Branch are proportionately greater than the alkalinity loadings in North Bald Eagle Creek, acid conditions extend downstream from Williamsport even as far as the mouth. This is frequently associated with heavy autumn rains in the Clearfield and Moshannon watersheds while correspondingly little rain is falling in the North Bald Eagle Creek watershed.

In the Pine Creek watershed, intense mining in the headwaters of Babb Creek has produced drainage which degrades the quality of Babb Creek from source to mouth. Twenty-eight discharges have been located in the watershed, and the total acidity contributed is 14,800 lb/day. Essentially, all of the significant discharges originate in abandoned deep mines. Six of these discharges are responsible for about three-quarters of the total acidity, and all but one of the discharges originate in deep mines.

Babb Creek is weakly acid at its confluence with Wilson Creek, which adds an acid loading of about 4,000 lb/day. Despite alkalinity from Stony Fork and other tributaries, Babb Creek remains mildly acid from Wilson Creek to its mouth. Because of its relatively small flow and low acid loading, it has no significant effect on the quality of Pine Creek.

Concentrations of other mine drainage indicators in the streams of the Pine Creek sub-basin are not significantly affected by mine drainage. Iron and manganese concentrations in Babb Creek, for example, are less than 1.0 mg/l throughout its length.

Loyalsock Creek is an alkaline stream at its mouth and bears no significant evidence of mine drainage indicators throughout most of its length. It does, however, receive mine drainage from abandoned mines in an isolated, semi-anthracite deposit in its headwaters.

Two drainage tunnels near the Village of Lopez (Figure 1A) discharge a total of 6 cfs of mine drainage with a net acidity loading of 2,000 lb/day. The addition of this acidity to the stream, which has a low, natural alkalinity, causes degradation for approximately eight miles downstream.

* * *

Pollution abatement in the Babb Creek watershed will require the same methods as those discussed for areas where drainage originates in deep mines. Two principal factors, however, indicate emphasis on treatment: (1) the abandoned mines range from 100 feet to less than 50 feet below the ground surface. This will make it extremely difficult to limit surface water infiltration to the mine; (2) the significant discharges are generally low in iron, manganese, and other mine drainage indicators. Thus, neutralization can be carried out with low sludge-handling costs. In-stream neutralization might even be feasible. The estimated cost of a complete pollution abatement program is 1.7 million dollars initially, with an annual cost of 300,000 dollars.

In the Loyalsock Creek watershed, low concentrations of mine drainage indicators and a tunnel system which conveys all mine drainage to one location make it probable that treatment will be used extensively. Since all of the mining has been abandoned, inundation might be applicable in addition to the more universally used measures discussed previously. Another method that might be considered is removal of all the remaining coal by surface mining. Restoration of the stripped area would probable abate the discharges. Pollution abatement in the watershed is estimated at 400,000 dollars initially, and at about 100,000 dollars annually.

A relatively low cost program to abate the small acid loadings would have a great effect upon stream quality in both the Pine and Loyalsock watersheds.

J U N I A T A   R I V E R   B A S I N

AREA DESCRIPTION

The Juniata River is 86 miles long, with a drainage area of 3406 square miles. It is formed by the junction of the Little Juniata River and Frankstown Branch Juniata River in Huntingdon County, 3.5 miles southeast of Huntingdon, Pennsylvania. The stream meanders easterly to its confluence with the Susquehanna River (Figure 1B).

Virtually the entire Juniata River Basin lies within the Ridge and Valley Province. This area is characterized by alternate long ridges and valleys which generally run southwest to northeast. The ridges in the western part of the basin are steep and rugged, while the eastern part is considerably more rolling in character. A small area of the western edge of the basin drains a part of the Appalachian Plateau Province. Extremes in elevation range from 340 to 2900 feet above mean sea level.

Forests cover approximately two-thirds of the watershed, with the remainder devoted to farming which is restricted mostly to the lower, more fertile valleys. Coal fields influencing stream quality are located in the southwestern portion of the watershed in Blair, Huntingdon, Bedford, and Fulton Counties. The largest coal deposit in the watershed is the Broad Top Coal Field, located in portions of Bedford, Huntingdon, and Fulton Counties. This field, which is approximately 81 square miles in area, lies in a highly dissected plateau known as Broad Top Mountain, east of the Allegheny Mountains. It is totally isolated from the main bituminous coal fields. The largest portion of the coal deposit and major coal producing area lies in the northeast corner of Bedford County. The remainder of the field lies in the southern end of Huntingdon County with an extension into the northwest corner of Fulton County. A small portion of the main bituminous coal field lies within the watershed on the western edge of Blair County along the eastern slope of Allegheny Mountain.

The production of bituminous coal is an important industry in the Juniata Basin, although no longer a major one. The first mining in the area occurred during the Revolutionary War when coal was mined for home use. The first commercial shipments were made in 1853, reaching a peak production of approximately 2.7 million short tons in 1918. By 1964, coal production had diminished to about 400,000 short tons.

Projections of production in the Juniata Basin are as follows:

1970 - 490
1985 - 780
2020 - 1520
(In thousand short tons) (6)

Reserves of coal have been estimated at 215 million short tons, of which approximately 129 million short tons are recoverable. Data collected in August 1965 indicate that mine drainage is discharged into four major tributaries of the Juniata River. The Little Juniata and Frankstown Branch are influenced primarily by active and abandoned mining operations along the eastern slope of Allegheny Mountain in western Blair County. The Raystown Branch and Aughwick Creek receive mine drainage originating in the Broad Top Coal Field.

Little Juniata River

Mining activity in the sub-basin has been limited almost exclusively to the Bells Gap Run watershed which has been extensively deep and strip mined.

Samples of the Little Juniata River upstream from its confluence with Bells Gap Run indicate an initial net alkalinity of 100 mg/l. This is accompanied by a low level of mine drainage indicators. Bells Gap Run, despite mine drainage contributions, exhibits very little evidence of mine drainage indicators at its mouth and contributes an alkaline loading of approximately 170 lb/day to the Little Juniata River.

* * *

Pollution abatement in this watershed will require extensive restoration of the areas disturbed by surface mining. Since the stream is used as a source of public water supply, it may prove economically feasible to provide demineralization treatment facilities, which will produce a high quality water suitable for use as a public water supply.

The Frankstown Branch exhibits an alkaline reserve of about 110 mg/l at its confluence with the Little Juniata. However, it contains significant levels of iron and hardness which are mine drainage indicators.

The major recipient of mine drainage contributors is the Beaver Dam Branch. Despite this influence, it contributes approximately 3,000 lb/day net alkalinity. The major sources of mine drainage to the Beaver Dam Branch are Burgoon Run and Sugar Run.

Burgoon Run receives mine drainage from Kittanning Run and Glenwhite Run, small streams whose watersheds have been almost completely disturbed by surface mining. Kittanning Run is diverted around a public water supply reservoir serving the City of Altoona and enters Burgoon Run downstream from the reservoir. The flow of the upper reaches of Burgoon Run and the normal flow of Glenwhite Run form the reservoir supply. During periods of high runoff, however, the flow of Glenwhite Run is also diverted to the by-pass.

Sugar Run has an acid loading at its mouth of 1,000 lb/day. Most of the acid originates in the discharge from one abandoned deep mine.

* * *

Pollution abatement activities should be directed toward producing suitable water for public use. Altoona is in serious need of additional water, and treatment of the mine drainage normally diverted around the reservoir would add appreciably to the City's supply. Ion exchange, or some other process which produces a high quality product, would be the most desirable treatment process.

Since one discharge is the primary source of pollution in Sugar Run, surface water control and treatment appear to be the most applicable abatement methods.

Pollution abatement costs are estimated at five million dollars initially, with an annual cost of 500,000 dollars.

Raystown Branch Sub-basin--Juniata River

Mine drainage in the Raystown Branch originates in the Broad Top Coal Field and is conveyed to the Raystown Branch by Longs Run, Six Mile Run, Shoups Run, and Great Trough Creek. East of the first three is acid from source to mouth. Great Trough Creek is weakly acid throughout its length in the coal fields, but tributaries neutralize the acid load and provide an alkaline reserve of 200 lb/day at the mouth. Concentrations of iron, manganese, and other mine drainage indicators are extremely low throughout its length.

The three acid streams contribute the following acid loading to the Raystown Branch:

Longs Run	- 5600 lb/day net acidity
Six Mile Run	- 2800 lb/day net acidity
Shoups Run	- 3200 lb/day net acidity

Despite the sizable acid contributions, the alkaline reserve of Raystown Branch upstream (42,000 lb/day) is more than ample to assimilate the acid (Figures 9A and 9B). The Raystown Branch downstream from the coal fields exhibits essentially no evidence of the mine drainage loading.

Water quality in the three acid streams is generally similar. They have a pH less than 4.5 and elevated concentrations of manganese, sulfate, hardness, and other mine drainage indicators. Iron concentrations in Shoups Run are normally less than 1.0 mg/l; while in Longs Run and in Six Mile Run, mean concentrations exceed 10 mg/l.

Most of the discharges located in the tributary watersheds originate in deep mines. A significant amount of surface mining has taken place in the basin; however, and its major influence is diversion of surface water into deep mines.

Thirty-nine discharges totaling 16,000 lb/day net acidity have been located so far, but location and characterization have not been completed. One discharge to Soups Run at Dudley contributes almost one-third of the total acid discharged into the watershed. The discharge receives drainage from an extensively mined area in the Trough Creek watershed. This inter-watershed diversion accounts in part for the relatively good quality of Great Trough Creek despite the extensive deep and strip mining carried out in the watershed.

* * *

In view of the slight damage to water quality in the Raystown Branch, resulting from discharges to these creeks, abatement programs might include conveying a portion of the mine drainage directly to the Raystown Branch itself. In addition, conventional methods such as treatment and surface reclamation might also be used.

Aughwick Creek

A small percentage of the Broad Top Coal Fields lies in the Aughwick Creek watershed. Roaring Run, a tributary of Sideline Hill Creek, which in turn is tributary to Aughwick Creek, is the only contributor of mine drainage in the watershed. With its acid loading of about 750 lb/day, Roaring Run degrades with quality of Sideling Hill Creek. Alkalinity contributed by other tributaries enables Sideling Hill Creek to recover from the acid loading and have an alkaline reserve at its mouth.

* * *

Most of the mine drainage to Roaring Run originates in one discharge, and abatement of pollution at this source would reclaim several miles of otherwise unpolluted streams. Pollution abatement is estimated to cost 400,000 dollars initially, and 70,000 annually.

T I O G A R I V E R

AREA DESCRIPTION

The Tioga River originates in Armenia Township in western Bradford County. Its drainage area (within Pennsylvania) covers 690 square miles and lies in portions of Potter, Tioga, and Bradford Counties. The stream is 58 miles long, 45 miles of which are in Pennsylvania. It flows in a southwesterly direction into Tioga County near Blossburg, Pennsylvania, and thence in a northerly direction to join the Chemung River in New York State (Figure 1C).

Located within the Allegheny Plateau physiographic province, the basin is characterized by broad valleys and steep, rounded hills. Shale and sandstone, along with coal in the upper portion of the area, are the dominant geologic formations. Most of the stream channels are bordered by wide, alluvial flood plains containing deposits of glacially derived boulders and gravel. Coal deposits are located in the extreme headwaters of the stream and are contained in a canoe-shaped, synclinal basin, underlying the watersheds of Morris Run, Coal Creek, Bear Creek, and Johnson Creek.

Historically, bituminous coal mining was the primary industry in the area. Mining activity began in the 1840's, reaching a maximum production of approximately 1.4 million tons in 1886. Production has since declined to a level of approximately 400,000 tons in 1964. Prior to World War II, all mining was conducted by deep mining methods. During and after the war, strip mining became dominant. Approximately 80 percent of the coal is now mined by this method. Projections of bituminous coal production for the Tioga River Basin are:

1970 - 360
1985 - 460
2020 - 660
(In thousand short tons) (6)

Reserves of coal have been estimated at a total of 41 million short tons, with approximately 16 million short tons considered recoverable (5).

A reconnaissance and sampling program was conducted during September and October 1965, and supplementary sampling has been done since that time. The results indicate that the quality of the Tioga River above its confluence with Morris Run is not significantly affected by mine drainage. In fact, the stream is classified as a trout stream by the Pennsylvania Fish Commission. Below this point, however, and for a distance of more than 30 miles, the stream is rendered acid by mine drainage from the watersheds of Morris Run, Coal Creek, Johnson Creek, and Bear Creek. Tributaries succeed in neutralizing the acid load downstream from the Cowanesque River. Biological studies indicate mine drainage inhibits aquatic life downstream to its confluence with the Canisteo River, an additional nine miles.

The Corps of Engineers is planning two multi-purpose dams at the confluence of Crooked Creek and the Tioga River. The dams will impound both streams in separate reservoirs. Mine drainage into the Tioga River will limit uses of the Tioga impoundment. The mean net acidity at the dam sites is 100 mg/l. Iron and manganese concentrations are 2.1 and 3.7 mg/l, respectively; the pH ranges from 2.9 to 5.7.

Johnson Creek

Although Johnson Creek contributes a weakly alkaline loading to the Tioga River, it receives mine drainage from abandoned surface and sub-surface mines near the Village of Arnot, about four miles from its mouth. Mine drainage in the Arnot area overcomes the stream's alkalinity for a short distance. Concentrations of mine drainage indicators are low, however. Two discharges with a total acid loading of 300 lb/day are the major mine drainage sources.

* * *

A limited program of treatment and surface reclamation would probably improve water quality substantially. Cost and benefits associated with abatement are insignificant when compared with those for abatement in other sources in the Tioga River Basin.

Morris Run, Coal Creek, and Bear Creek

Although these three streams constitute individual sources of mine drainage to the Tioga River, they overlie a common coal deposit. Underground and surface mining diverts surface and ground water from one watershed to another; for this reason, they are discussed together.

The total acidity from the three streams exhausts the Tioga River's rather weakly alkaline reserve and produces an acid residual of 15,500 lb/day downstream from Bear Creek (Figures 10A and 10B). The mean net acidity concentration downstream from Bear Creek is 180 mg/l; mean iron and manganese concentrations are 16 and 4.9 mg/l, respectively. Other mine drainage indicators are proportionately high.

The quality of each stream is essentially uniform from source to mouth. All have acidity concentrations of 500 to 1,000 mg/l, iron concentrations of 20 to 100 mg/l, and manganese concentrations of 20 to 50 mg/l. Morris Run receives mine drainage from two major as well as approximately 20 minor sources. Most of the drainage originates in abandoned, deep mines; however, their flow is influenced by drainage from strip mines, some of which lie in the Coal Creek and Bear Creek watersheds. Mine drainage in the Coal Creek and Bear Creek watersheds comes from many major discharges draining abandoned surface and sub-surface mines.

* * *

Abatement work will involve an extensive program of surface reclamation and treatment. The estimated initial cost is 6.8 million dollars, and the annual cost will be about 700,000 dollars.

Since the streams will not have a continuous flow if mine drainage discharges are abated, abatement should be directed towards protecting the quality of the Tioga.

The coal measures are isolated from the main bituminous field and cover an area of only about ten square miles. Abatement here could be done without involving a large geographical area. The extensive degradation of the Tioga River and the effect on uses of water to be impounded by the Tioga River Dam should give the area a high priority for future abatement.

Since the Tioga River joins Crooked Creek downstream from the Tioga River Dam, discharges from the two dams should be scheduled to take full advantage of the neutralizing capacity of Crooked Creek.

ANTHRACITE REGION

AREA DESCRIPTION

Anthracite coal deposits in Pennsylvania lie in four individual fields in Northeastern Pennsylvania (Figure 1D). The coal fields underlie an area of 484 square miles and are designated as the Northern Field, Western Middle Field, Eastern Middle Field, and Southern Field. All of the Northern Field lies within the Susquehanna River Basin. Approximately 50 percent of the Eastern Middle Field, 90 percent of the Western Middle Field, and 40 percent of the Southern Field drain into the Susquehanna River Basin. The remainder of the fields drain to the Delaware River.

Major streams in the Susquehanna River Basin draining the anthracite area are listed below.

Name	Drainage Area (square miles)	Mile Point of Confluence
Lackawanna River	346	195
Nescopeck Creek	172	159
Catawissa Creek	155	143
Shamokin Creek	138	122
Mahanoy Creek	155	112
Mahantango Creek	164	102
Wiconisco Creek	116	96
Swatara Creek	567	60

The anthracite area lies entirely within the Ridge and Valley Province of the Appalachian Highlands, the principal feature of which is a series of canoe-shaped valleys where the coal deposits are located. The ridges trend generally northeast to southwest with elevations varying from 1400 to 2700 feet.

All the rocks of the area are of sedimentary origin and are, more specifically, of the Paleozoic Era. They belong to the Carboniferous, Devonian, and Silurian Systems except one formation of the Ordovician System. The Carboniferous System is subdivided into the Lewellyn (Post-Pottsville) and Pottsville Formations.

While several anthracite beds are found in the Pottsville Formation, the major production is in the Lewellyn Formations. These formations consist of sandstone, shale, fireclay, black carbonaceous slate, and beds of coal ranging from seams several inches thick to the Great Mammoth bed which has a thickness, in some places, exceeding 60 feet. The anthracite-bearing formations contain 12 to 26 potentially productive coal beds separated by intervening shale, sandstone, and conglomerate.

In the Northern Field, coal deposits are in a canoe-shaped syncline with a flat bottom and steep sides outcropping along the mountain ridges. The field is about 62 miles long and five miles wide at its broadest point and covers an area of approximately 176 square miles.

At Ashley, south of Wilkes-Barre, the coal measures reach a depth of 2100 feet and contain 18 workable strata with a combined thickness of about 100 feet. A structural saddle, called the Moosic Saddle near Old Forge, Pennsylvania, separates the Northern Field into two coal basins: the Lackawanna and the Wyoming.

The Eastern Middle Field is approximately 33 square miles in area and consists of a number of long, narrow coal basins that trend east and west. These coal basins are separated by members of the Pottsville conglomerate which contains no anthracite. Most of the deposits lie above surface drainage level and are drained by tunnels driven expressly to provide gravity drainage to surface streams. Numerous mine openings, slopes, drifts, and short tunnels also provide drainage.

The Western Middle Field is a series of parallel, irregularly shaped coal basins covering an area of approximately 120 square miles. The Field, about 42 miles long and from two to five miles wide, contains strata which lie nearly horizontal or pitch steeply according to the location. Deposits resemble those in the Eastern Middle Field, except that most of the deposits lie below surface drainage level and are now flooded.

The Southern Field, about 70 miles long and from one to six miles wide, covers an area of about 200 square miles. The Field is a series of basins extending from the Lehigh River Valley on the east almost to the Susquehanna River on the west. The geologic structure here is more complicated than in the other fields. Dips of the synclines and anticlines are much steeper than elsewhere and mining conditions are difficult. The largest tonnage of anthracite reserve lies in this field.

Approximately 95 percent of the Nation's true anthracite lies in the watersheds of the Susquehanna and Delaware Rivers. This is the "hard coal" of commerce which has found its greatest use as a domestic and industrial fuel. Since 1808, the anthracite industry has shipped over five billion tons of clean coal. Peak production was slightly more than 100 million tons (2). Production has decreased gradually to a low of about 16.5 million tons in 1964. Production during the period 1962-64 was only 75 percent of that during the 1946-48 period. Strip and underground mining production declined by 33 percent and 83 percent, respectively.

Projected Anthracite Production

	(thousands of short tons)		
	1970	1985	2020
Susquehanna Basin	5900	3200	2500
Delaware Basin	5300	4200	9500

Anthracite coal reserves within the Susquehanna River Basin have been estimated at 8.2 billion short tons. Economically recoverable reserves are estimated at 1.6 billion short tons (5).

Lackawanna River

Changes in mining activity and mine drainage discharge points have greatly altered the quality of the Lackawanna River within the past ten years. Prior to 1960, extensive mining with associated mine drainage discharges severely degraded stream quality. Declines in demand for anthracite coal, the cost of pumping the high volumes of water encountered, and other circumstances gradually forced the abandonment of most of the deep mines. Cessation of mine water pumping results in a very significant increase in stream alkalinity although some mine drainage influence persists.

In January 1961, the pools of water developing in the abandoned underground workings broke through to the surface in a gravity discharge to the Lackawanna River at Duryea, approximately two miles from its mouth. This was the largest discharge in the Anthracite Field and has been since separated into two parts; the "Duryea Gravity Discharge" and the discharge from a borehole at Old Forge. The borehole was drilled one mile upstream from Duryea to stabilize the level of the underground pools. The combined discharges have an average flow of 58 mgd, a net acid load of approximately 132,000 lb/day, and an iron load of approximately 62,000 lb/day.

Most of the mine water in the Lackawanna River comes to the surface through the Duryea and Old Forge discharge points. Water quality in the river is also influenced, however, by other mine drainage discharges (Figures 11A and 11B).

The initial effect of mine drainage is felt immediately above Carbondale and downstream from Elk Creek. Based on an acidity-alkalinity balance, this reach of the Lackawanna River receives a net acid loading of at least 1,000 lb/day from two deep mines on Elk Creek. Between Carbondale and Old Forge, the river receives mine drainage from the Jermyn Water Tunnel, which contributes approximately 5500 lb/day net acidity.

Between the entry of the Jermyn discharge and the confluence with the Susquehanna River, the Lackawanna River receives the Duryea and Old Forge discharges as well as a number of smaller discharges. These overcome the stream's residual alkalinity and are primarily responsible for the acid loading of 47,000 lb/day net acidity. The Lackawanna River discharge does not deplete the Susquehanna River's alkalinity reserve; however, iron loadings originating in the Duryea and Old Forge discharges are responsible for substantial degradation of the Susquehanna River.

At its mouth, the pH of the Lackawanna River is generally between 4 and 6. The acidity concentration is about 150 mg/l, and iron and manganese concentrations are normally in the 50 mg/l and 10 mg/l range, respectively (Figures 11A and 11B).

* * *

Because of the vastness of the underground workings and the large area disturbed by surface mining in the sub-basin, reclamation work alone will not make for a completely effective abatement program. This work is needed, however, to reduce the amount of surface water diverted to the underground mine workings. Other measures such as treatment or conveyance are also needed.

A preliminary study has been made on the feasibility of combining the Duryea and Old Forge discharges and providing lime neutralization treatment. The cost of collection and treatment is estimated to be 4.3 million dollars initially, with annual costs of 760,000.

Surface reclamation to limit infiltration of water to mine pools would reduce treatment costs. Maintaining surface flow would have the added advantage of assuring high stream flows and increasing the capacity to assimilate mine drainage and other potential discharges. It is not likely that a significant amount of additional flow augmentation can be provided by surface impoundments, since most of the available sites are used to capacity for public water supplies.

Susquehanna River--Lackawanna River to Nescopeck Creek

During the sampling period the quality of the Susquehanna River was degraded from the Lackawanna River to the Nescopeck by the poor quality of the water from the Lackawanna and discharges in the Wyoming Valley portion of the Northern Anthracite Field. Streams carrying mine drainage from the Wyoming Valley include Mill Creek, Solomons Creek, Warrior Run, Nanticoke Creek, and Newport Creek. They conveyed discharges from pumping stations at active deep mines and abandoned ones in which the surfaces were maintained at constant levels to prevent the water from entering the active mines. The active operations pumping significant amounts of acid to the Susquehanna are operated by the Blue Coal Company. Pumps stabilizing the pool levels in abandoned mines were purchased with funds provided in conjunction with an 8.5 million dollar Joint Federal-State Anthracite Mine Water Control Program in 1955.

Total flows of pumped discharges averaged 62 mgd; the net acid averaged 361,000 lb/day; and the iron loading averaged 134,000 lb/day.

Although the river received sizable acid from the pumped discharges, its alkaline reserve was not seriously threatened (Figure 12A). Other indicators, particularly manganese and sulfates, were present, however, in relatively high concentrations.

From Mile 196, upstream from the Lackawanna, to Mile 179, which is downstream from all significant sources in the Northern Anthracite Field, there was a significant reduction in alkalinity and increases in other indicators. Alkalinity dropped from about 84 mg/l to 38 mg/l. Iron, manganese, and sulfates increased from 0.1, 0.09, and 30 mg/l to about 0.3, 1.5, and 190 mg/l, respectively. Iron concentrations in this reach were abnormally low. Other data indicate that the increase in iron concentrations and other mine drainage indicators through the reach is considerably more dramatic under other flow conditions.

In October 1967, the Blue Coal Company began to phase out pumping operations at most of its operations, and by December 1967 only the pumps serving its Wanamie mining complex were operating. These pumps discharge an average of 86,700 lb/day net acidity and 17,600 lb/day total iron to Newport Creek. Discontinuation of pumping which abated about three-quarters of the acid discharged and almost 90 percent of the iron loading is not a permanent solution to the area's mine drainage problem. The mines are gradually filling with water and, when the water reaches a level higher than normal river elevation, gravity discharges are likely to occur. When equilibrium conditions prevail in the water pools of the mine, the discharge volumes are likely to be only about 70 to 80 percent of the volume formerly pumped. The initial quality will be considerably poorer than when the mines were kept dewatered. The loading of mine drainage indicators discharged to the Susquehanna, therefore, may be even greater than during the survey period. The discharge points are likely to be near the Susquehanna River: probably Mill Creek, Solomons Creek, or even directly to the River in the Plains area north of Wilkes-Barre.

The last regularly sampled discharge in this reach is a gravity discharge from an isolated mine water pool at Mocananqua. It contributes approximately 6,000 lb/day net acidity and has no observable effects on the alkaline reserve of the Susquehanna River.

Downstream from the Nescopeck, stream quality rapidly improves. Other tributaries draining the anthracite area contribute mine drainage indicators, but do not significantly affect stream quality. Biological surveys show significant degradation of aquatic life in the reach from the Lackawanna to the Nescopeck and slight effect further downstream. Periodic degradation of stream quality downstream from the Nescopeck has occurred during periods of high stream flow following extended low flow periods. Iron salts which precipitate during low flow periods to form sludge upstream from Berwick are scoured out by the increased stream velocity and are evident all the way to the confluence with the West Branch of the Susquehanna River.

* * *

Pollution abatement will involve treating the equilibrium discharge from the pools as well as treating the discharge from the Wanamie complex, if it continues operating. Mine drainage flow can probably be reduced by surface reclamation. Some stream bed lining and flume construction across areas disturbed by subsidence or surface mines has been done with funds allocated to the Federal-State Mine Water Control Program; however, much remains to be done.

State agencies are developing plans to stabilize pool elevations at a specified level by pumping at strategic locations and providing for at least one gravity overflow. This method will prevent property damage which might otherwise result from flooding and surface subsidence which would occur if the mine pools reach equilibrium by themselves. It will also provide water of uniform quality and quantity, minimizing treatment costs. The plan, however, has the disadvantage of high pumping costs and of inundating less of the acid-forming material than if gravity discharges were permitted. The cost of a program to completely abate mine drainage pollution is about 12 million dollars initially and two million annually.

Since iron and not acidity is the most critical pollutant, flow regulation cannot be relied upon to reduce abatement costs. The cost of flow augmentation to dilute low flow iron concentrations would probably be more costly than abating iron to comparable levels by treatment facilities.

Nescopeck Creek

The results of a sampling program conducted during August and September 1965 indicate that the quality of Nescopeck Creek above its confluence with Little Nescopeck Creek is not significantly degraded by mine drainage. In fact, this ten-mile reach is classified as a trout stream by the Pennsylvania Fish Commission. Below the confluence, however, stream quality is degraded by mine drainage from Little Nescopeck Creek and Black Creek.

Initial water quality degradation is caused by mine drainage from Little Nescopeck Creek (Figures 13A and 13B). Approximately 7,000 lb/day net acidity from Little Nescopeck Creek overcomes Nescopeck Creek's natural alkaline reserve and renders it acid.

The Jeddo Tunnel is the only source of pollution to Little Nescopeck Creek: it is a gravity discharge point for a large area of abandoned deep mines in the Black Creek coal basin of the Western Middle Field. The tunnel discharges an average of 20 mgd with a net acid loading of 98,000 lb/day.

The mean acidity in Nescopeck Creek is 240 mg/l, and the mean iron and manganese concentrations are 6.5 and 8 mg/l, respectively, immediately downstream from the confluence with Little Nescopeck Creek. Stream quality improves through the 18 miles to the mouth. However, stream quality is still poor at the mouth. Although Black Creek brings sizable loadings of mine drainage indicators (acid load of 14,000 lb/day), the concentrations are less than those in Nescopeck Creek. The mixture of the two streams thus slightly improves the quality of Nescopeck Creek.

Black Creek receives essentially all of its mine drainage from the Gowan and Derringer Drainage Tunnels. In addition to mine drainage pollution, Little Nescopeck Creek and Black Creek receive coal silt from coal processing operations as well as surface runoff from piles of coal fines.

* * *

Three drainage tunnels that collect mine drainage from an extensive area are the primary sources of pollution. Treatment, therefore, will probably play a major role in pollution abatement. The structural stability of the tunnels may be such that seals can be constructed to inundate at least a portion of the abandoned mine workings to improve discharge quality. Seals would also make it unnecessary to provide surface facilities to convey and impound mine drainage flows which are greater than the treatment plant capacity.

Surface reclamation in the area overlying the workings drained by the Jeddo Tunnel would reduce significantly the surface water contribution to mine drainage flows. The estimated pollution abatement cost is 7.8 million dollars initially and 1.3 million dollars annually.

Pollution abatement benefit might be accomplished at a lower cost by conveying the mine drainage to a point further down on the Nescopeck or even to the Susquehanna River itself. Since most of the mine drainage originates in Black Creek watershed and is drained to Little Nescopeck Creek by the Jeddo Tunnel, pollution could be abated in Little Nescopeck Creek and eight miles of Nescopeck Creek by sealing Jeddo Tunnel and diverting the discharge to Black Creek. These measures, while perhaps slightly less costly than a program involving collection and treatment, would have no value in a comprehensive, basin-wide pollution abatement program and, consequently, should probably not be utilized.

Catawissa Creek

Catawissa Creek is an acid stream throughout most of its length. At a point approximately 38 miles from its mouth, the stream is normally alkaline, although bearing evidence of mine drainage, and it is diverted underground by an abandoned surface mining complex; this diversion completely disrupts surface drainage patterns. The stream then apparently flows through abandoned deep mine workings for a distance of approximately 4,000 feet, emerging at the Green Mountain Water Level Tunnel discharge. The stream bears a net acid load of about 150 lb/day and is further degraded, about three miles downstream, by about 24,000 lb/day net acidity from two drainage tunnels, Audenreid and Green Mountain. The stream never recovers from this heavy acid loading (Figures 14A and 14B).

Iron, manganese, and net alkalinity concentrations at most places are essentially equivalent to those in Nescopeck Creek. Sulfate concentrations are, however, about twice as great in Catawissa Creek as in Nescopeck Creek.

Tomhicken Creek, with its contribution of 1700 lb/day net acidity, constitutes the only other significant source of acid and mine drainage indicators. It does not, however, significantly degrade the quality of Catawissa Creek, since indicator concentrations are somewhat lower than those in the receiving stream. Most of the acid from Tomhicken Creek originates in the Cox #3 drainage tunnel, which contributes about 1200 lb/day net acidity.

Some active deep mining is being carried out in the sub-basin; however, most of the drainage originates in abandoned mines. Deep mining activity is expected to decline. No surface mine discharges were located, but surface mining has interrupted surface drainage in large areas and adds appreciably to the mine drainage flow.

Although all of the known discharges enter the Catawissa in the upper third of its length, the weak natural alkalinity and relatively small flow of downstream tributaries are not adequate to neutralize the heavy acid loadings entering at the headwaters. Catawissa Creek brings approximately 18,500 lb/day net acidity to the Susquehanna River. This loading is about 80 percent of the largest single source, the Audenreid Drainage Tunnel.

Unlike many of the streams in the anthracite area, Catawissa Creek is not significantly influenced by coal silt. This is probably because there are no active coal processing operations in the sub-basin.

* * *

A comprehensive pollution abatement program in the sub-basin will involve restoration of surface drainage, reclamation, mine flooding, and probably treatment. Treatment of the Audenreid discharge would provide an immediate benefit by restoring the alkalinity in Catawissa Creek to an alkaline condition, although its quality would be degraded by other mine drainage and sewage discharges.

Pollution abatement methods and costs for the drainage originating in Green Mountain Water Level Tunnel and the Cox #3 drainage tunnel were studied by the consultant. The recommended program involves inundating the entire coal deposit by sealing the three drainage tunnels, then treating the overflow at a new discharge point. Surface reclamation measures in the extensively disturbed area overlying the coal deposit is not considered feasible from an economic standpoint. The recommended program did include restoration of surface flow in Catawissa Creek upstream from the Green Mountain Water Level Tunnel. The first cost of the program in the area studied by the consultant is an estimated 1.8 million dollars. The annual cost would be 300,000 dollars.

Conditions in the remainder of the sub-basin are somewhat different, and complete inundation of the mine workings probably will not be possible. Surface reclamation measures and treatment will be the basis of pollution abatement at the Cox #1 and Audenreid Tunnels. The total pollution abatement cost for the watershed is an estimated 6.2 million dollars initially and 900,000 dollars annually.

Shamokin Creek

Shamokin Creek is an acid stream throughout 28 miles of its 35-mile length. The remaining seven miles (the extreme headwaters) are alkaline, but have high concentrations of mine drainage indicators, particularly iron and manganese. Downstream from Mile 29, the stream is rendered acid by mine drainage from the North Branch Shamokin Creek and the Excelsior Drainage Tunnel (Figures 15A and 15B). Although the stream's acidity decreases uniformly from about 200 mg/l, at this point, to about 100 mg/l at the mouth, the acid loading increases from about 9,000 lb/day net acidity to about 35,000 lb/day. During the survey period, iron concentrations reached a peak of 147 mg/l at Mile 23 and then declined to less than 20 mg/l at the mouth. Mean manganese concentrations ranged from 6 mg/l to 3 mg/l, and sulfate concentrations ranged from 470 mg/l at Mile 22 to 430 mg/l at the mouth.

In the Shamokin Creek sub-basin, all seven major discharges enter in the upper one-third of the stream. All discharges originate in underground mines, although they are undoubtedly influenced by surface water diverted underground in areas disturbed by surface mining. The seven major discharges contribute 28,000 lb/day net acidity.

Discharges that originate from both active and inactive mines reach the surface by gravity or pumping. One of the largest discharges is a pumped discharge from the Glen Burn Colliery which contributes more than 5200 lb/day net acidity. Two large discharges were found bringing more than 5500 lb/day net acidity to the North Branch Shamokin Creek. The stream disappears underground a short distance downstream, however, and is believed to be a source of the Excelsior discharge.

In addition to mine drainage indicators, the stream is heavily laden with coal silt, much of which apparently originates at cleaning and processing operations in the sub-basin.

* * *

Because of the way in which mines were developed in the sub-basin, and because a significant amount of drainage originates in active operations, sealing will probably not play a significant role in abatement. Treatment and reclamation measures aimed at surface water control will probably be most effective in this sub-basin. The estimated cost of this program is 8.7 million dollars initially and 1.2 million annually.

The first step should be construction of surface water control measures to limit mine drainage flow. Restoration of flow in the North Branch Shamokin Creek should have high priority. Extensive surface disturbance upstream from the Excelsior discharge makes it unlikely that appreciable benefit can be realized from abatement in the foreseeable future. Treatment of the discharges downstream from this point, possibly supplemented by some in-stream treatment, will produce most of the water use benefits in the sub-basin. Treatment in the upstream portion could be undertaken in conjunction with a reclamation program designed to restore usefulness of the land.

Mahanoy Creek

Mahanoy Creek discharges a load of approximately 1,000 lb/day net alkalinity to the Susquehanna River but is one of the most severely degraded streams draining the anthracite area. A study carried out in July, August, and September of 1965 determined the source of pollution to be alkaline discharges containing high concentrations of iron, manganese, and other mine drainage indicators. Severely degraded quality was observed throughout the entire 52-mile length of the stream.

Mine drainage reaches Mahanoy Creek through the following tributaries: North Branch Mahanoy Creek, Waste House Run, Shenandoah Creek, Big Mine Run, and Zerbe Run. In addition, five large, deep mine discharges enter the creek directly.

The stream's natural alkalinity is overcome in its upper reaches (Figures 16A and 16B). This is primarily the result of an 800 lb/day net acidity from the East Barrier gravity discharge, a discharge of 4200 lb/day that is intermittently pumped from the Springdale tunnel, and by a 10,500 lb/day net acidity discharge from Waste House Run which originates predominately in pumped discharges.

Alkalinity from the combined Girardville discharges (drainage tunnels numbers one and two) and the Big Mine Run overcome the acid residual and increase the stream's alkaline reserve to a peak of approximately 15,000 lb/day downstream from Big Mine Run. This reserve steadily decays to a minimum of 1,000 lb/day at the mouth. Reductions in the alkaline reserves occur in response to acid contribution and to the oxidation of acid precursors from the large alkaline discharges. The largest acid contribution in the portion of the sub-basin downstream from Big Mine Run is Zerbe Run with its loading of 7900 lb/day net acidity. Zerbe Run receives essentially all of its acid loading from the Trevortown tunnel which discharges 12,000 lb/day.

Concentrations of mine drainage indicators vary along the length of the stream (Figure 16B). Mean manganese concentrations range from 3.0 mg/l to 110 mg/l. Sulfate concentrations range from 1050 mg/l to 1500 mg/l in nearly the entire length of the stream. Coal silt discolors the stream and practically chokes the channel in some places.

* * *

This sub-basin will be one of the most difficult in the anthracite area to provide with an abatement program. The reasons for this are the large area involved, the large number and variety of discharges to handle, as well as the quality differences among these discharges. Since a number of the major discharges originate in active mines, treatment will probably play a major role in a pollution abatement program. Mine drainage conveyance facilities may be applicable in combining acid and alkaline discharges. Surface water control should be utilized to the maximum.

Either ion exchange or distillation appears to be the most applicable for reducing the pollution characteristics of the alkaline discharges which also have high concentrations of other drainage constituents.

Since cost data are not available for the facilities to remove dissolved solids, only very rough estimates of abatement costs can be made. Capital and annual costs might be about nine million dollars and 2.5 million, respectively.

Mahantango Creek

Mahantango Creek is an acid stream through approximately 17 miles of its 32-mile length and contributes approximately 3500 lb/day net acidity to the Susquehanna River.

Essentially all of the mine drainage discharged in the Mahantango Creek sub-basin comes from the Rausch Creek watershed. This is a small tributary of Pine Creek which in turn is a tributary of Mahantango Creek.

Rausch Creek, with its acid loading of 5,000 lb/day net acidity, exhausts the alkaline reserve of Pine Creek at their confluence and renders it an acid stream for 13 miles to its mouth. The quality of Pine Creek is slightly improved by water from alkaline tributaries, the largest of which is Deep Creek. Although influenced by mine drainage from the Hans Yost Creek watershed, Deep Creek contributes a net alkaline loading of about 70 lb/day.

The residual acid loading of about 3,000 lb/day which reaches Mahantango Creek easily overcomes its weak alkaline reserve and renders it an acid stream to its mouth (Figure 17A). The portion of Mahantango Creek upstream from Pine Creek, although low in alkalinity, is generally of good quality. A biological reconnaissance in 1964 showed that this reach supports normal aquatic life.

Upstream from Pine Creek, Mahantango Creek is almost free of all mine drainage indicators and, in fact, has surprisingly low mineral content. For example, its mean sulfate concentration is 7 mg/l. Mean iron concentration is 0.4 mg/l, while no trace of manganese was found. Downstream from Pine Creek, stream quality is relatively constant. Iron and manganese concentrations are slightly less than 0.6 mg/l. Mean net acidity ranged between 35 and 45 mg/l (Figure 17B).

Mine drainage sources in the Mahantango Creek watersheds are not collected by drainage tunnels, although they are clustered in a relatively small area of the Rausch Creek watershed. Mine drainage in Rausch Creek comes from 22 known pumped discharges and ten gravity discharges. The largest gravity discharges are the Markson and Valley View. These two discharges are responsible for a total of 1600 lb/day net acidity.

* * *

Because of the large number of discharges and the large percentage of active operations in the sub-basin, pollution abatement in the immediate future can probably be done most cheaply by treatment. A treatment plant for the entire Rausch Creek flow would have been called upon to treat approximately 5 mgd during July of 1965. Although this was a low flow period, it indicates that the treatment plant required would not be exceptionally large. Low acidity concentrations and the generally low mineralization of the water indicate treatment will be relatively inexpensive because alkaline reagent needs will be modest and sludge volumes will be low. The estimated first cost of a pollution abatement program is 2.3 million dollars, and the annual cost is estimated at 200,000 dollars. A significant percentage of the mine drainage originates in active mines; therefore, public funds would not be required to finance the entire program.

This sub-basin should receive high priority in any limited abatement program. This is due to the great length of stream influenced by drainage from the Rausch Creek watershed, as well as to the low cost of treatment and the ease of collecting the polluted waters.

Wiconisco Creek

Wiconisco Creek contributes approximately 6,000 lb/day net alkalinity to the Susquehanna River. The major mine drainage sources are the Porter and Keefer drainage tunnels and Bear Creek which receives its mine drainage from two tunnels. All of the major discharges are located in the upper one-third of the stream's length. Alkalinity reserves in Bear Creek of 6,000 lb/day net alkalinity overcomes the effect of 900 lb/day net acidity from the Porter and Keefer tunnels (Figure 18A). Although iron, manganese, and sulfate concentrations in Wiconisco Creek are temporarily elevated by loadings from Bear Creek, about 25 miles of stream downstream from Bear Creek are of relatively good quality (Figure 18B). The summary of a biological survey of the stream reports essentially no aquatic life upstream from Bear Creek. Several species of clean water organisms were collected at the mouth, indicating at least partial recovery from the upstream loadings. Coal silt loadings in the Wiconisco are heavy. These apparently originate in coal washeries in the sub-basin.

* * *

Abatement work can be accomplished at relatively low cost because of the relatively small number, low volume, and low strength of major discharges. As in the Mahantango Creek sub-basin, low dissolved solids in the major mine drainage source suggest that treatment can be accomplished with minimum utilization of costly sludge disposal facilities. An abatement program using both surface water control and treatment would cost an estimated 3.2 million dollars initially and 500,000 annually. These costs might be reduced by providing an out-of-stream impoundment for blending acid and alkaline discharges to neutralize acid and precipitate iron salts. A parallel program aimed at abating sewage and coal silt pollution should also be undertaken.

Swatara Creek

Mine drainage renders this stream acid from its headwaters to its point of confluence with Mill Run, a distance of approximately 24 miles. Streams bringing significant amounts of drainage to it are Panther Creek, Good Spring Creek, and Lower Rausch Creek. Panther Creek contributes only 13 lb/day net acidity and does not significantly affect the alkalinity reserve of Swatara Creek (Figure 19A). It does, however, carry other mine drainage indicators.

The alkalinity reserve of Swatara Creek is affected by the contribution of 2,000 lb/day net acidity from Good Spring Creek. Most of the mine drainage in the Good Spring Creek watershed originates in the watershed of Middle Creek, a tributary which enters Good Spring Creek about one mile from its mouth. Lower Rausch Creek yields a net acid loading of 1300 lb/day, most of which originates in three drainage tunnel discharges.

The acid load in Swatara Creek reaches a peak of 3600 lb/day at Mile 58, immediately downstream from Lower Rausch Creek, and then declines in response to the influence of alkalinity in tributary streams.

Stream quality of the headwaters fluctuates rather weakly in response to small additions of mine drainage; mean iron and manganese concentrations are about 3.5 mg/l. Sulfate concentrations are normally less than 250 mg/l. Downstream from Mile 60, concentrations of all mine drainage indicators decline.

Considerable mining is being carried on throughout the sub-basin; however, most of the significant discharges originate in abandoned mines.

* * *

Pollution abatement in the sub-basin will involve essentially the same measures as those described for other sub-basins in the anthracite area. Inundation will probably be impractical because of the way the mines were developed and because some of the mines are still in operation. Mine drainage from an isolated coal deposit near Tremont and discharging to Good Spring Creek and Middle Creek was studied by a consultant (13). This area is responsible for about two-thirds of the acid entering Swatara Creek, and mining conditions are representative of the conditions in the remainder of the watershed. An abatement program based on the study recommends restoration and diversion of surface water at some of the unrestored strip mines; stream channel restoration and treatment are also recommended. It is estimated that the preventive measures could effect a 20 percent reduction in the acidity, iron loadings, and flow. The estimated

cost of the area is 2.4 million dollars initially, with an annual cost of 300,000 dollars. Pollution abatement in the entire Swatara watershed will cost an estimated 4.7 million dollars initially and 700,000 annually.

The Pennsylvania Department of Mines and Mineral Industries is carrying out a reclamation program on a portion of the Middle Creek watershed. Work recently completed prevents a small tributary of Coal Run from entering the underground mines and eventually emerging as a mine drainage discharge. The project will involve other areas disturbed by surface mining and will probably reduce significantly the loadings to Middle Creek by a large margin.

Plans are being developed by the Pennsylvania Department of Forests and Waters for a multi-purpose dam on Swatara Creek at Swatara Gap in a reach degraded by upstream drainage discharges. Abatement of most, if not all, of the major discharges will be necessary to assure that water quality in the impoundment will be consistent with the planned uses.

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A P P E N D I C E S

Table 1 - Water Use Damage Associated with Mine Drainage Pollution in Reaches of Individual Streams

River Reach	Stream	Av. Aug Flow cfs	Affected Reach Miles	Affected Reach Acres	Recreation and Aesthetics An $	Recreation and Aesthetics Weighted Points	M & I Water An $	M & I Water Weighted Points	Fish and Wildlife Fish Days An $	Fish and Wildlife Weighted Points	Agriculture An $	Agriculture Weighted Points	Waste Assim. Weighted Points	Corrosion Weighted Points	Total Damages An $	Total Damages Points
West Branch Susquehanna																
G	Upper West Br.	150	31	165	18,600	494.0	-------	39.8	5,800	494.0	2,500	296.4	24.7	74.1	26,900	1,423.0
	Chest	140	3	14	1,600	19.6	-------	19.6	3,000	29.4	-----	9.8	2.0	5.9	4,600	86.3
	Anderson	50	10	33	4,950	16.5	-------	-------	7,200	33.0	-----	8.3	1.7	5.0	12,150	64.5
	(L. Anderson)	12	6	5	750	0.5	-------	-------	1,100	1.2	-----	--------	0.1	0.1	1,850	1.9
H	West Branch[1]	350	21	1,100	650,000	9,250.0	-------	-------	34,600	7,700.0	-----	1,930.0	385.0	1,930.0	684,600	21,195.0
H-1	West Branch	400	12	250	33,000	2,000.0	35,000	1,250.0	8,000	1,500.0	-----	--------	100.0	500.0	76,000	5,350.0
	Clearfield	170	61	422	47,500	1,145.6	-------	-------	92,400	1,432.0	9,100	859.2	71.6	214.8	149,000	3,723.2
I	West Branch	550	37	897	134,500	10,040.0	-------	-------	31,400	7,530.0	-----	2,510.0	502.0	1,506.0	165,900	22,088.0
	Moshannon	100	52	292	43,800	467.2	21,000	70.3	63,900	438.0	-----	146.0	29.2	87.6	128,700	1,238.3
J	West Branch	650	22	900	120,000	9,360.0	-------	1,330.0	30,000	8,775.0	-----	--------	585.0	1,755.0	150,000	21,805.0
K	Sinnemahoning	300	16	485	54,600	24,080.3	-------	-------	106,200	24,080.3	500	1,746.0	145.5	436.5	161,300	50,488.6
	Bennett Branch	150	35	218	24,500	654.0	-------	-------	47,700	654.0	1,200	392.4	32.7	98.1	73,400	1,831.2
	Kettle	70	2	24	3,600	336.0	-------	-------	5,250	336.0	-----	--------	16.8	50.4	8,860	739.2
L	West Branch	900	45	1,942	306,300	41,952.0	280,000	1,940.0	70,000	26,220.0	-----	8,740.0	1,748.0	5,244.0	656,300	85,844.0
	Bald Eagle (Beech)	60	30	171	25,700	209.2	-------	-------	37,400	209.2	6,[illegible]00	125.5	10.3	31.4	69,900	585.6
	Pine (Babb)	10	20	65	9,750	13.0	-------	-------	14,200	13.0	2,400	7.8	0.7	2.0	26,350	36.5
	Loyalsock	10	6	14	2,100	3.4	-------	-------	3,100	2.8	-----	0.7	0.1	0.4	5,200	7.4
M	West Branch	1,600	16	880	144,000	28,200.0	-------	-------	31,000	28,200.0	-----	7,050.0	1,410.0	4,230.0	175,000	69,090.0
N	West Branch	2,500	30	4,000	250,000	100,000.0	-------	-------	125,000	100,000.0	-----	50,000.0	10,000.0	30,000.0	375,000	290,000.0
	Sub-Totals[1]		455	11,877		228,241.3		4,649.7		207,647		73,822.1	15,065.4	46,171.3		575,597.7
		Annual $			$1,875,250		$336,000		$717,260		$22,500				$2,951,010	

1 Includes Curwensville Reservoir Area

Table 1 Continued

River Reach	Stream	Av. Aug. Flow cfs	Miles	Acres	Recreation and Aesthetics		M & I Water		Fish and Wildlife		Agriculture		Waste Assim.	Corrosion	Total Damages	
					An $	Weighted Points	An $	Weighted Points	An $	Weighted Points	An $	Weighted Points	Weighted Points	Weighted Points	An $	Points
Tioga River																
D	Tioga[1]	25	20	763	198,000	458.0	-------	-------	13,600	458.0	29,500	229.5	19.1	95.6	281,100	1,260.2
E	Tioga	54	21	104	11,700	56.1	-------	-------	3,600	44.8	------	11.2	5.6	11.2	15,300	128.9
	Sub-Totals		41	867												
		Annual			$209,700				$17,200		$29,000		$40,000		$296,400	

1 Includes Tioga-Hammond Reservoir Area

Table 1 Continued

River Reach / Stream	Av. Aug. Flow cfs	Affected Reach Miles	Affected Reach Acres	Recreation and Aesthetics An $	Recreation and Aesthetics Weighted Points	M & I Water An $	M & I Water Weighted Points	Fish and Wildlife Fish Days An $	Fish and Wildlife Weighted Points	Agriculture An $	Agriculture Weighted Points	Waste Assim. Weighted Points	Corrosion Weighted Points	Total Damages An $	Total Damages Points
Juniata River															
Beaverdam Br.	32	3	4	600	2.0	------	---	300	2.0	----	------	0.1	0.4	1,500	4.5
(Burgoon)	2	1	1	---	---	21,000	0.1	---	---	----	------	---	---	21,000	0.1
(Sugar)	2	1	1	---	---	21,000	0.1	---	---	----	------	---	---	21,000	0.1
Bells Gap Run	4	1	1	---	---	35,000	0.1	---	---	----	------	---	---	35,000	0.1
Raystown Br.															
(Longs)	2	6	3	450	0.1	------	---	---	---	----	------	---	---	450	0.1
(Six Mile)	2	6	3	450	0.1	------	---	---	---	----	------	---	---	450	0.1
(Shoups)	2	7	6	700	0.1	------	---	---	---	----	------	---	---	700	0.1
(Great Trough)	4	5	2	300	0.1	------	---	400	0.1	----	------	---	---	700	0.2
Aughwick Cr.															
(Roaring Run)	2	7	3	450	0.1	------	---	---	---	----	------	---	---	450	0.1
Sub-Totals		37	24					$1,300						$81,250	
	Annual			$2,950		$77,000									

Table 1 Continued

River Reach	Stream	Av. Aug. Flow cfs	Affected Reach Miles	Affected Reach Acres	Recreation and Aesthetics An $	Recreation and Aesthetics Weighted Points	M & I Water An $	M & I Water Weighted Points	Fish and Wildlife An $	Fish and Wildlife Weighted Points	Agriculture An $	Agriculture Weighted Points	Waste Assim. Weighted Points	Corrosion Weighted Points	Total Damages An $	Total Damages Points
Anthracite Area																
	Lackawanna	127	31	174	19,600	530.4	-------	35.7	6,100	442.0	-----	-----	66.3	110.5	25,700	1,184.0
	Nescopeck	68	18	99	11,100	101.0	-------	-------	21,700	161.5	5,500	80.8	5.7	-------	36,300	350.0
	Little Nescopeck	15	6	14	1,600	3.2	-------	-------	3,100	3.2	-----	-----	0.2	-------	4,700	6.6
	Black	5	18	37	4,200	2.9	-------	-------	8,100	1.9	-----	-----	0.2	-------	12,300	5.0
A	Susquehanna	2,700	37	4,000	45,600	26,352.0	490,000	2,960.0	14,200	21,960.0	-----	-----	1,038.0	5,490.0	549,000	57,860.0
B	Susquehanna	2,700	14	1,500	10,000	4,050.0	-------	-------	3,000	4,030.0	-----	-----	405.0	2,025.0	13,000	10,530.0
	Catawissa	45	39	167	18,800	112.8	-------	-------	36,600	189.5	6,600	90.2	7.5	22.6	60,000	413.6
	Shamokin	100	35	135	15,200	270.0	-------	19.3	29,600	270.0	-----	67.5	13.5	40.5	44,800	680.8
	Mahanoy	50	52	224	25,200	168.0	-------	-------	49,000	201.6	-----	56.0	11.2	33.6	74,200	470.4
	Mahantango	40	17	108	5,000	64.8	-------	-------	5,700	64.8	-----	21.6	4.3	-------	10,700	155.5
	Pine	10	13	41	4,600	6.2	-------	-------	8,900	6.2	-----	-----	0.4	-------	13,500	12.8
	Wiconisco	35	12	26	[illegible]	13.7	-------	-------	[illegible]	3.1	-----	[illegible]	[illegible]	2.7	3,500	31.0
	Swatara[1]	30	30	410	250,000	295.2	203,000	51.4	[illegible]	295.2	1,200	147.6	[illegible]	21.5	474,000	397.8
	Sub-Totals		316	6,995		31,270.2		3,076.4		27,640.0		468.3	1,751.1	[illegible]		79,598.4
		Annual $			$415,900		$603,000		206,900		$13,300				$1,347,900	
SUSQUEHANNA RIVER TOTALS		Annual $			$2,501,600		$1,106,000		$242,700		$65,300			$40,000	$4,656,000	

1 Includes proposed Swatara Gap Reservoir Area

Table 2 - Influence of Tributary Mine Drainage Contributions on Successive Reaches of Receiving Stream[1]

Reach	Reach Limits	Acid Load at Lower End of Reach 1000 #/Day*	Principal Acid Sources	Acid Load From Each Source 1000 #/Day*	Effect on Receiving Reach %	Effect on Successive Downstream Reaches: Reach "H-1" %	Reach "I" %	Reach "J" %	Reach "L" %	Reach "M" %	Reach "N" %
West Branch Susquehanna River											
G	Upper West Branch to Chest Creek	53.5		53.5	100	70	24	15	13	12	12
H	Chest Creek to Curwensville Dam	61.8	From Reach G (Upper West Branch)	53.5	87						
			Chest Creek	8.3	13	11	4	2	2	1	1
H-1	Curwensville Dam to Clearfield Creek	76.2	From Reach H	61.8	81						
			Anderson Creek	7.3	10	--	3	2	2	1	1
			Other	7.1	9						
I	Clearfield to Moshannon Creek	225.8	From Reach H-1	76.2	33						
			Clearfield Creek	45.2	21	--	21	12	11	10	10
			Sandy Creek	10.0	5						
			Congress Run	11.4	5						
			Deer Creek	15.4	7	--	7	4	4	3	3
			Alder Creek	18.0	8						
			Other	49.6	21						
J	Moshannon Creek to Sinnemahoning	368.5	From Reach I	225.8	61						
			Moshannon Creek	135.2	37	--	--	37	32	30	30
			Other	7.5	2						
L	Sinnemahoning Creek to Bald Eagle	427.4	From Reach J	362.2	85						
			Sinnemahoning Creek	32.9	8	--	--	--	8	7	7
			Cooks Run	6.0	2						
			Kettle Creek	19.0	5	--	--	--	5	4	4
			Other	1.0	--						
M	Bald Eagle to Lycoming Creek	463.9	From Reach L	421.1	92						
			Beech Creek	21.7	5	--	--	--	--	5	5
			Babb Creek	14.8	3	--	--	--	--	3	3
N	Lycoming Creek to Mouth	463.9									
	Total percentage contribution, major source streams					81	59	72	77	76	76

1 Excluding minor tributaries to West Branch Susquehanna for which basic data are not adequate to permit consideration at this time.

Table 2 Continued

Reach	Reach Limits	Acid Load at Lower End of Reach* 1000 #/Day	Principal Acid Sources	Acid Load From Each Source* 1000 #/Day	Effect on Receiving Reach %	Effect on Successive Downstream Reaches					
						Reach "H-1" %	Reach "I" %	Reach "J" %	Reach "L" %	Reach "M" %	Reach "N" %
Susquehanna River											
A	Lackawanna River to Nescopeck Creek	288.6	Lackawanna River	146.6	51						
			Wyoming Valley	142.0	49						
B	Nescopeck Creek to Fishing Creek	367.4	Lackawanna River	146.6	40						
			Wyoming Valley	142.0	39						
			Nescopeck Creek	78.8	21						

* The acid load from the sources for each reach, Column 3, may not equal the acid load at the lower end of the reach because of alkaline loadings in the area.

Table 3 - Cost-Damage Comparisons

Watershed	Individual Program An. $ ($ 1000)	Individual Program Wtd Pts (1000)	Comprehensive Program An. $ ($ 1000)	Comprehensive Program Wtd Pts (1000)	Annual Costs Total ($ 1000)	Damage-Cost Analysis: Individual Program Damage Cost Units ($)	Damage-Cost Analysis: Individual Program An Cost Wtd Pts ($/Pts)	Damage-Cost Analysis: Comprehensive Program Damage Cost Units ($)	Damage-Cost Analysis: Comprehensive Program An Cost Wtd Pts ($/Pts)	Sub-Basin Rankings: Individual Program Highest Damage Cost Ratio	Sub-Basin Rankings: Individual Program Least Cost/Point	Sub-Basin Rankings: Comprehensive Program Highest Damage Cost Ratio	Sub-Basin Rankings: Comprehensive Program Least Cost/Point
WEST BRANCH SUSQUEHANNA RIVER													
Upper West Branch	620.9	19,823	975.9	108,614	2,040	0.305	0.103	0.479	0.019	4	4	2	6
Chest Creek	95.2	2,881	143.9	12,514	379	0.251	0.131	0.379	0.030	5	5	5	9
Anderson Creek	14.0	66	59.2	9,292	158	0.089	2.4	0.374	0.017	11	14	6	4
Clearfield Creek	149.0	3,720	399.1	74,800	1,625	0.091	0.439	0.245	0.022	10	6	8	7
Deer Run	-----	------	84.1	22,300	276	-----	-----	0.304	0.012	--	--	7	2
Moshannon Creek	128.7	1,240	696.2	181,000	11,550	0.011	9.3	0.060	0.064	20	18	17	10
Sinnemahoning	234.7	52,300	353.6	94,000	768	0.305	0.015	0.460	0.008	3	1	3	1
Kettle Creek	8.9	739	80.4	25,500	415	0.021	0.562	0.193	0.016	19	9	10	3
Beech Creek	69.9	585	106.1	24,200	537	0.130	0.919	0.197	0.022	7	10	9	8
Babb Creek	26.4	37	48.1	14,000	262	0.100	7.17	0.183	0.018	9	17	11	5
Loyalsock Creek	5.2	7	5.2	7	117	0.044	15.8	0.044	16.0	15	20	19	21
West Branch Minor Tributaries[1]					3,520								
TIOGA RIVER													
Morris Run Area	281.1	1,260	296.4	1,260	710	0.395	0.56	0.395	0.56	2	8	4	15
JUNIATA RIVER													
Longs Run	0.5	0.1	0.5	0.1	206	0.002	2,060	0.002	2,060	25	24	25	25
Six Mile Run	0.5	0.1	0.5	0.1	290	0.002	2,900	0.002	2,900	24	25	26	26
Shoups Run	0.7	0.1	0.7	0.1	512	0.001	5,120	0.001	5,120	26	26	27	27
Great Trough	0.7	0.2	0.7	0.2	154	0.004	770	0.004	770	22	23	23	24
Roaring Run	0.5	0.1	0.5	0.1	67	0.002	670	0.002	670	23	22	24	23
Beaverdam Branch	43.5	4.5	43.5	4.5	518	0.083	125	0.083	125	12	21	14	22

1 Basic data is not adequate to permit pollution abatement benefit ranking at the present time.

Table 3 Continued

Watershed	Individual Program		Comprehensive Program		Annual Costs Total ($1000)	Damage-Cost Analysis				Sub-Basin Rankings			
						Individual Program		Comprehensive Program		Individual Program		Comprehensive Program	
	An. $ ($ 1000)	Wtd Pts (1000)	An. $ ($ 1000)	Wtd Pts (1000)		Damage Cost Units ($)	An Cost Wtd Pts ($/Pts)	Damage Cost Units ($)	An Cost Wtd Pts ($/Pts)	Highest Damage Cost Ratio	Least Cost/ Point	Highest Damage Cost Ratio	Least Cost/ Point
ANTHRACITE													
Lackawanna	317.7	34,815	317.7	34,815	2,273	0.140	0.065	0.140	0.065	6	2	12	11
Wyoming Valley	268.1	32,550	268.1	32,550	2,123	0.126	0.066	0.126	0.066	8	3	13	12
Nescopeck Creek	55.3	362	58.0	2,572	1,280	0.043	3.55	0.045	0.50	16	15	18	13
Catawissa Creek	62.0	414	62.0	414	875	0.070	2.11	0.070	2.11	14	13	16	18
Shanokin Creek	44.8	681	44.8	681	1,230	0.036	1.80	0.036	1.80	17	11	20	16
Mahanoy Creek	74.2	470	74.2	470	2,310	0.032	4.91	0.032	4.91	18	16	21	19
Mahantango Creed	24.2	168	24.2	168	310	0.078	1.84	0.078	1.84	13	12	15	17
Wiconisco Creek	3.8	31	3.8	31	450	0.008	14.50	0.008	14.50	21	19	22	20
Swatara Creek	474.2	1,390	474.2	1,390	733	0.647	0.53	0.647	0.523	1	7	1	14

1 Basic data is not adequate to permit pollution abatement benefit ranking at the present time.

Table 4

ESTIMATED MINE DRAINAGE POLLUTION ABATEMENT COSTS

Reach	Watershed	Mine Drainage Design Volume mgd	Mine Drainage Design Acid Load lb/day	Mine Drainage Design Iron Load lb/day	Preventive Measures Cost First $\$x10^6$	Preventive Measures Cost Annual $\$x10^6$	Collection & Impoundment Cost First $\$x10^6$	Collection & Impoundment Cost Annual $\$x10^6$	Treatment Cost First $\$x10^6$	Treatment Cost Annual $\$x10^6$	Total Cost First $\$x10^6$	Total Cost Annual O & M $\$x10^6$	Total Cost Annual $\$x10^6$
WEST BRANCH SUSQUEHANNA RIVER													
G	Upper W. Branch	12.7	155,800	23,000	11.2	0.67	4.34	0.364	2.61	0.169	18.32	1.017	2.040
H	Chest Creek	5.1	15,650	2,200	1.44	0.089	0.69	0.058	0.66	0.232	2.79	0.220	0.379
H	Anderson	2.0	5,500	1,500	0.65	0.040	0.21	0.018	0.26	0.100	1.12	0.095	0.158
H	Minor Tribs.	6.4	17,000	1,900	0.94	0.057	0.89	0.074	1.02	0.385	2.84	0.304	0.516
I	Clearfield	28.4	107,400	12,900	5.50	0.338	2.62	0.219	2.90	1.068	11.03	1.010	1.625
I	Congress Run	0.71	24,000	2,000	1.32	0.081	0.10	0.008	0.28	0.119	1.70	0.113	0.208
I	Deer Creek	1.37	33,500	2,400	1.84	0.113	0.19	0.016	0.30	0.117	2.33	0.146	0.276
I	Sandy Run	0.68	20,000	1,250	1.27	0.069	0.09	0.008	0.24	0.103	1.46	0.098	0.180
I	Alder Run	2.55	38,000	1,450	2.09	0.128	0.37	0.031	0.27	0.206	2.74	0.169	0.321
I	Minor Tribs.	17.0	103,100	10,300	5.67	0.336	2.45	0.206	2.93	1.025	11.05	0.952	1.567
J	Moshannon	94.7	372,400	76,200	22.72	1.780	18.74	1.734	6.81	2.440	52.60	3.071	11.550
J	Minor Tribs	4.7	24,700	9,100	1.34	0.080	0.66	0.057	1.32	0.388	3.33	0.337	0.526
L	Sinnemahoning	6.98	66,800	5,400	3.67	0.230	0.96	0.081	0.84	0.461	5.48	0.462	0.768
L	Cooks Run	0.85	13,000	1,300	0.71	0.044	0.09	0.007	0.26	0.096	1.06	0.087	0.147
L	Kettle Creek	4.25	41,600	7,300	1.44	0.088	0.33	0.028	0.95	0.056	2.73	0.261	0.415
L	Minor Tribs.	0.22	2,300	600	0.13	0.008	0.02	0.002	0.21	0.056	0.36	0.042	0.062

Table 4 (Continued)

ESTIMATED MINE DRAINAGE POLLUTION ABATEMENT COSTS

Reach	Watershed	Mine Drainage Design Volume mgd	Acid Load lb/day	Iron Load lb/day	Preventive Measures Cost First $\$x10^6$	Annual $\$x10^6$	Collection & Impoundment Cost First $\$x10^6$	Annual $\$x10^6$	Treatment Cost First $\$x10^6$	Annual $\$x10^6$	Total Cost First $\$x10^6$	Annual O & M $\$x10^6$	Annual $\$x10^6$
M	Beech Creek	8.55	39,800	4,500	2.19	0.134	1.12	0.094	0.65	0.309	3.96	0.313	0.537
M	Babb Creek	5.2	12,400	1,200	0.68	0.042	0.69	0.057	0.30	0.163	1.67	0.168	0.262
N	Loyalsock	10.4	4,000	-----	0.26	0.016	----	-----	0.17	0.101	0.43	0.094	0.117
Total											127.00	8.959	21.654
	TIOGA RIVER	10.5	60,100	7,200	3.75	0.216	1.99	0.167	1.02	0.324	6.77	0.348	0.710
JUNIATA RIVER													
	Longs Run	2.9	6,900	300	0.41	0.026	1.10	0.087	0.25	0.103	1.76	0.104	0.206
	Six Mile Run	3.5	7,500	700	0.41	0.026	1.78	0.140	0.39	0.022	2.59	0.141	0.290
	Shoups Run	11.0	6,800	400	0.51	0.032	4.46	0.352	0.34	0.128	5.30	0.207	0.512
	Great Trough Cr.	2.8	800	50	0.04	0.002	1.13	0.089	0.06	0.060	1.23	0.084	0.154
	Aughwick Creek	0.50	2,200	100	0.16	0.010	0.19	0.015	0.02	0.042	0.37	0.047	0.067
	Beaverdam	9.9	16,200	1,600	0.90	0.055	3.99	0.315	0.35	0.148	5.24	0.231	0.518
Sub-Total											16.49	0.814	1.747

Table 5

ESTIMATED MINE DRAINAGE POLLUTION ABATEMENT COSTS

Reach	Watershed	Survey MD Acid Load lb/day	Mine Drainage Design Volume mgd	Mine Drainage Design Acid Load lb/day	Mine Drainage Design Iron Load lb/day	Preventive Measures Cost First $x10^6$	Preventive Measures Cost Annual $x10^6$	Collection & Impoundment Cost First $x10^6$	Collection & Impoundment Cost Annual $x10^6$	Treatment Cost First $x10^6$	Treatment Cost Annual $x10^6$	Total Cost First $x10^6$	Total Cost Annual O & M $x10^6$	Total Cost Annual $x10^6$
ANTHRACITE														
	Lackawanna River	143,000	75.3	146,600	62,900	6.39	0.562	3.07	0.309	4.52	1.402	13.99	1.409	2.273
	Wyoming Valley	142,000	58.8	142,000	62,300	6.12	0.538	1.24	0.126	4.59	1.457	11.95	1.215	2.123
	Nescopeck Creek	78,800	43.0	108,600	5,100	4.78	0.418	1.51	0.149	1.51	0.712	7.79	0.780	1.280
	Catawissa Creek	27,500	29.2	44,100	700	1.82	0.154	3.16	0.314	1.19	0.407	6.16	0.509	0.875
	Shamokin Creek	32,800	24.6	50,900	25,500	2.37	0.208	3.97	0.400	2.33	0.622	8.67	0.710	1.230
	Mahanoy Creek	44,000	63.5	62,000	33,400	3.66	0.321	10.20	1.029	3.26	0.960	17.12	1.288	2.310
	Mahantango Creek	6,000	9.2	9,400	2,200	0.44	0.038	1.48	0.149	0.41	0.128	2.33	0.178	0.310
	Wiconisco Creek	2,200	13.1	8,600	3,500	0.40	0.035	2.06	0.208	0.72	0.207	3.18	0.262	0.450
	Swatara Creek	9,400	16.8	15,400	4,300	0.77	0.061	2.69	0.271	1.23	0.410	4.69	0.460	0.733
Sub-Total												75.88	6.811	11.584
SUSQUEHANNA RIVER												226.14	16.932	35.695

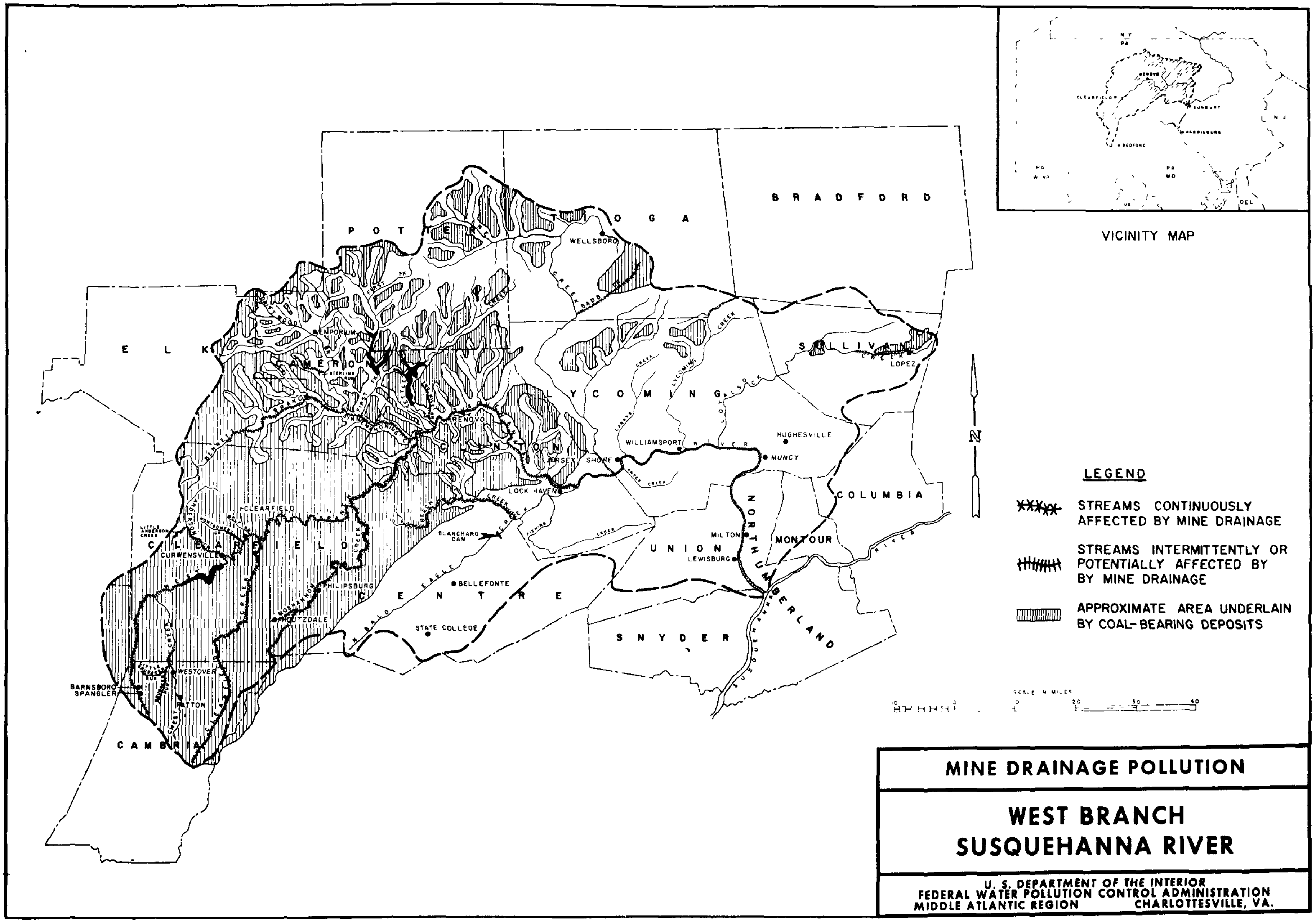
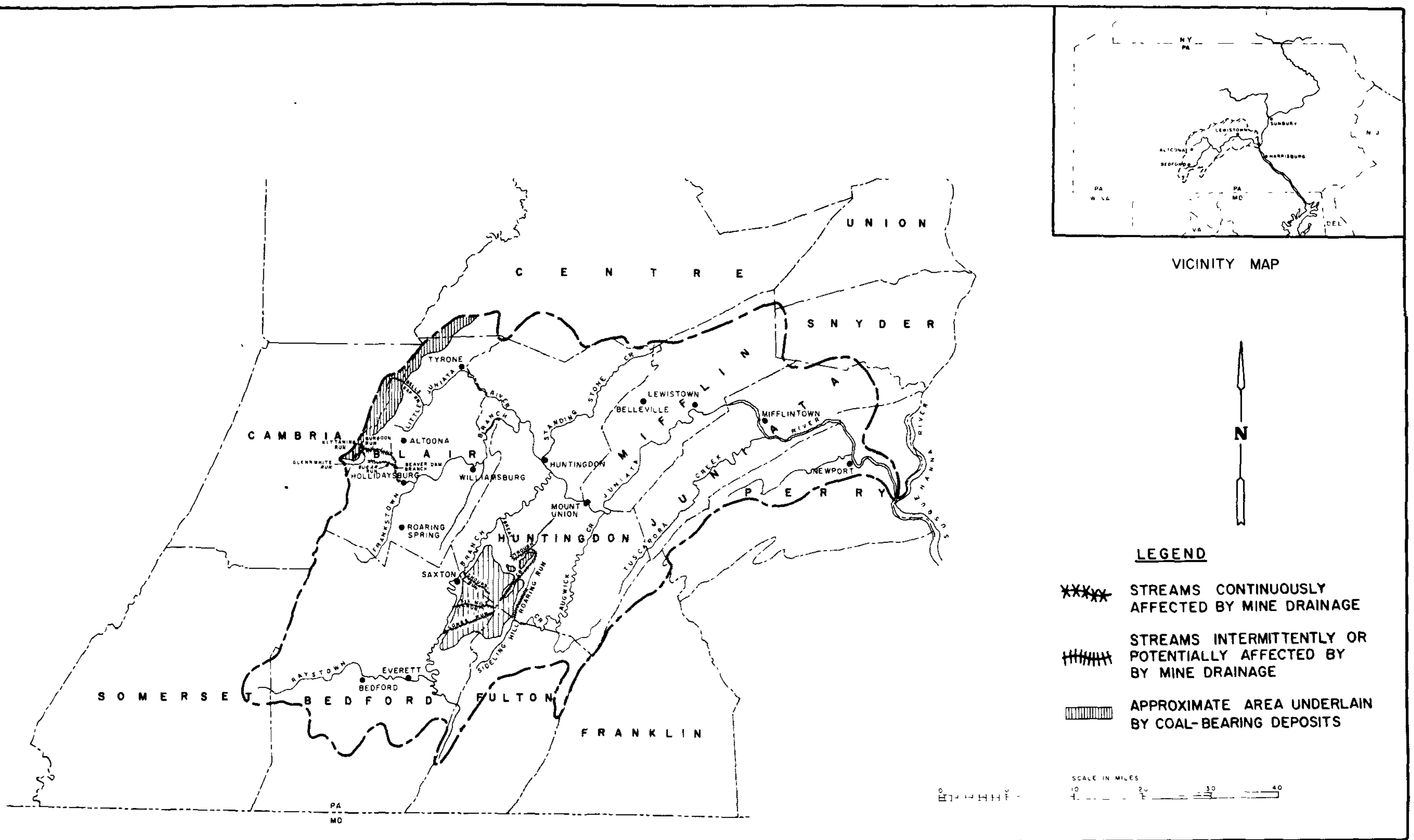

VICINITY MAP
LEGEND
STREAMS CONTINUOUSLY AFFECTED BY MINE DRAINAGE
STREAMS INTERMITTENTLY OR POTENTIALLY AFFECTED BY BY MINE DRAINAGE
APPROXIMATE AREA UNDERLAIN BY COAL-BEARING DEPOSITS
SCALE IN MILES
BRADFORD
TIOGA
POTTER
ELK
CAMERON
LYCOMING
SULLIVAN
CLINTON
CLEARFIELD
CENTRE
UNION
SNYDER
NORTHUMBERLAND
MONTOUR
COLUMBIA
CAMBRIA
WELLSBORO
EMPORIUM
RENOVO
LOCK HAVEN
WILLIAMSPORT
HUGHESVILLE
MUNCY
LOPEZ
MILTON
LEWISBURG
BELLEFONTE
STATE COLLEGE
BLANCHARD DAM
PHILIPSBURG
HOUTZDALE
CLEARFIELD
CURWENSVILLE
WESTOVER
PATTON
BARNSBORO
SPANGLER
MINE DRAINAGE POLLUTION
WEST BRANCH SUSQUEHANNA RIVER
U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE 1-A

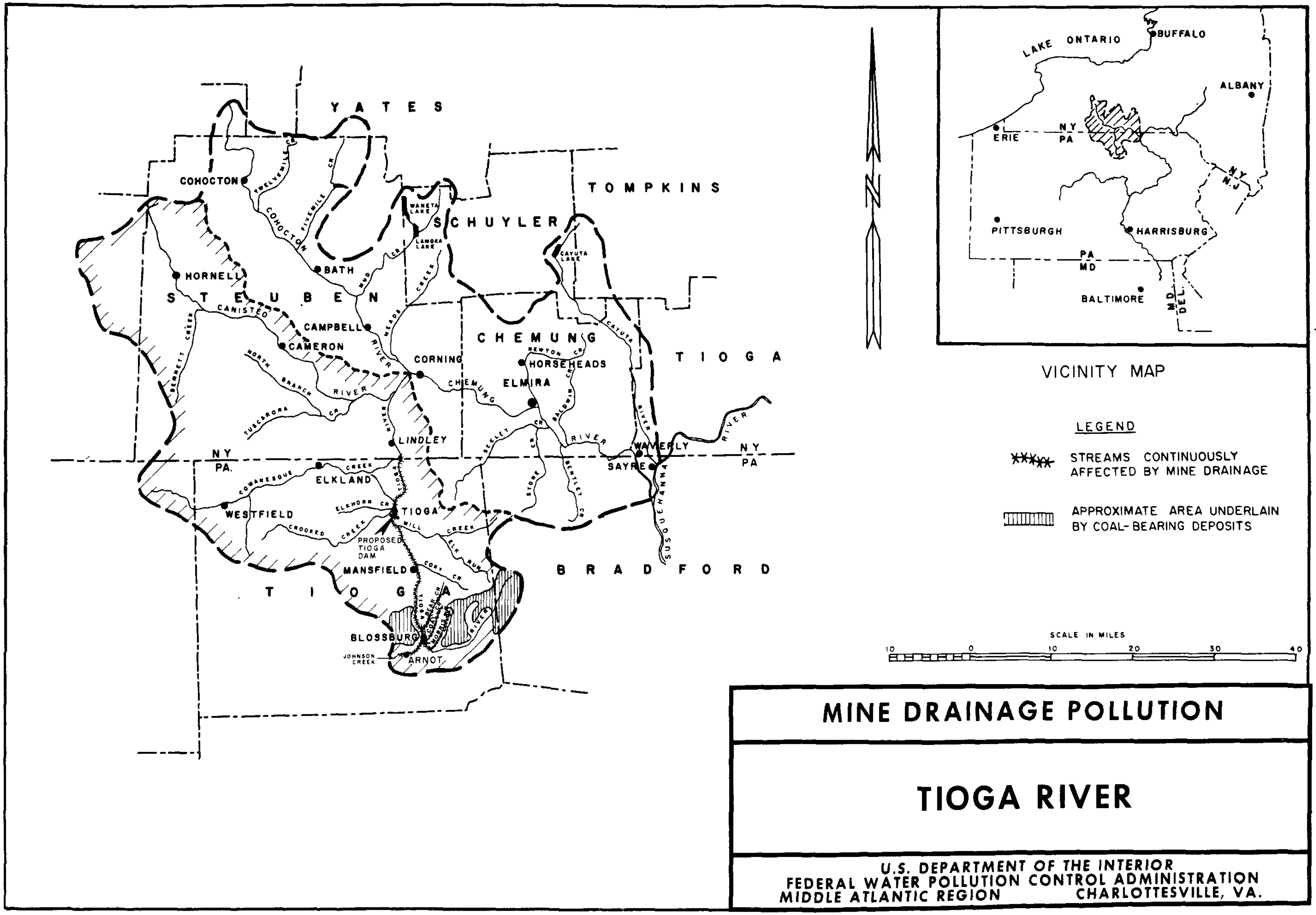


MINE DRAINAGE POLLUTION

JUNIATA RIVER

U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-B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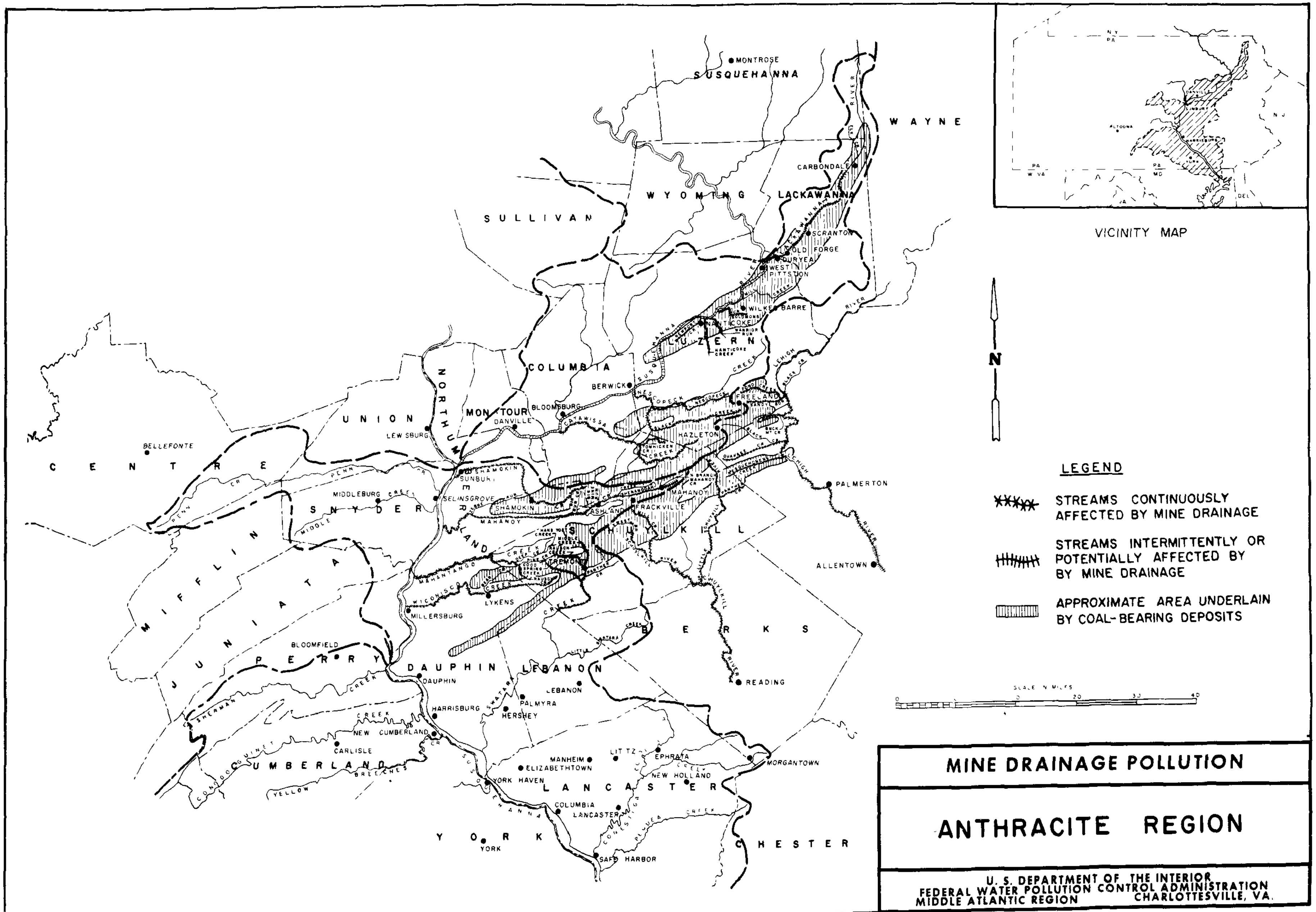
SCHUYLER
STEUBEN
CHEMUNG
TIOGA
BRADFORD
TIOGA
COHOCTON
HORNELL
BATH
CAMPBELL
CAMERON
CORNING
HORSEHEADS
ELMIRA
LINDLEY
WAVERLY
SAYRE
ELKLAND
WESTFIELD
TIOGA
PROPOSED TIOGA DAM
MANSFIELD
BLOSSBURG
ARNOT
JOHNSON CREEK
COHOCTON
TWELVEMILE CR
FIVEMILE CR
MUD CR
MEADS CREEK
WANETA LAKE
LAMOKA LAKE
CAYUTA LAKE
CAYUTA
CANISTEO
BENNETT CREEK
NORTH BRANCH
RIVER
TUSCARORA CR
CHEMUNG
NEWTON CR
BALDWIN CR
SEELEY CR
STONE CR
BENTLEY CR
RIVER
SUSQUEHANNA
COWANESQUE
CREEK
ELKHORN CR
CROOKED CREEK
MILL CREEK
ELK RUN
CORY CR
NY
PA.
NY
PA
LAKE ONTARIO
BUFFALO
ALBANY
ERIE
NY
PA
NY
NJ
PITTSBURGH
HARRISBURG
PA
MD
BALTIMORE
MD
DEL
VICINITY MAP
LEGEND
STREAMS CONTINUOUSLY AFFECTED BY MINE DRAINAGE
APPROXIMATE AREA UNDERLAIN BY COAL-BEARING DEPOSITS
SCALE IN MILES
10 0 10 20 30 40
MINE DRAINAGE POLLUTION
TIOGA RIVER
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-C

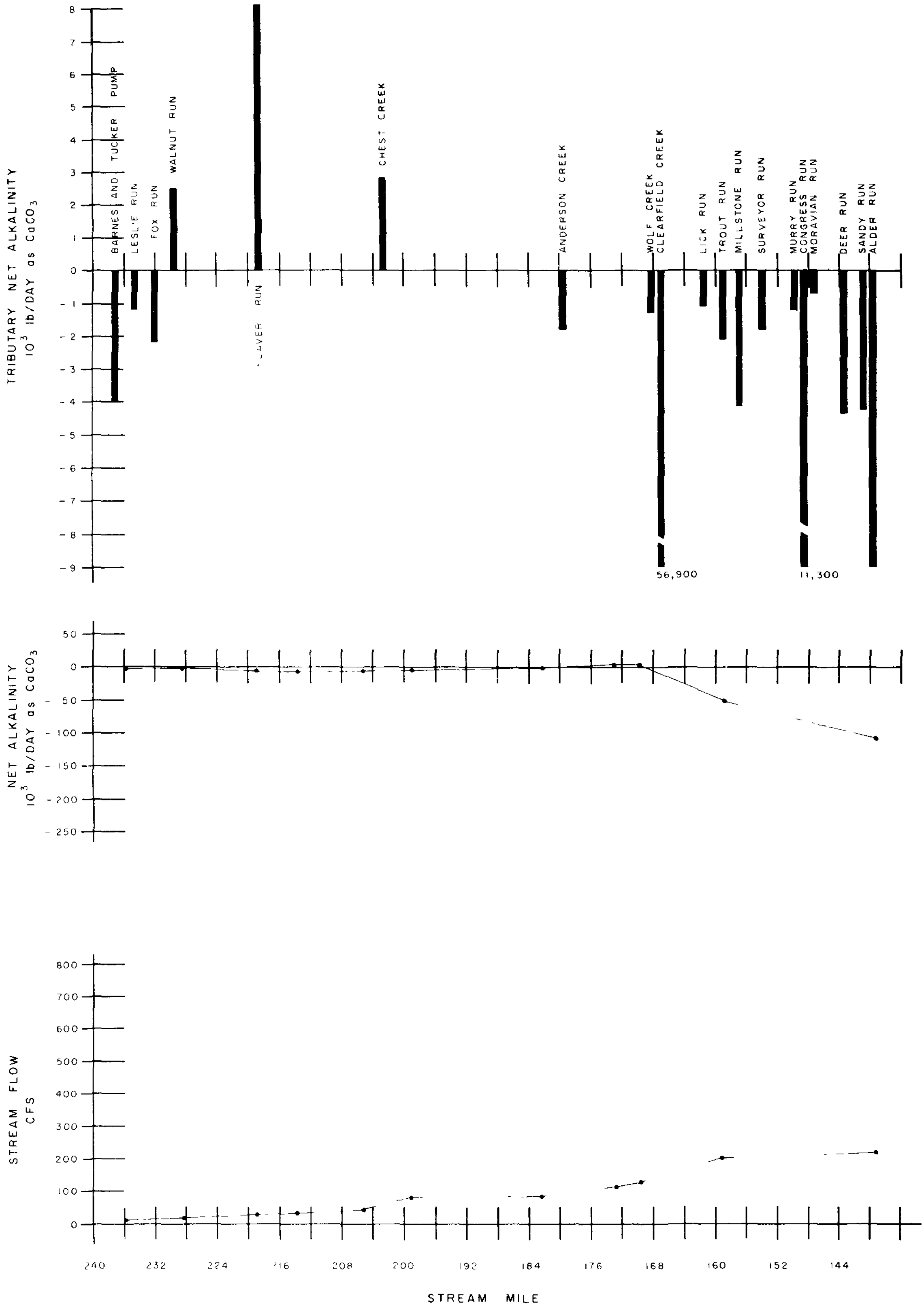


MINE DRAINAGE POLLUTION

ANTHRACITE REGION

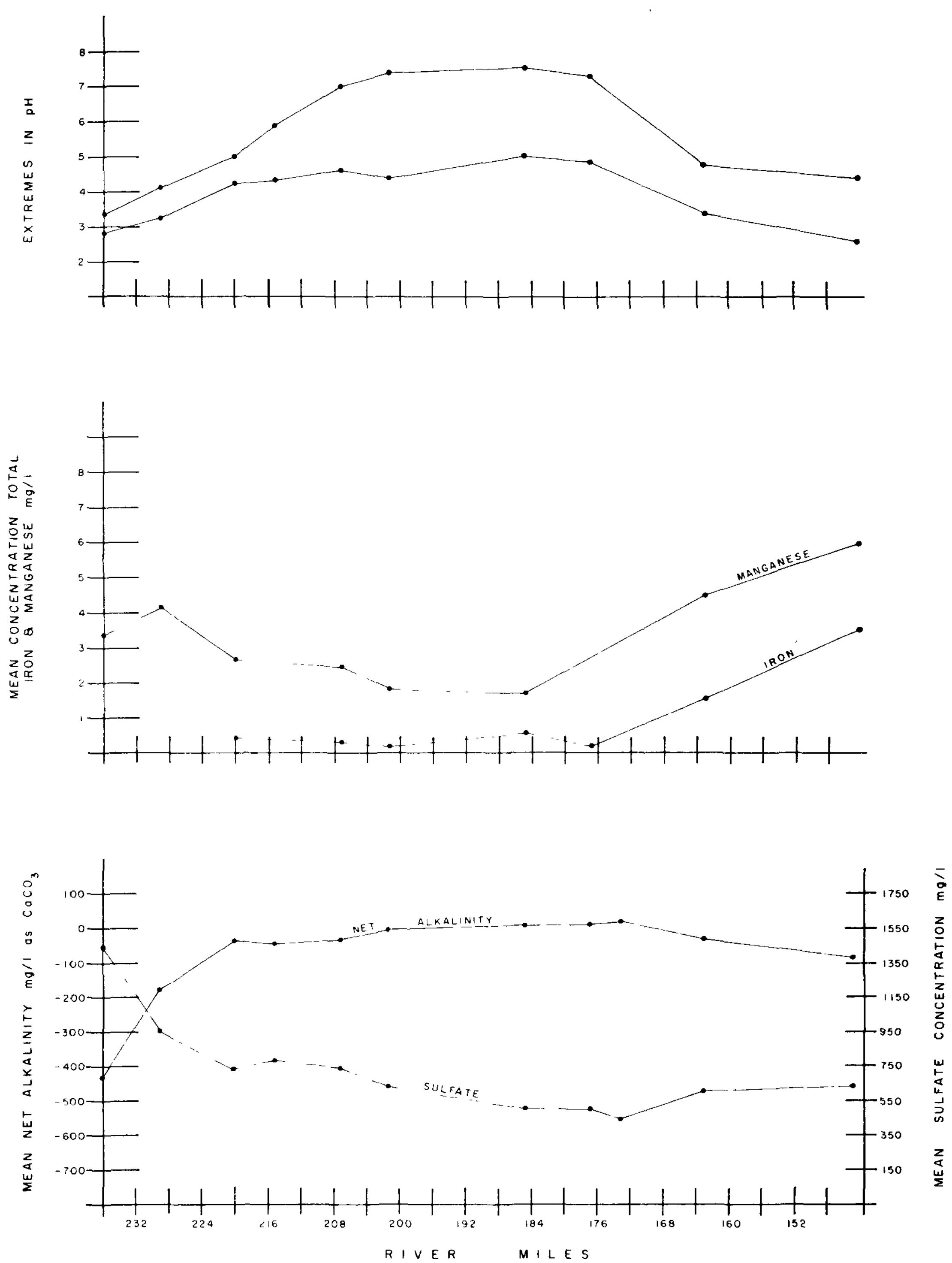
U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
MIDDLE ATLANTIC REGION CHARLOTTESVILLE, VA.

FIGURE I-?



PROFILE OF FLOW, NET ALKALINITY OF WEST BRANCH SUSQUEHANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY - SEPTEMBER, 1966

FIGURE 2-A

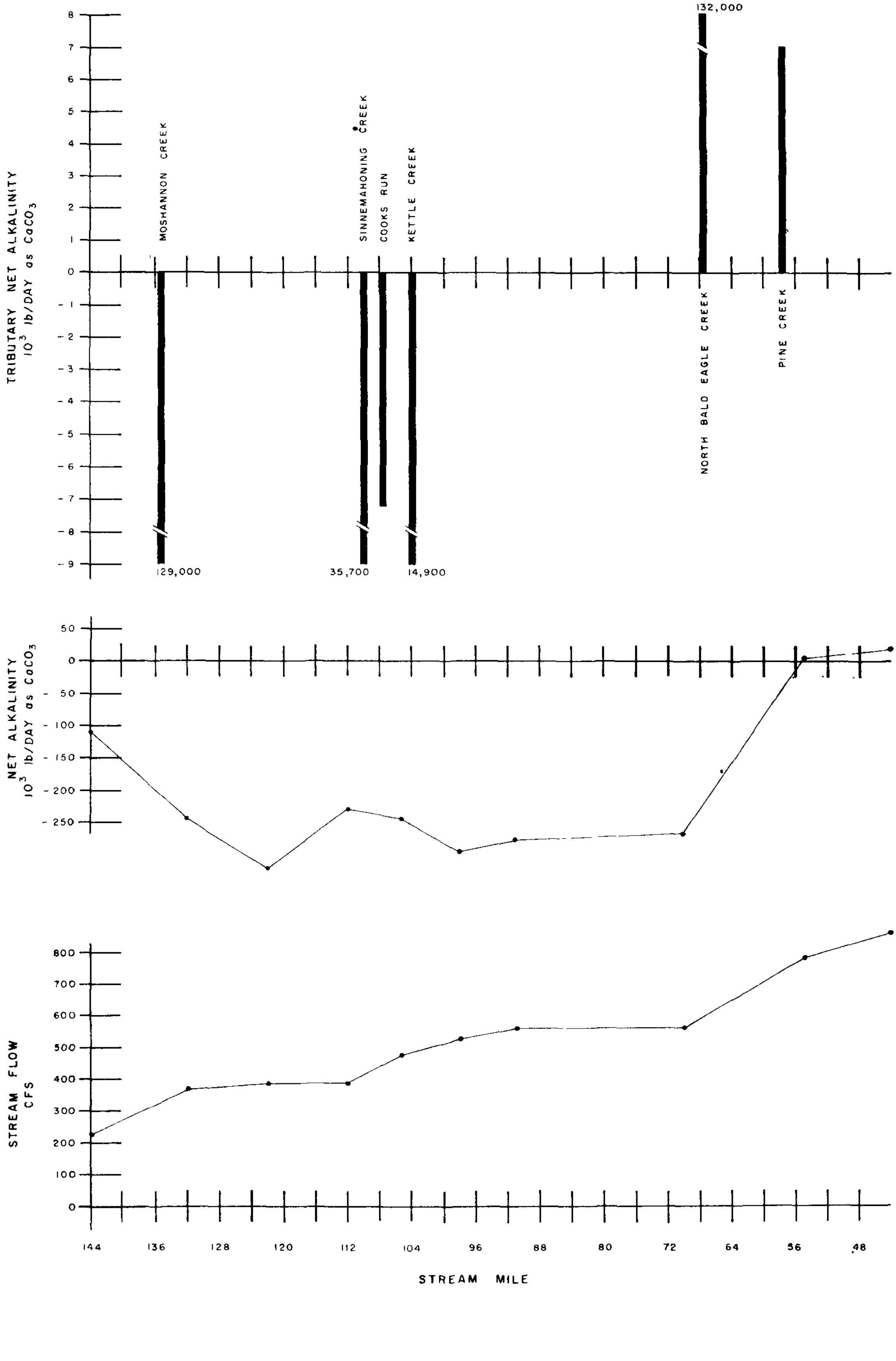


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

WEST BRANCH, SUSQUEHANNA RIVER

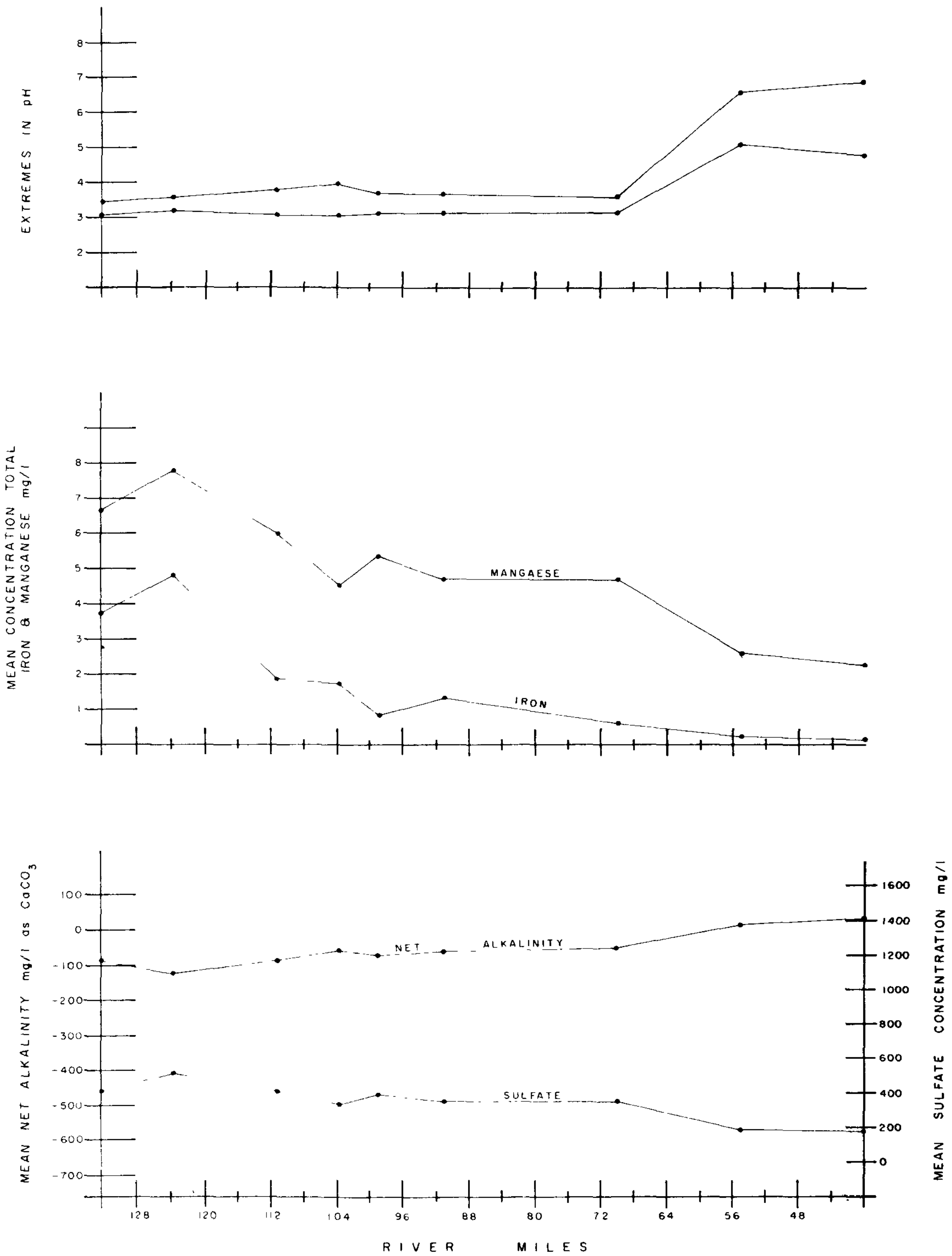
JULY - SEPTEMBER, 1966

FIGURE 2-B



PROFILE OF FLOW, NET ALKALINITY OF WEST BRANCH SUSQUEHANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY – SEPTEMBER, 1966

FIGURE 3-A

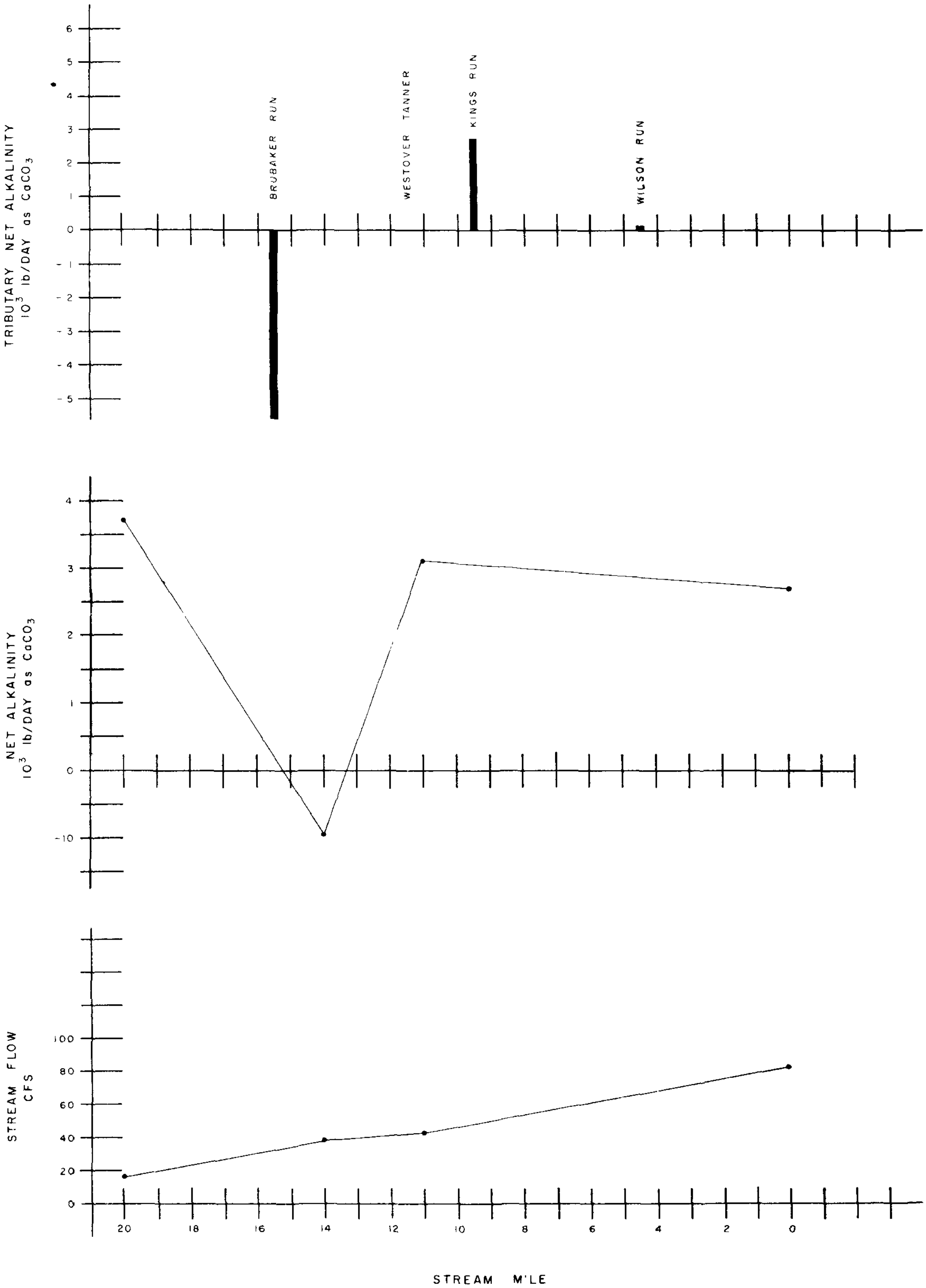


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

WEST BRANCH, SUSQUEHANNA RIVER

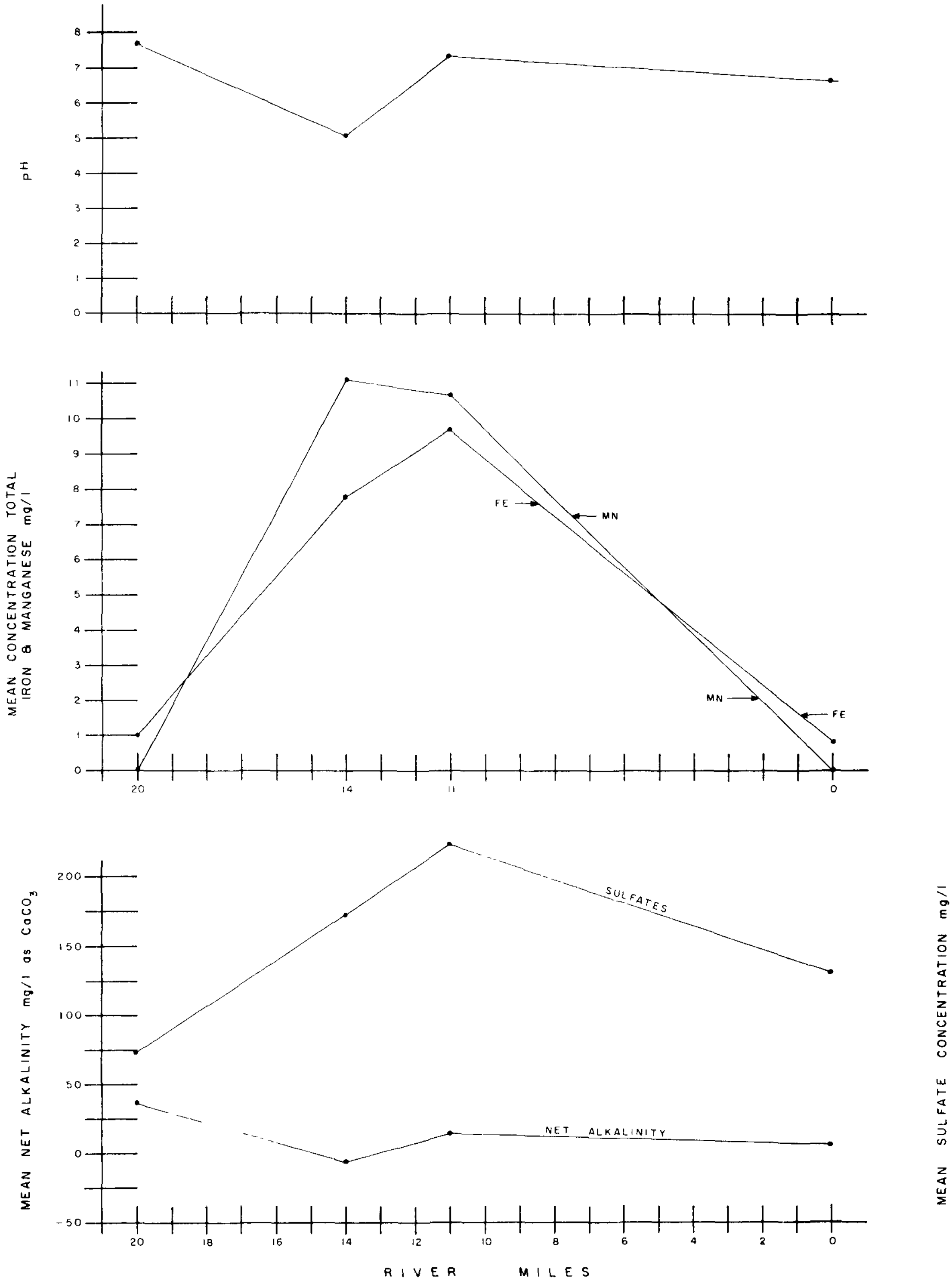
JULY - SEPTEMBER, 1966

FIGURE 3-B



PROFILE OF FLOW, NET ALKALINITY OF CHEST CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY - AUGUST, 1967

FIGURE 4-A

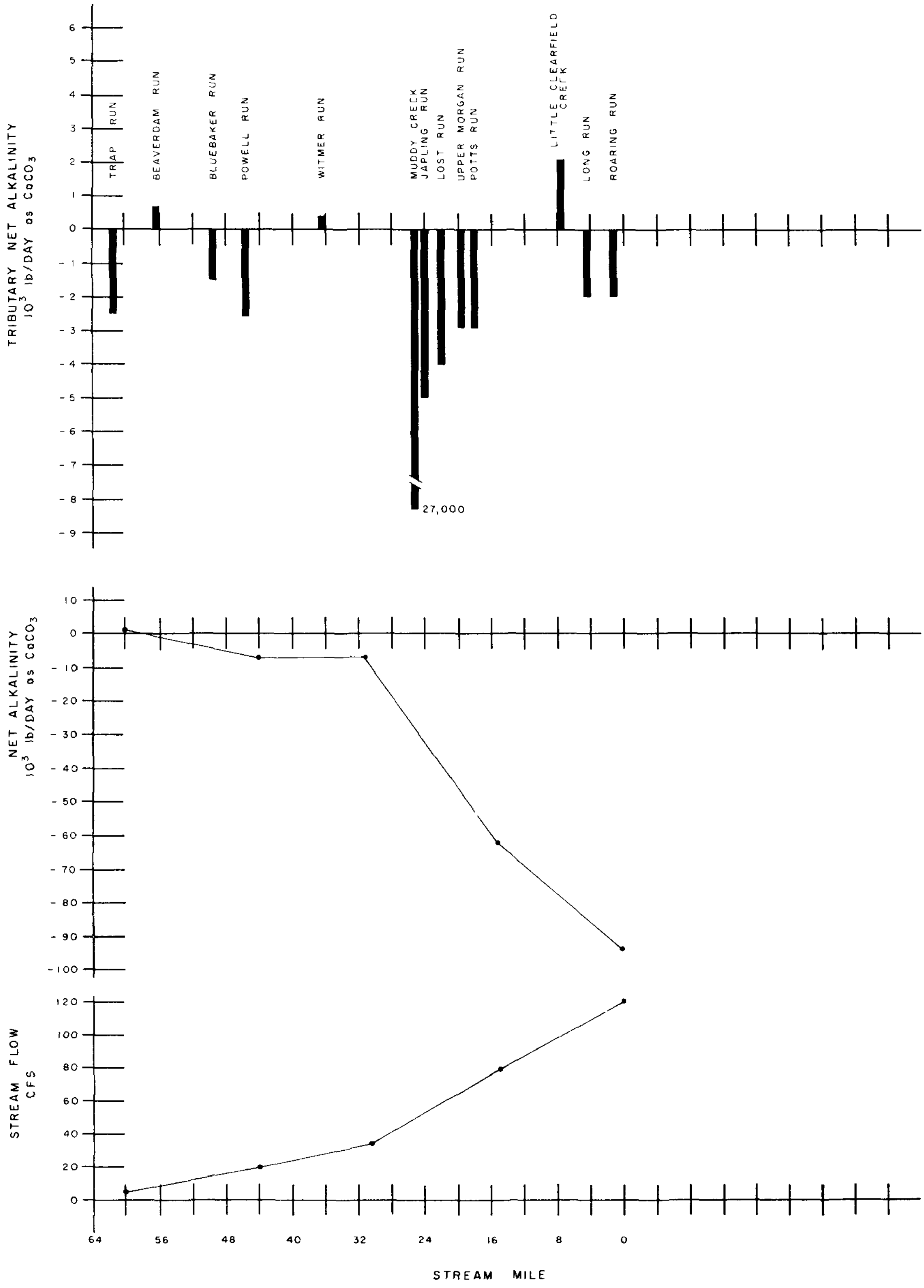


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

CHEST CREEK

JULY – AUGUST, 1967

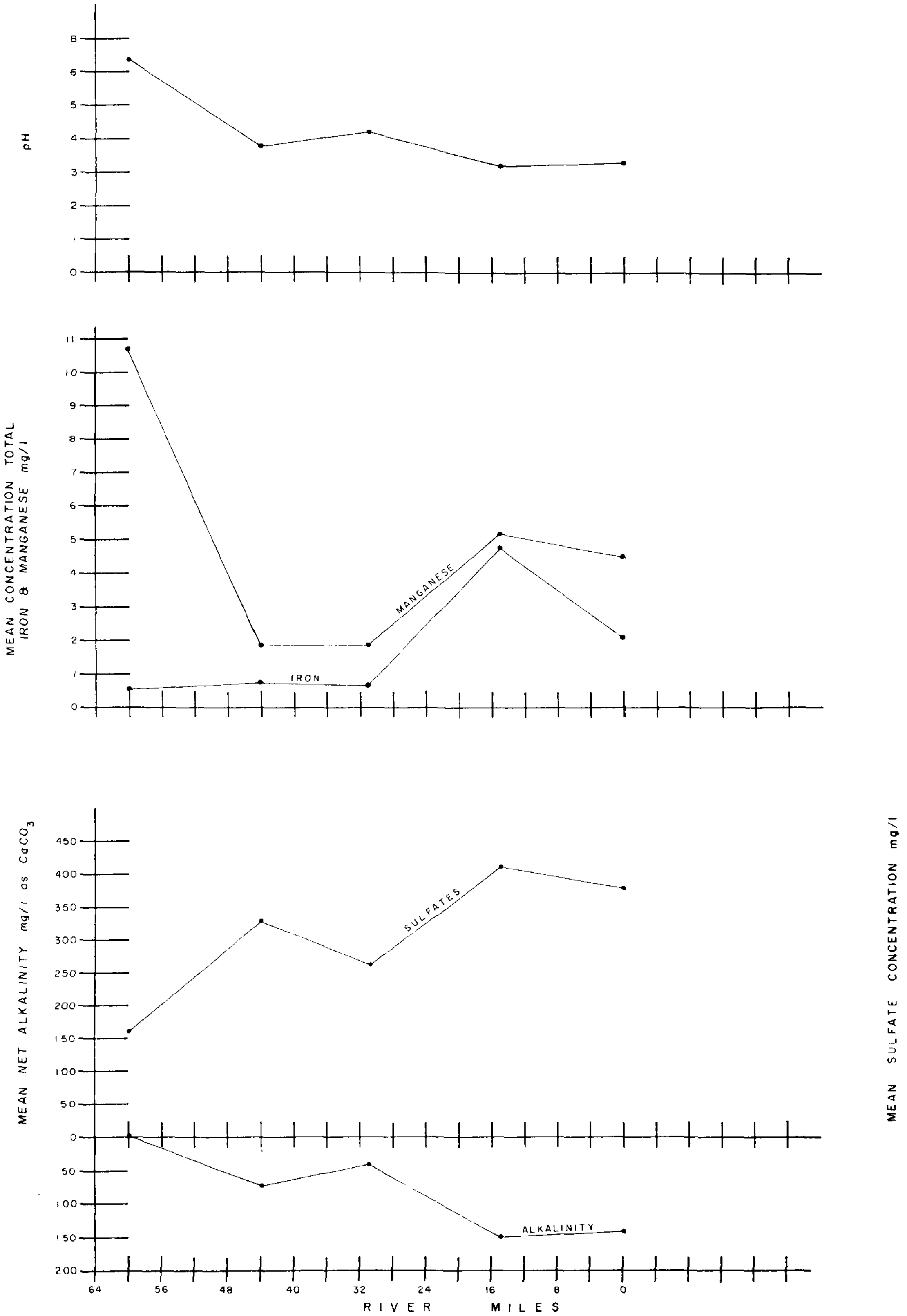
FIGURE 4-B



PROFILE OF FLOW, NET ALKALINITY OF CLEARFIELD CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

JULY - AUGUST, 1967

FIGURE [illegible]

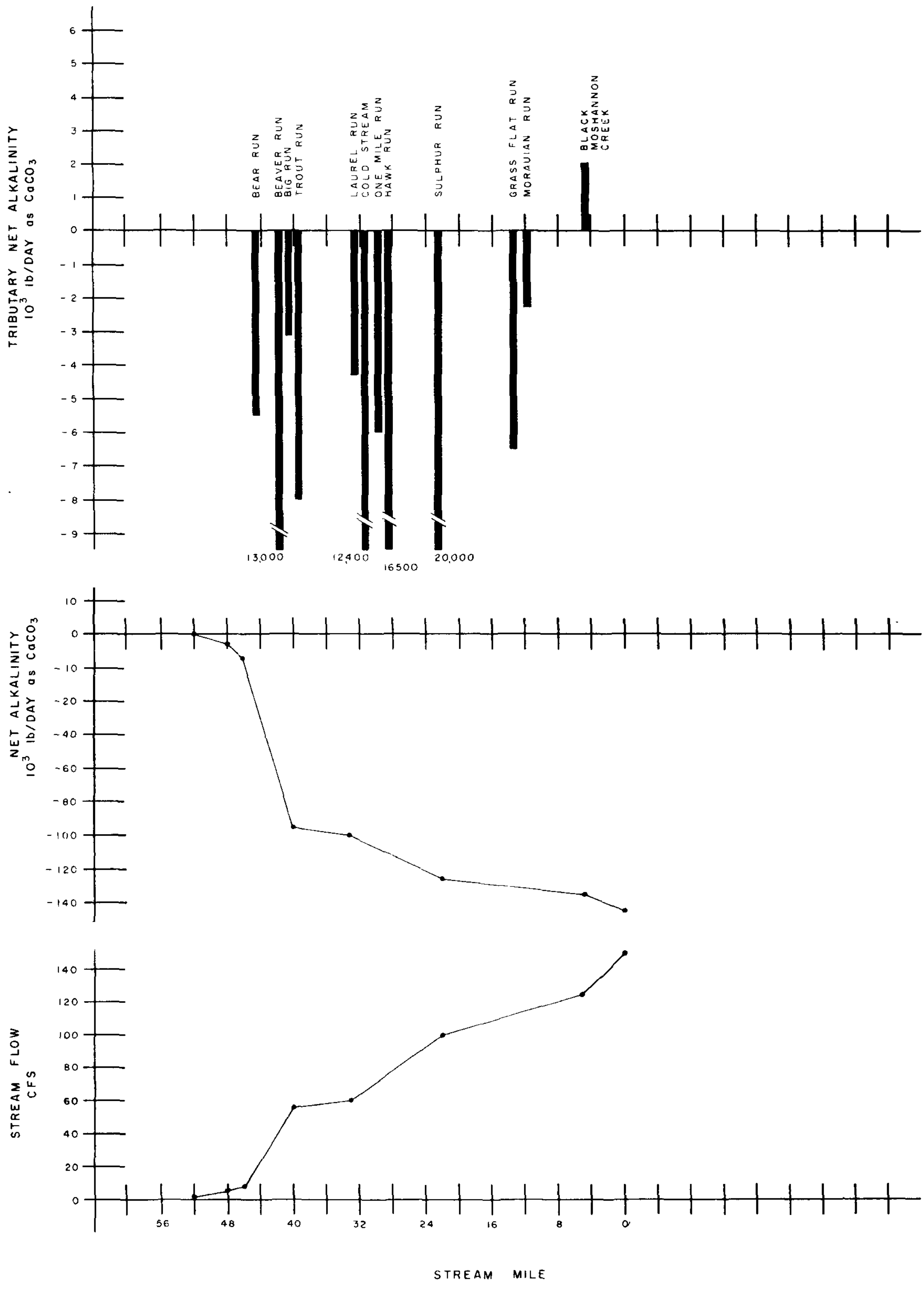


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

CLEARFIELD CREEK

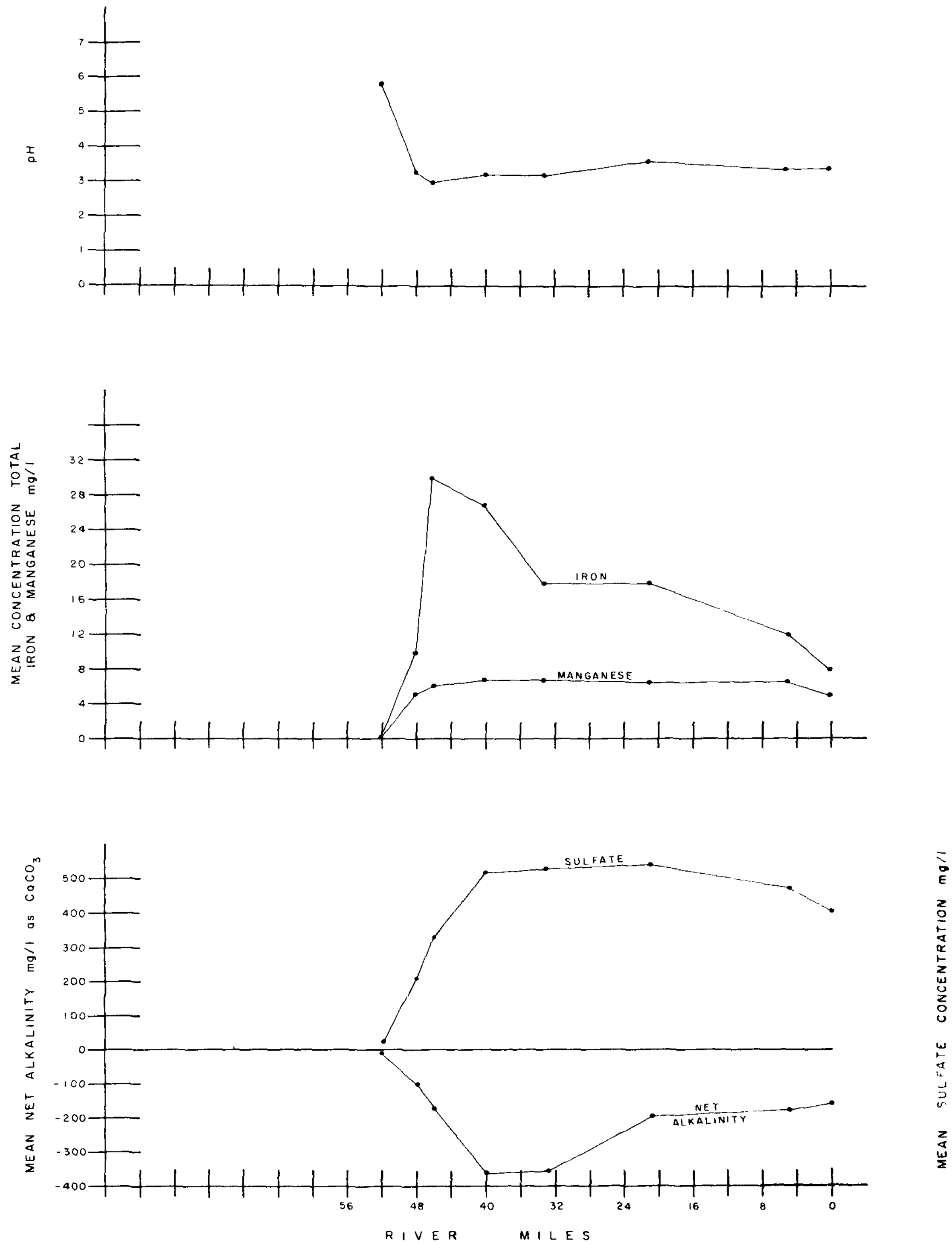
JULY – AUGUST, 1967

FIGURE 5-B



PROFILE OF FLOW, NET ALKALINITY OF MOSHANNON CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY – AUGUST, 1967

FIGURE 6

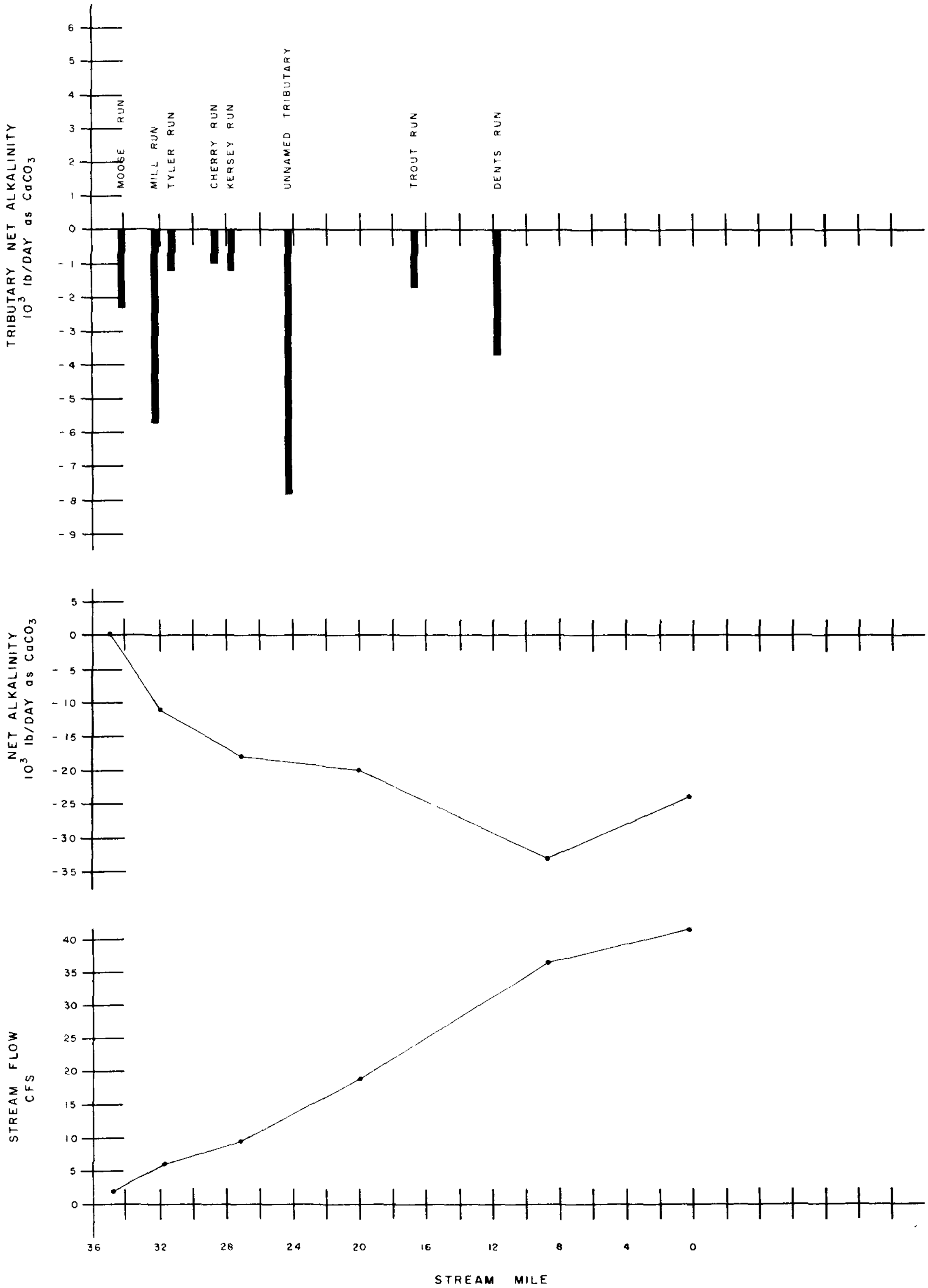


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

MOSHANNON CREEK

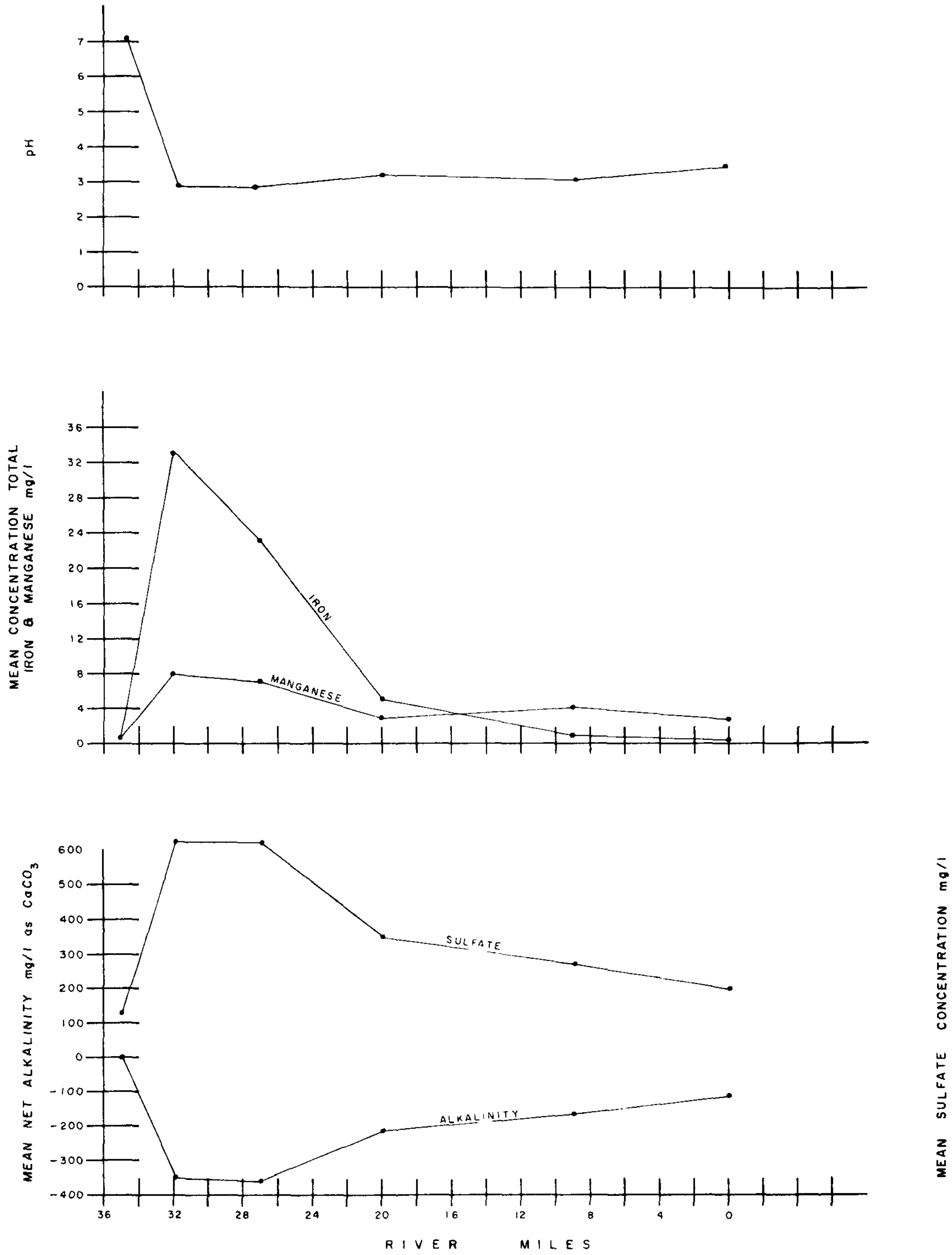
JULY – AUGUST, 1967

FIGURE 6-B



PROFILE OF FLOW, NET ALKALINITY OF BENNETT BR. SINNEMAHONING CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
SEPTEMBER 1967

FIGURE 7-A

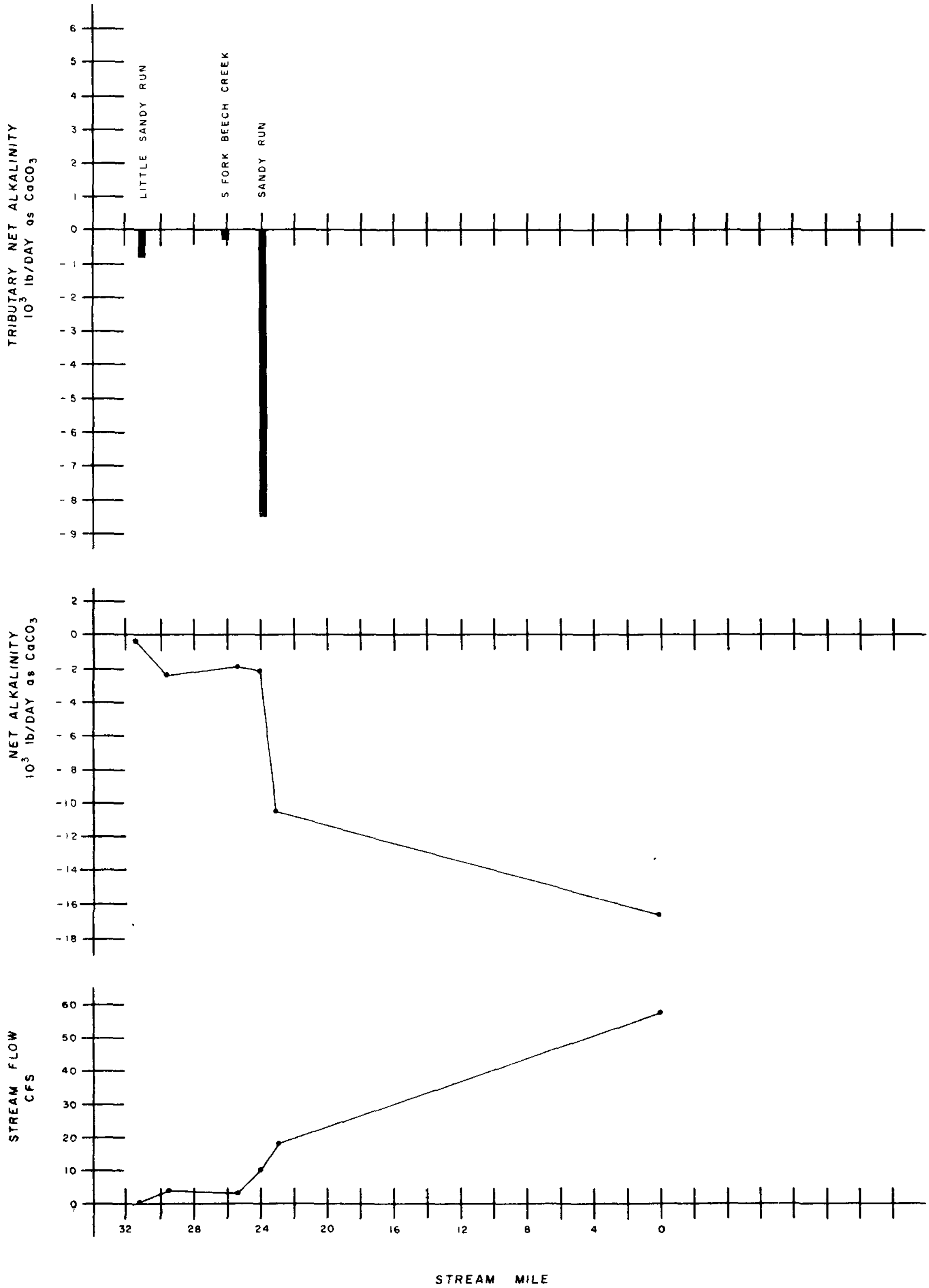


PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

BENNETT BR. SINNEMAHONING CREEK

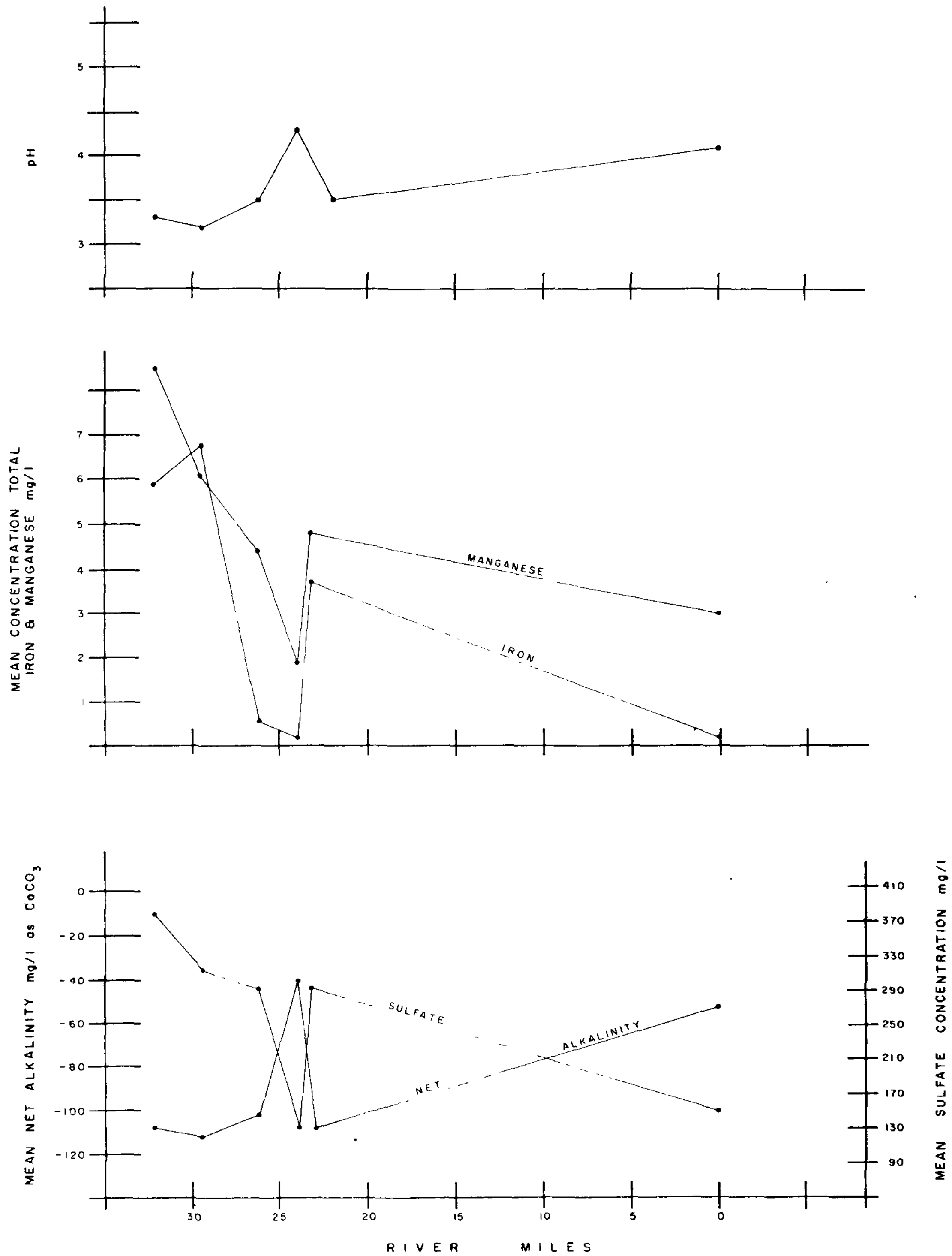
SEPTEMBER, 1967

FIGURE 7-B



PROFILE OF FLOW, NET ALKALINITY OF BEECH CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY – AUGUST, 1967

FIGURE 8-1

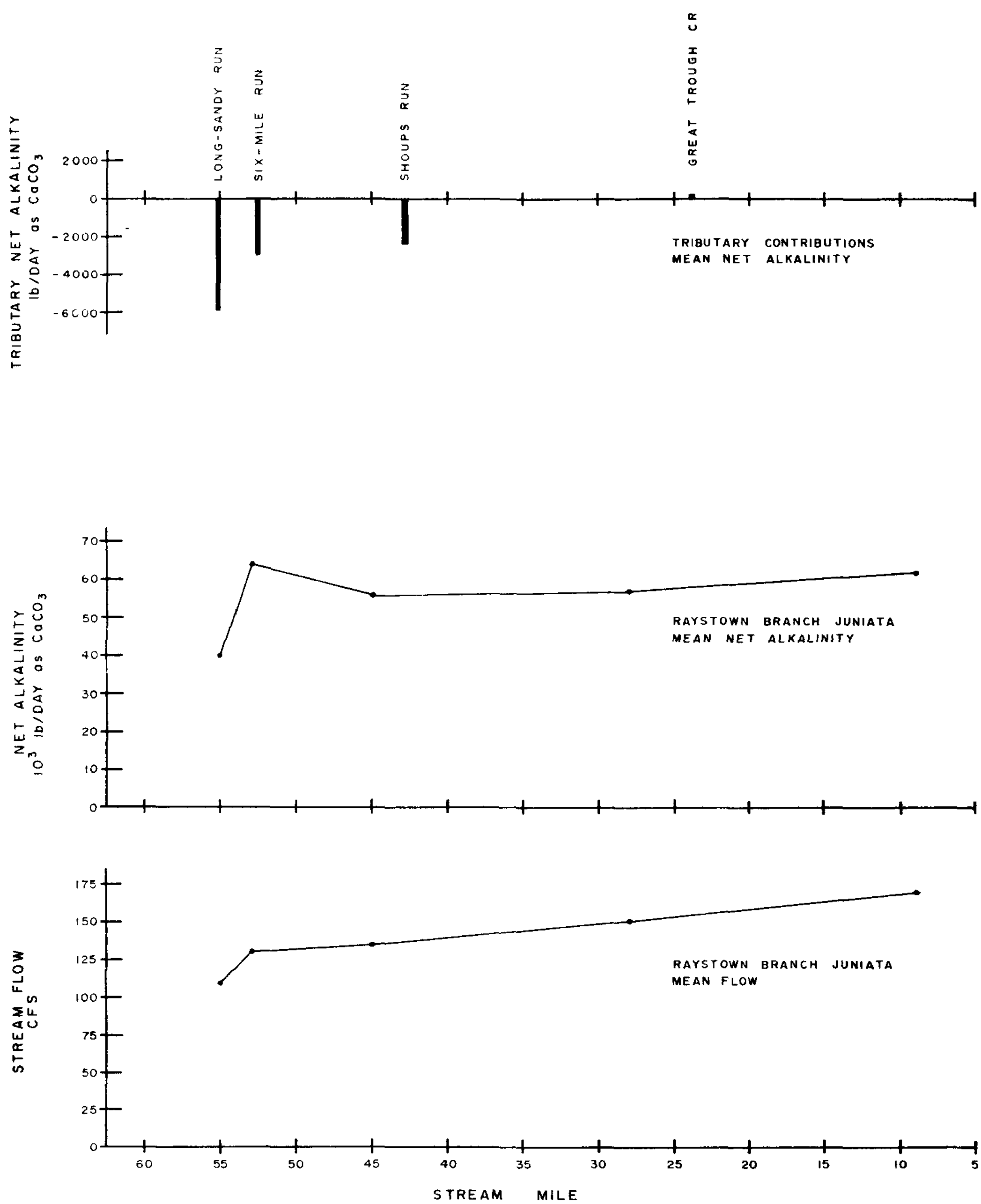


PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

BEECH CREEK

JULY – AUGUST, 1967

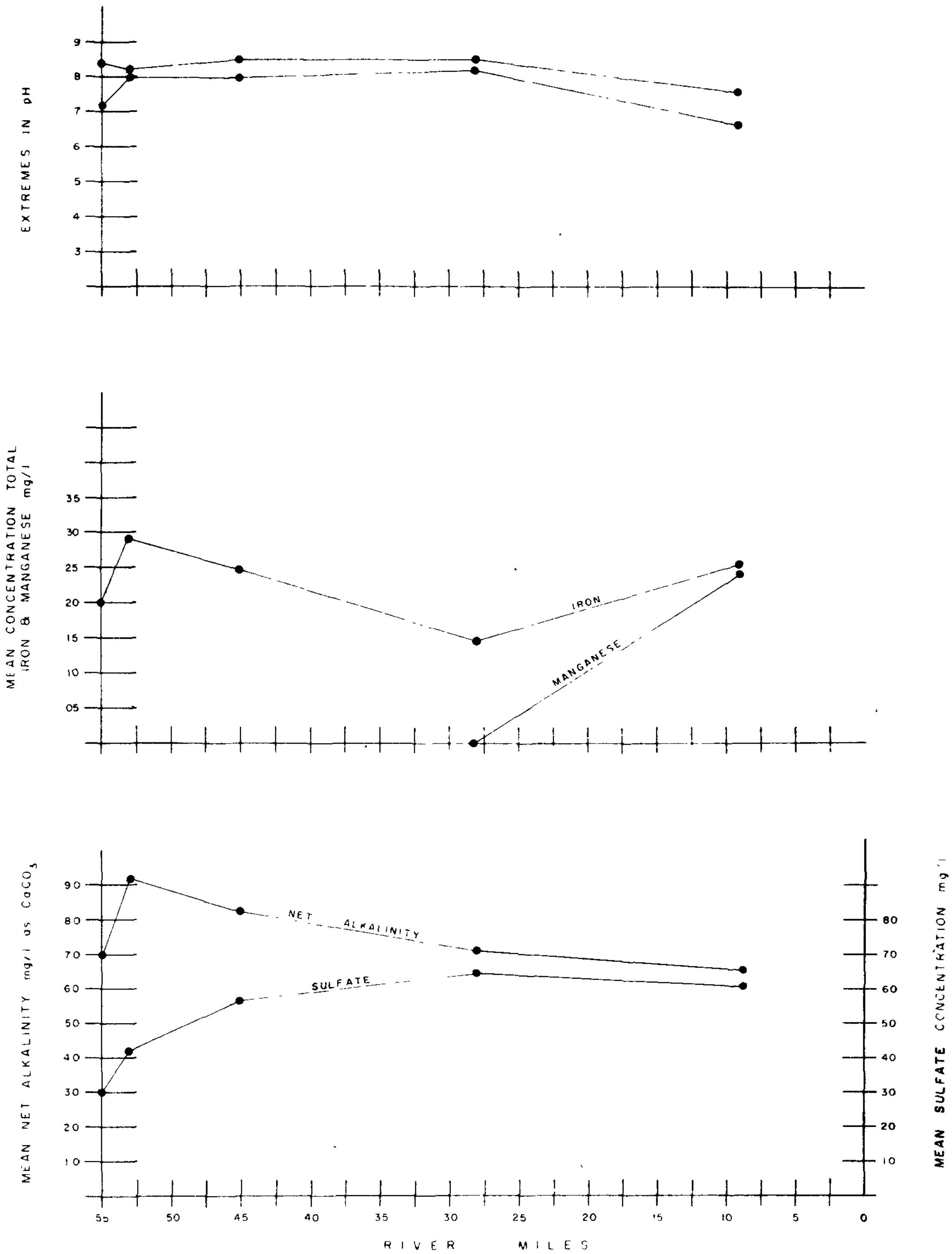
FIGURE 8-1



PROFILE OF FLOW, NET ALKALINITY OF RAYSTOWN BRANCH JUNIATA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

AUGUST-1965

FIGURE 9-A

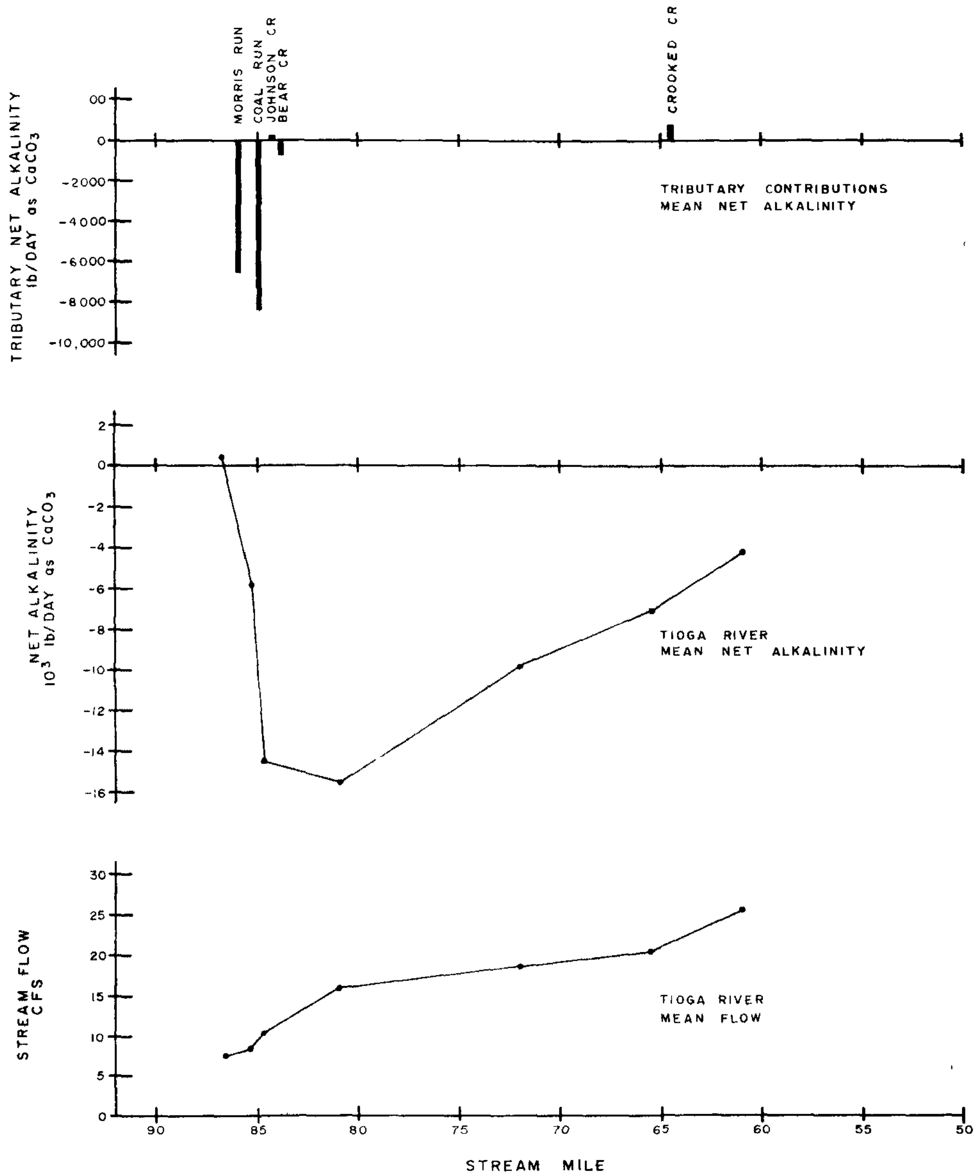


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

RAYSTOWN BRANCH, JUNIATA RIVER

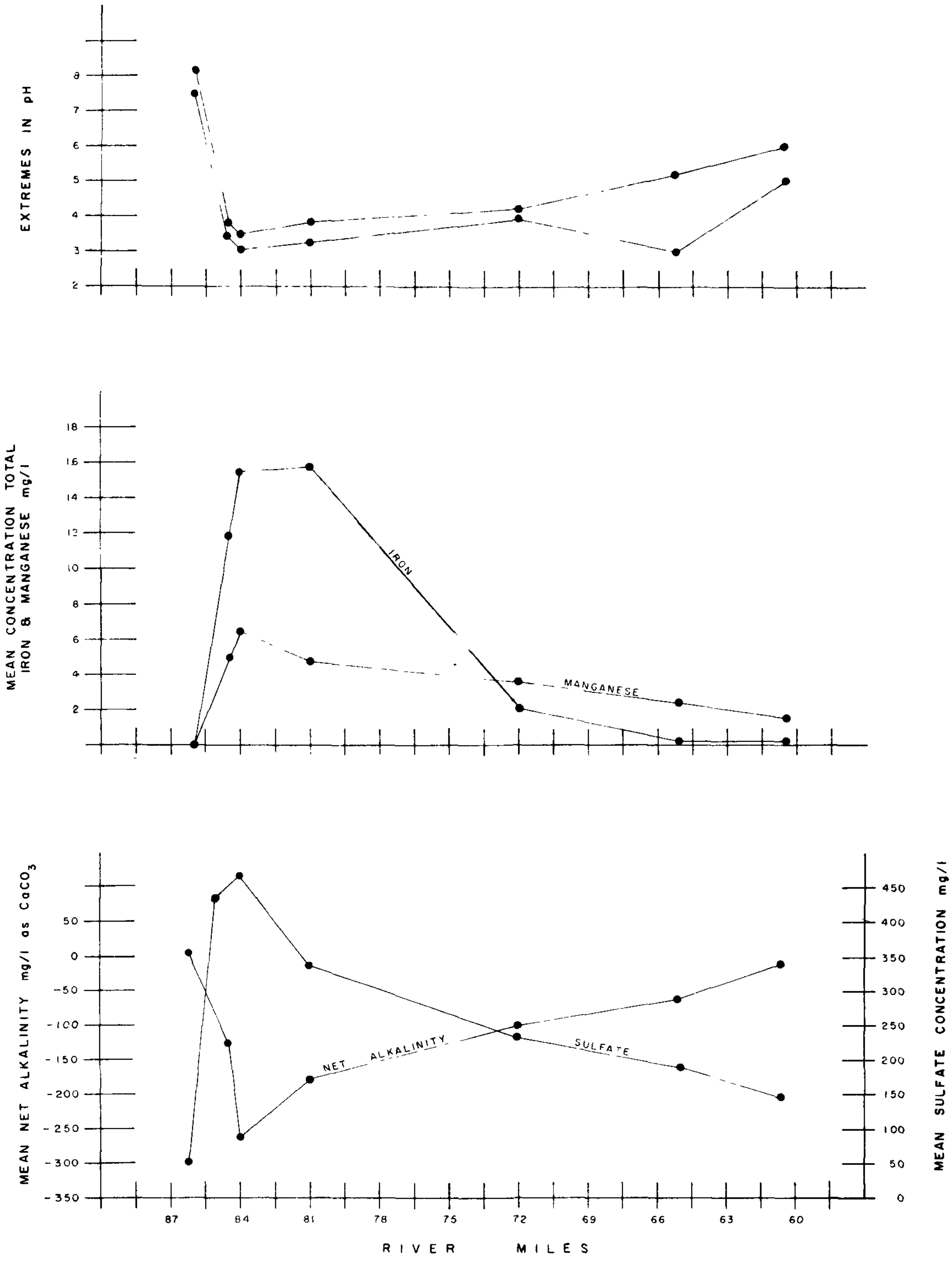
AUGUST - 1965

FIGURE 9-B



PROFILE OF FLOW, NET ALKALINITY OF TIOGA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
SEPTEMBER - NOVEMBER, 1965

FIGURE 10-1

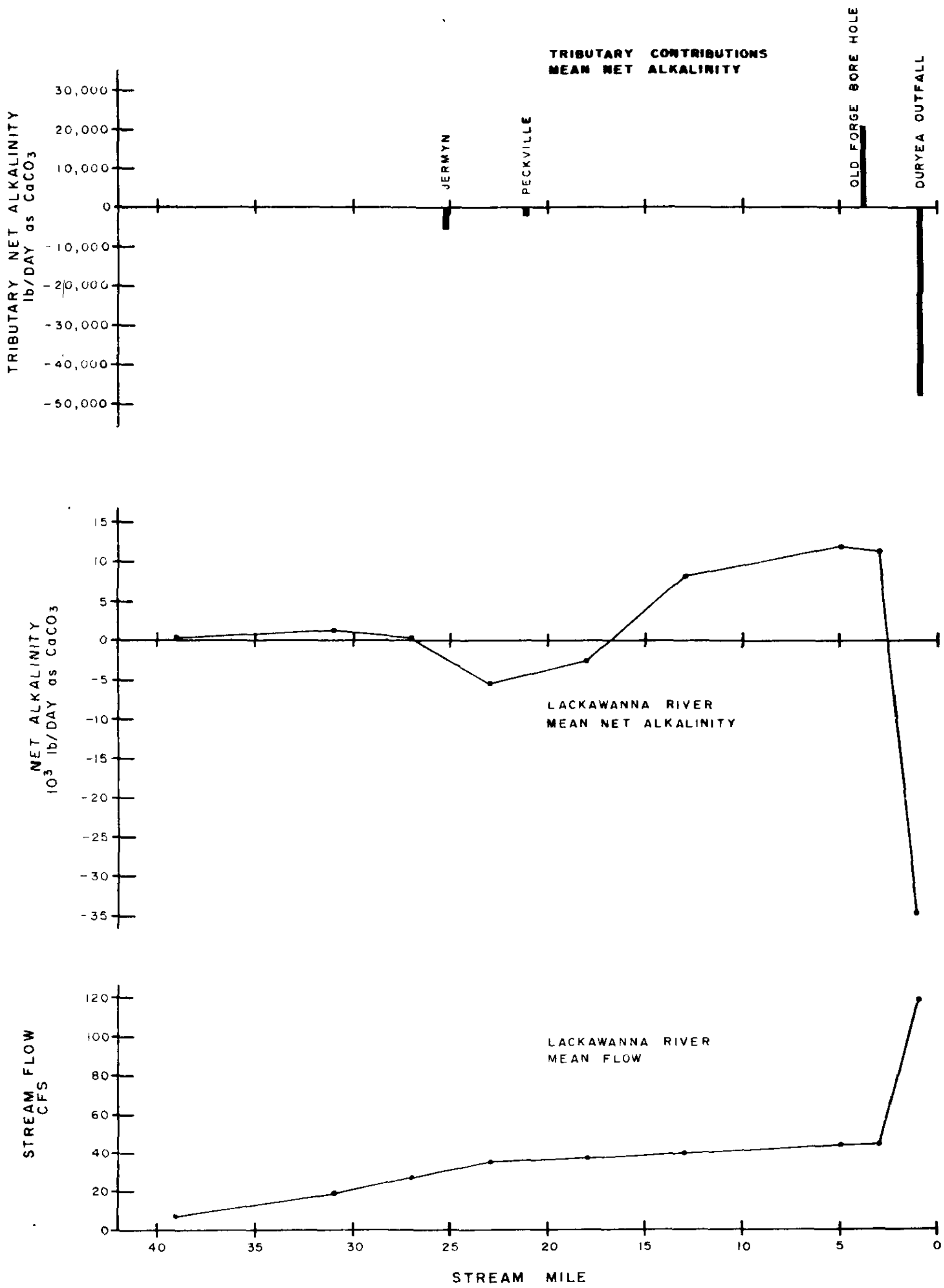


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

TIOGA RIVER

SEPTEMBER – NOVEMBER, 1965

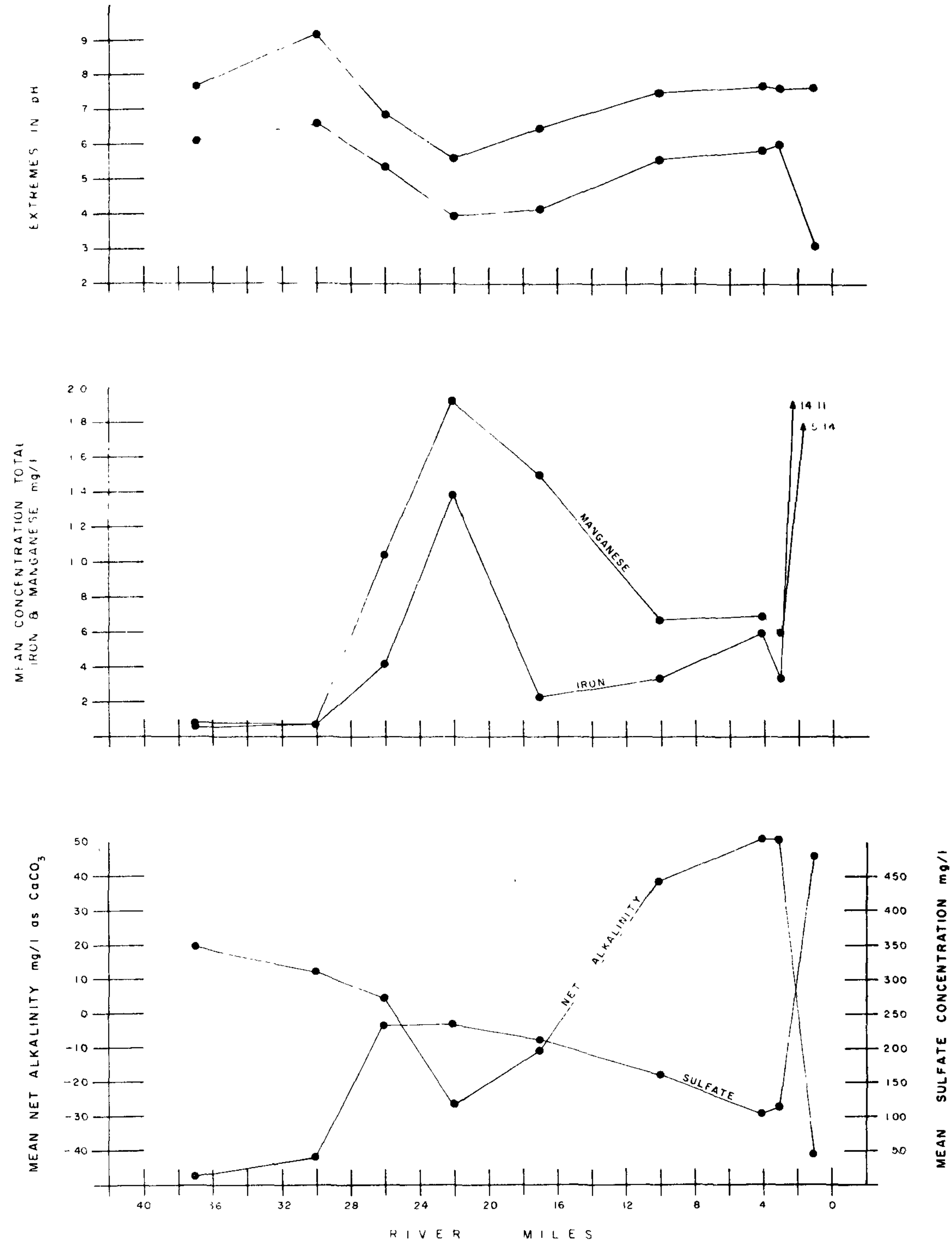
FIGURE 10-B



PROFILE OF FLOW, NET ALKALINITY OF LACKAWANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

JULY - OCTOBER, 1965

FIGURE II-A

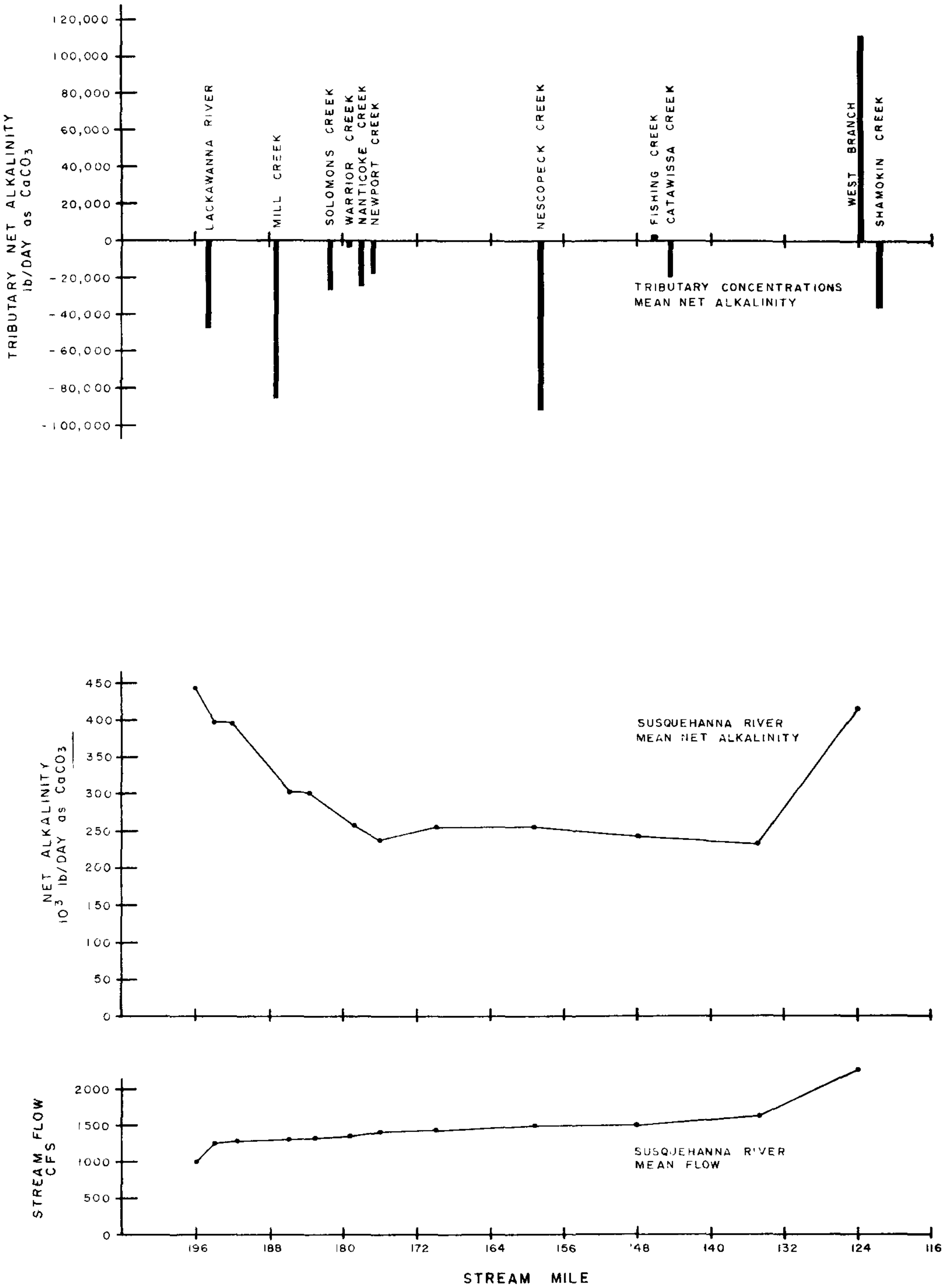


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

LACKAWANNA RIVER

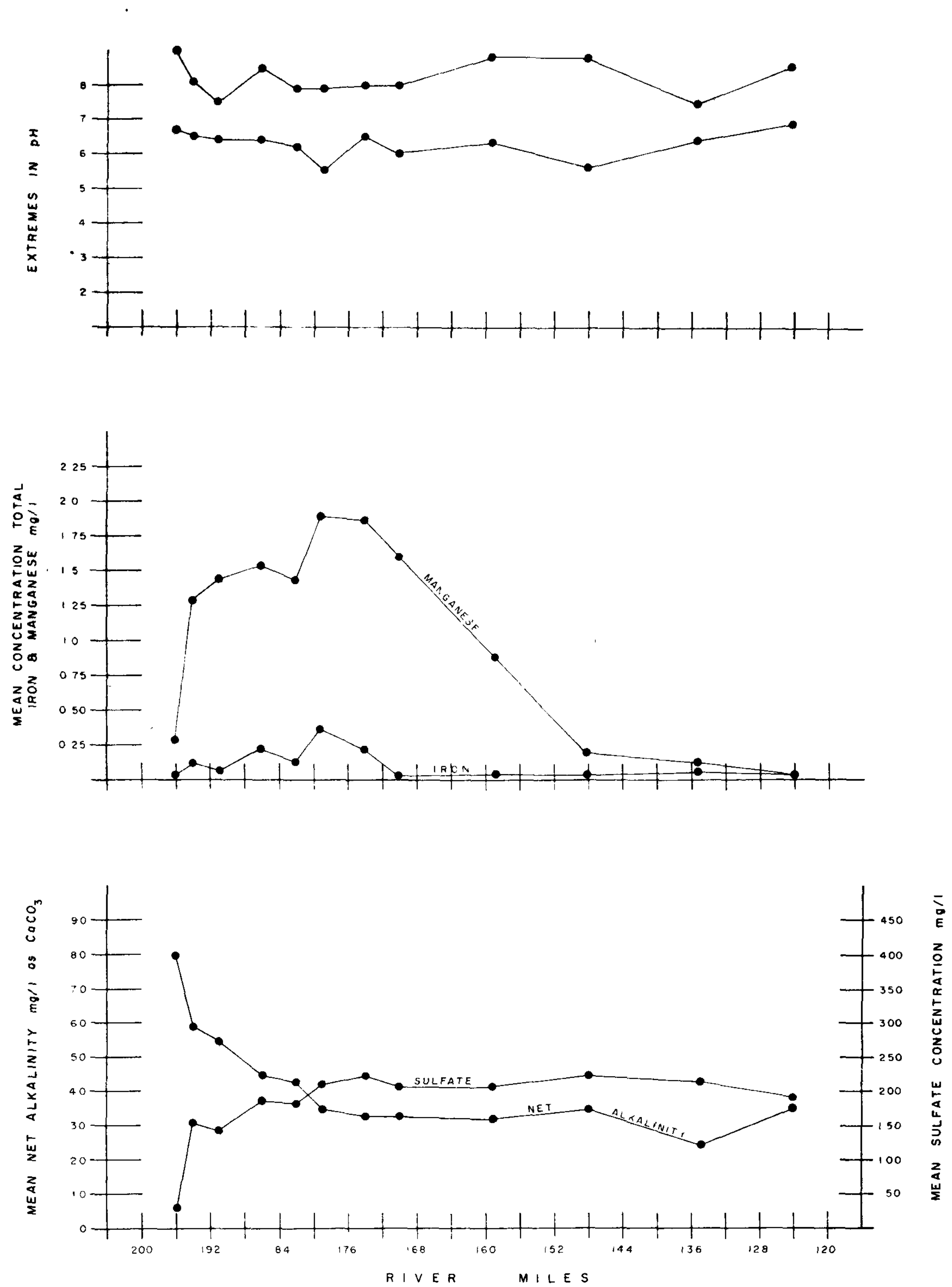
JULY - OCTOBER, 1965

FIGURE II-B



PROFILE OF FLOW, NET ALKALINITY OF SUSQUEHANNA RIVER
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
AUGUST - 1965

FIGURE 12-A

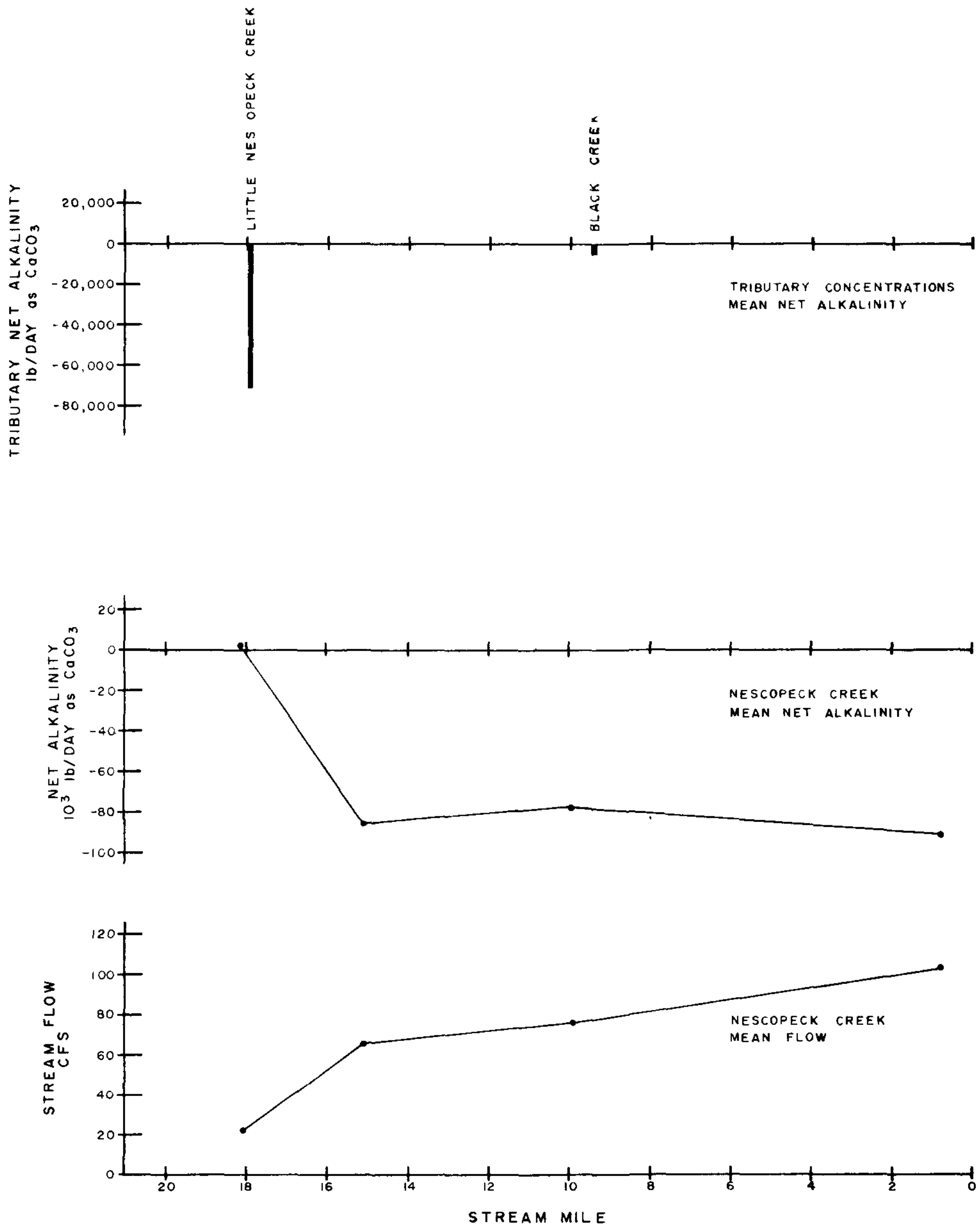


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

SUSQUEHANNA RIVER

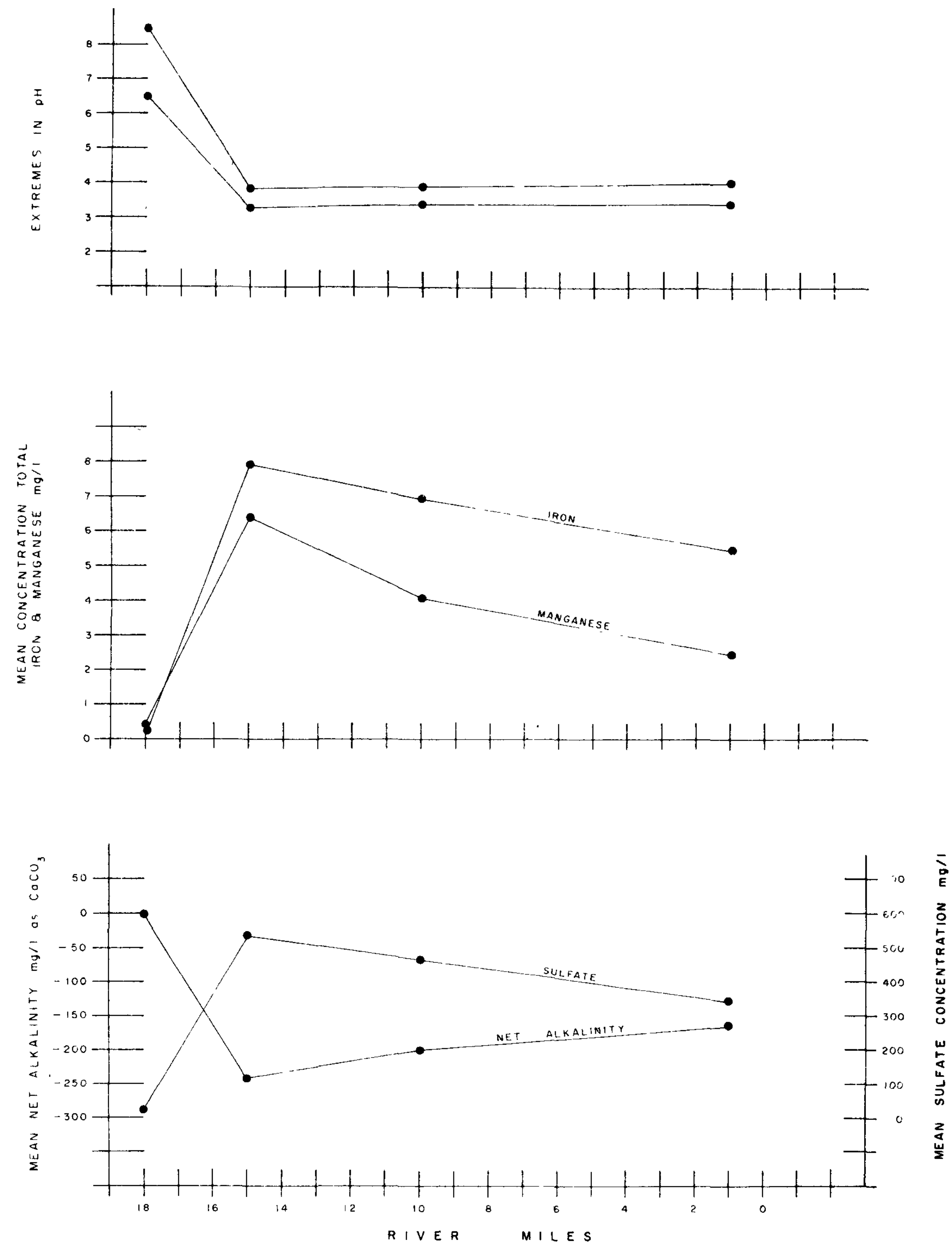
AUGUST - 1965

FIGURE 12-E



PROFILE OF FLOW, NET ALKALINITY OF NESCOPECK CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
AUGUST - SEPTEMBER, 1965

FIGURE 13-A

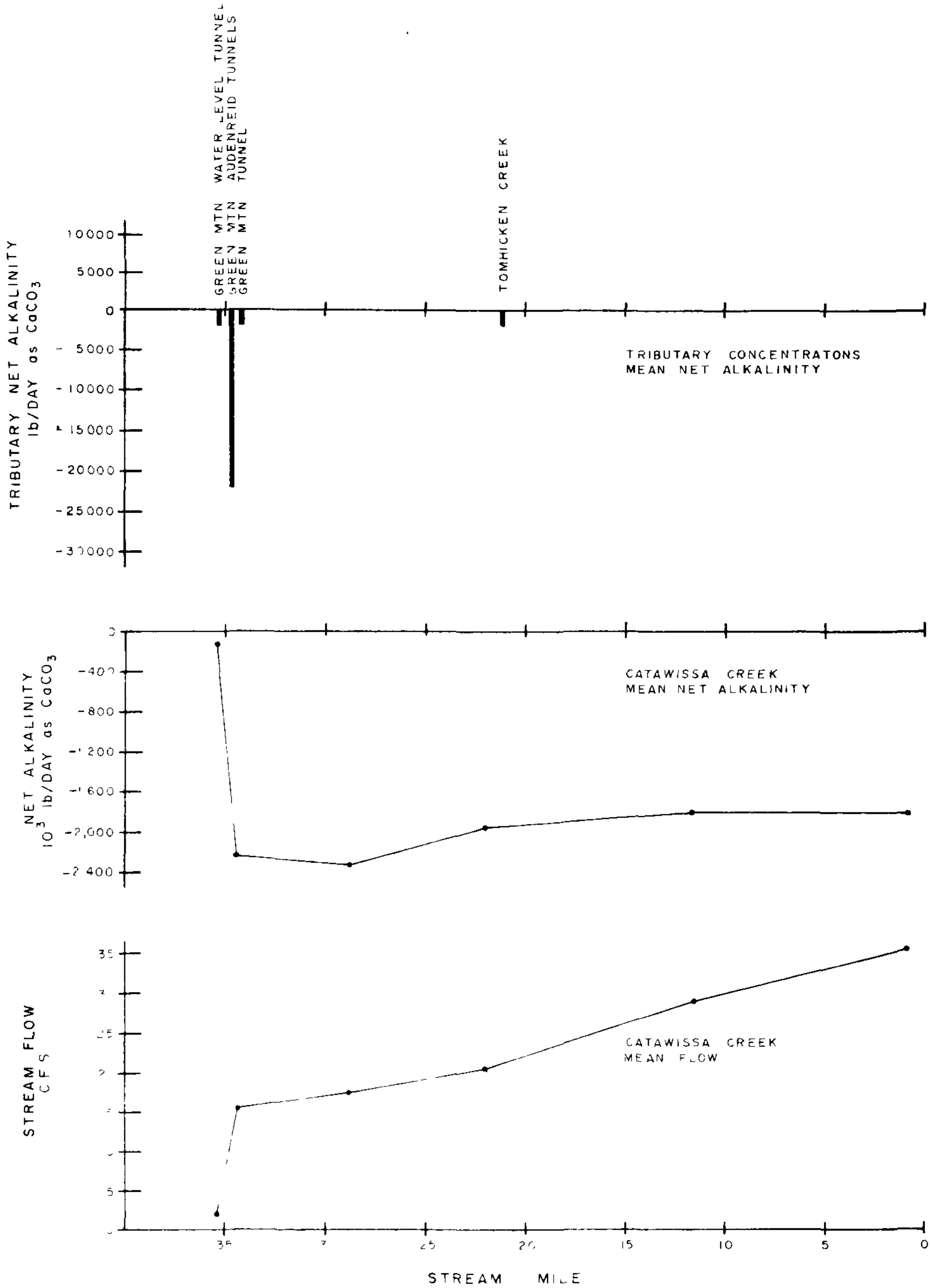


PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

NESCOPECK CREEK

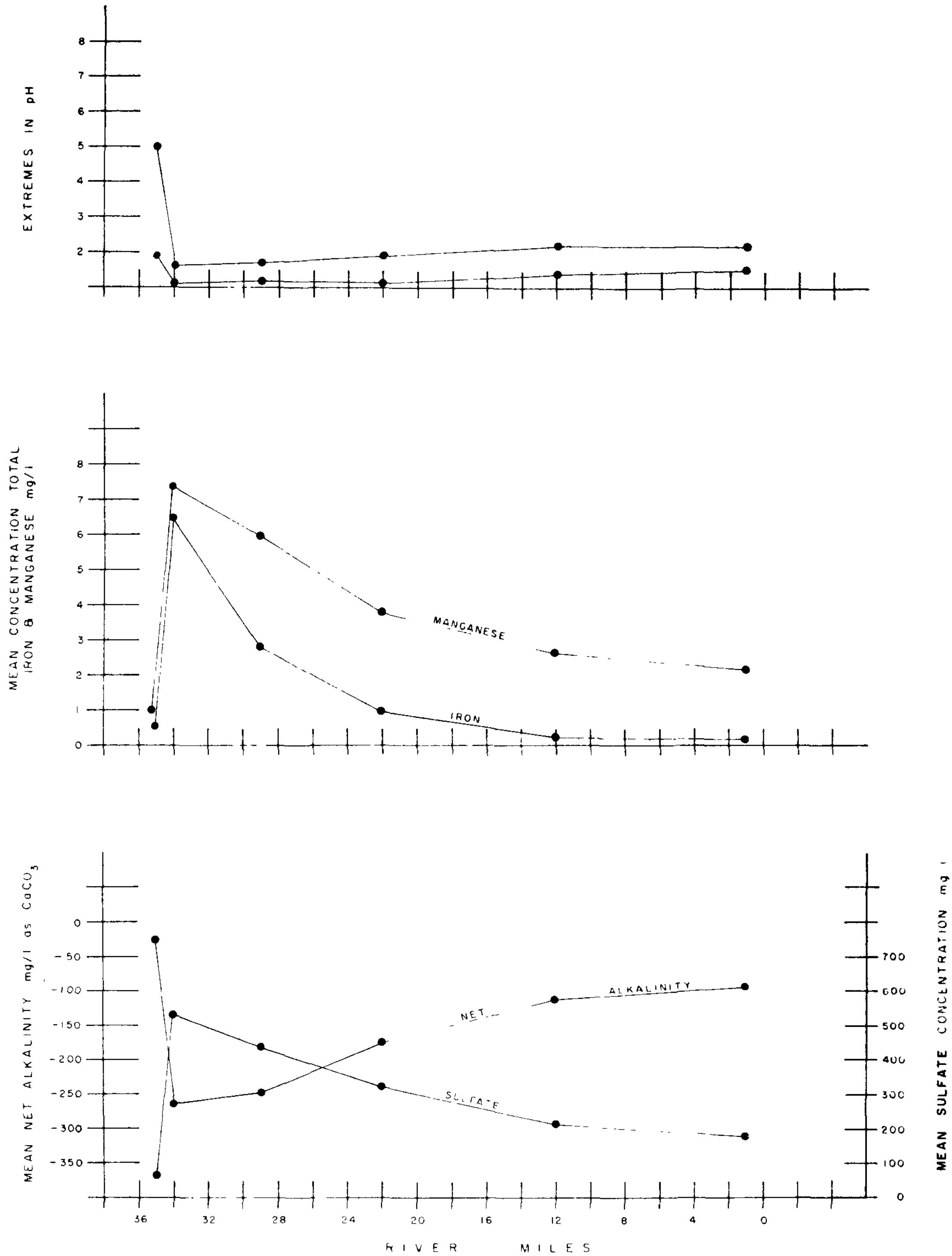
AUGUST – SEPTEMBER, 1965

FIGURE 13-8



PROFILE OF FLOW, NET ALKALINITY OF CATAWISSA CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
AUGUST – SEPTEMBER, 1965

FIGURE 14-A

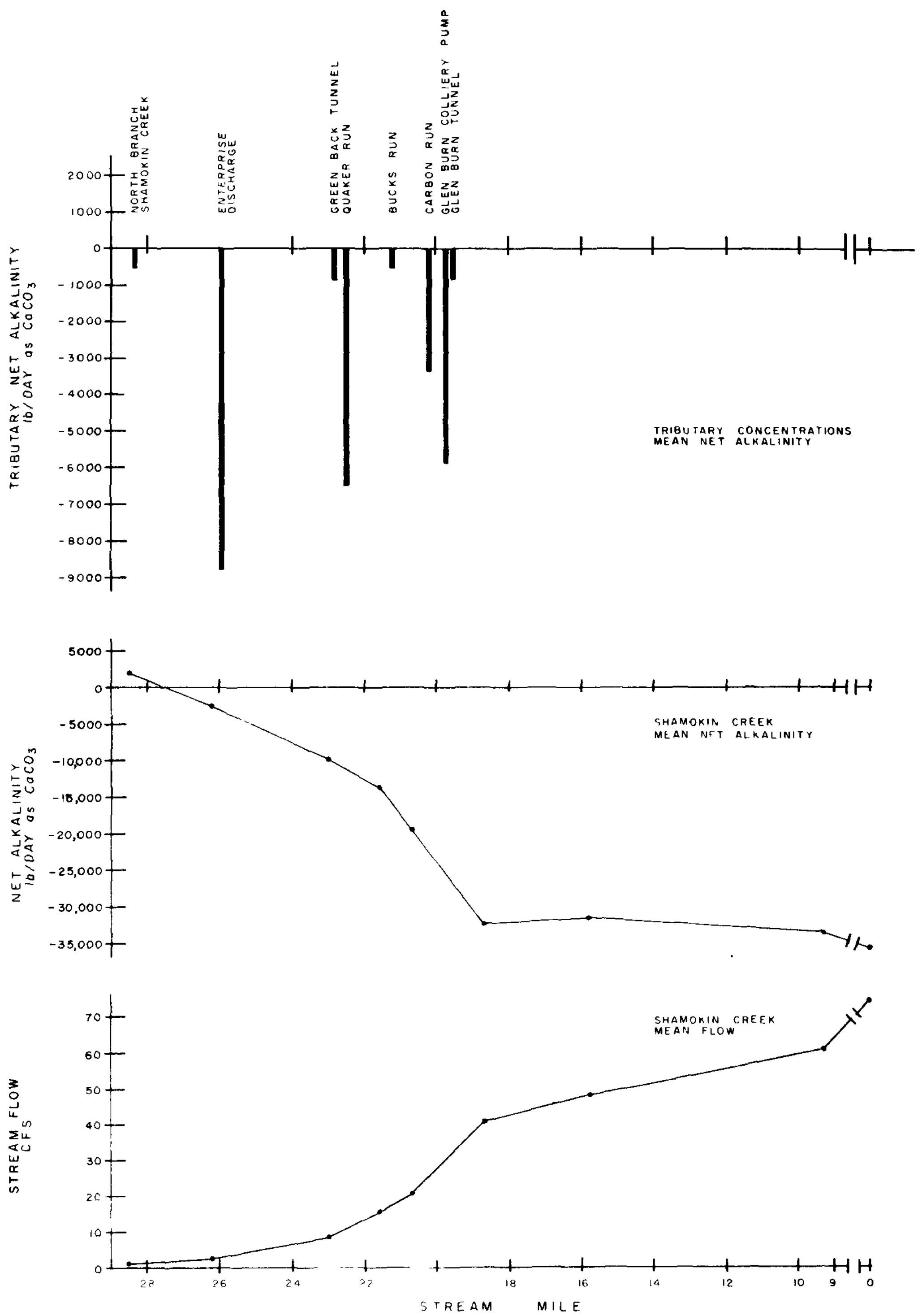


PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

CATAWISSA CREEK

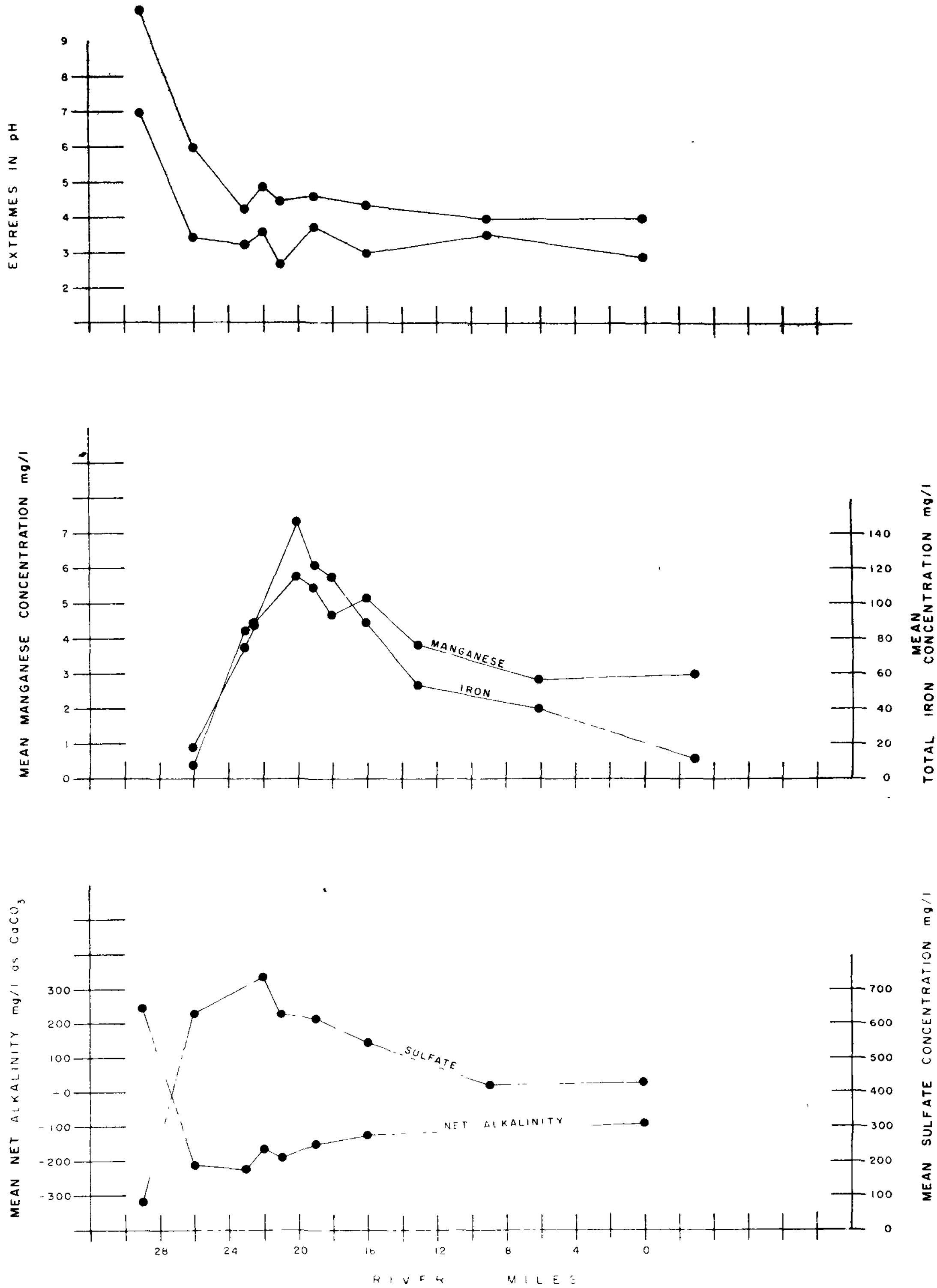
AUGUST – SEPTEMBER, 1965

FIGURE 14-8



PROFILE OF FLOW, NET ALKALINITY OF SHAMOKIN CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
OCTOBER - NOVEMBER, 1965

FIGURE 15-A

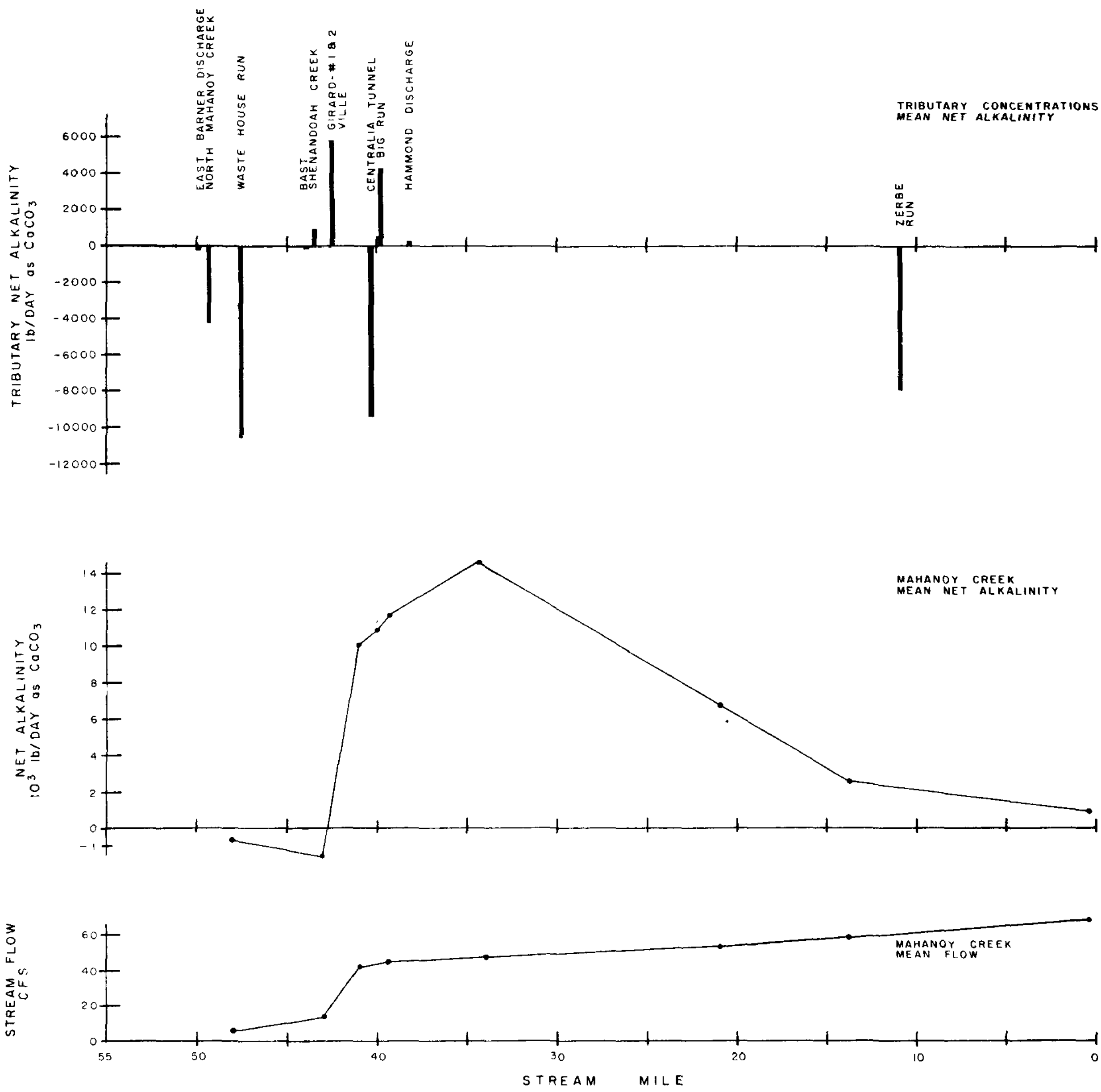


PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

SHAMOKIN CREEK

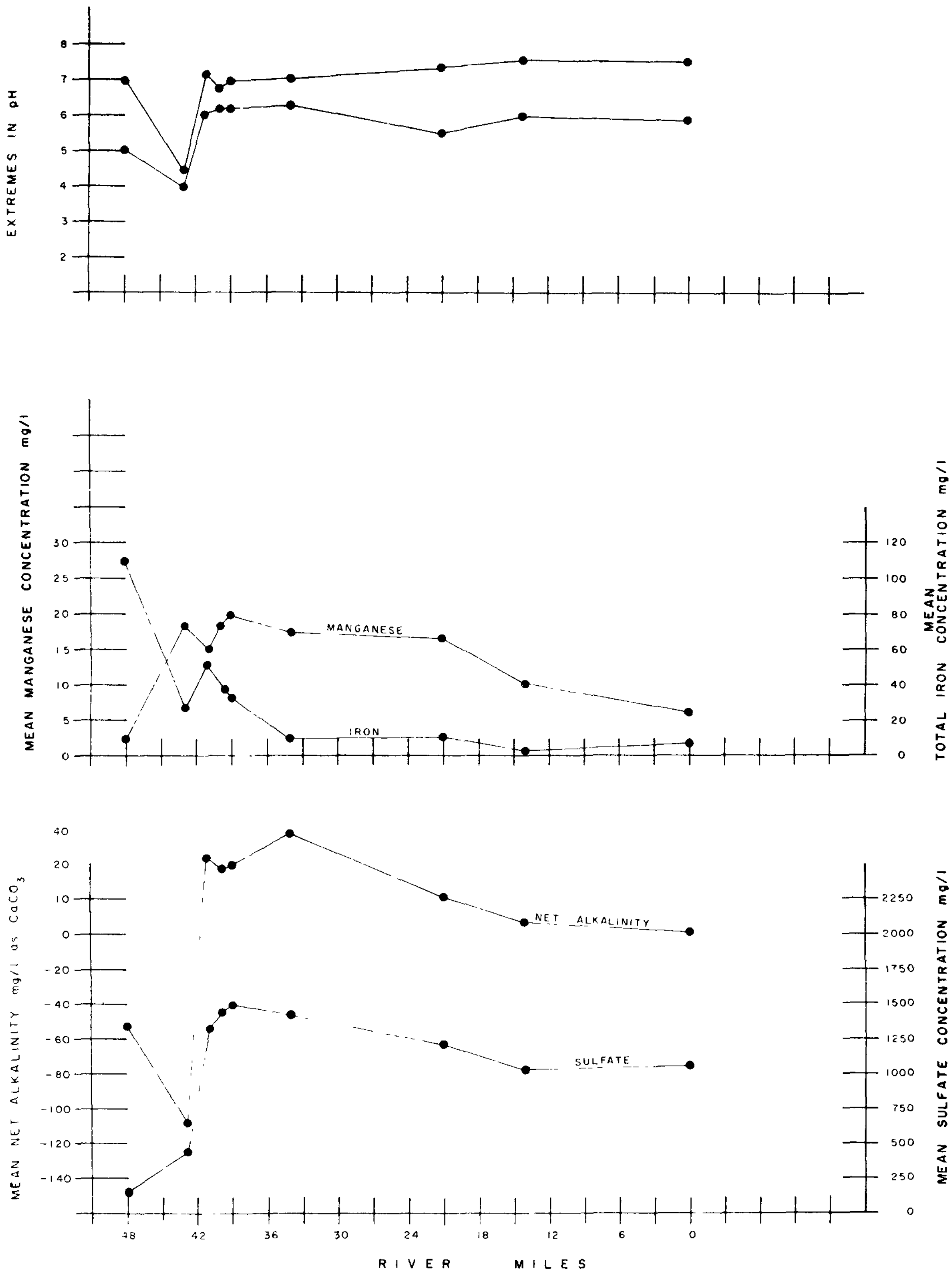
OCTOBER – NOVEMBER, 1965

FIGURE 15-B



PROFILE OF FLOW, NET ALKALINITY OF MAHANOY CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY - SEPTEMBER, 1965

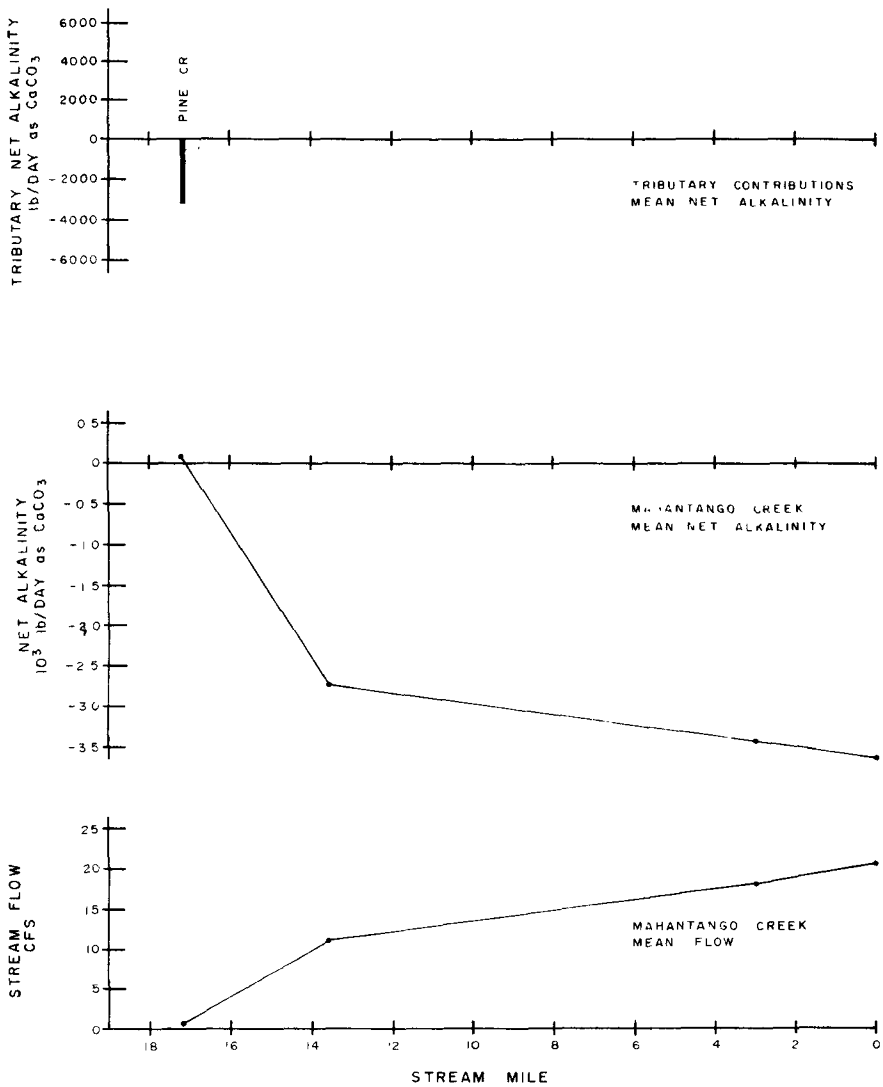
FIGURE 16-A



PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

MAHANOY CREEK

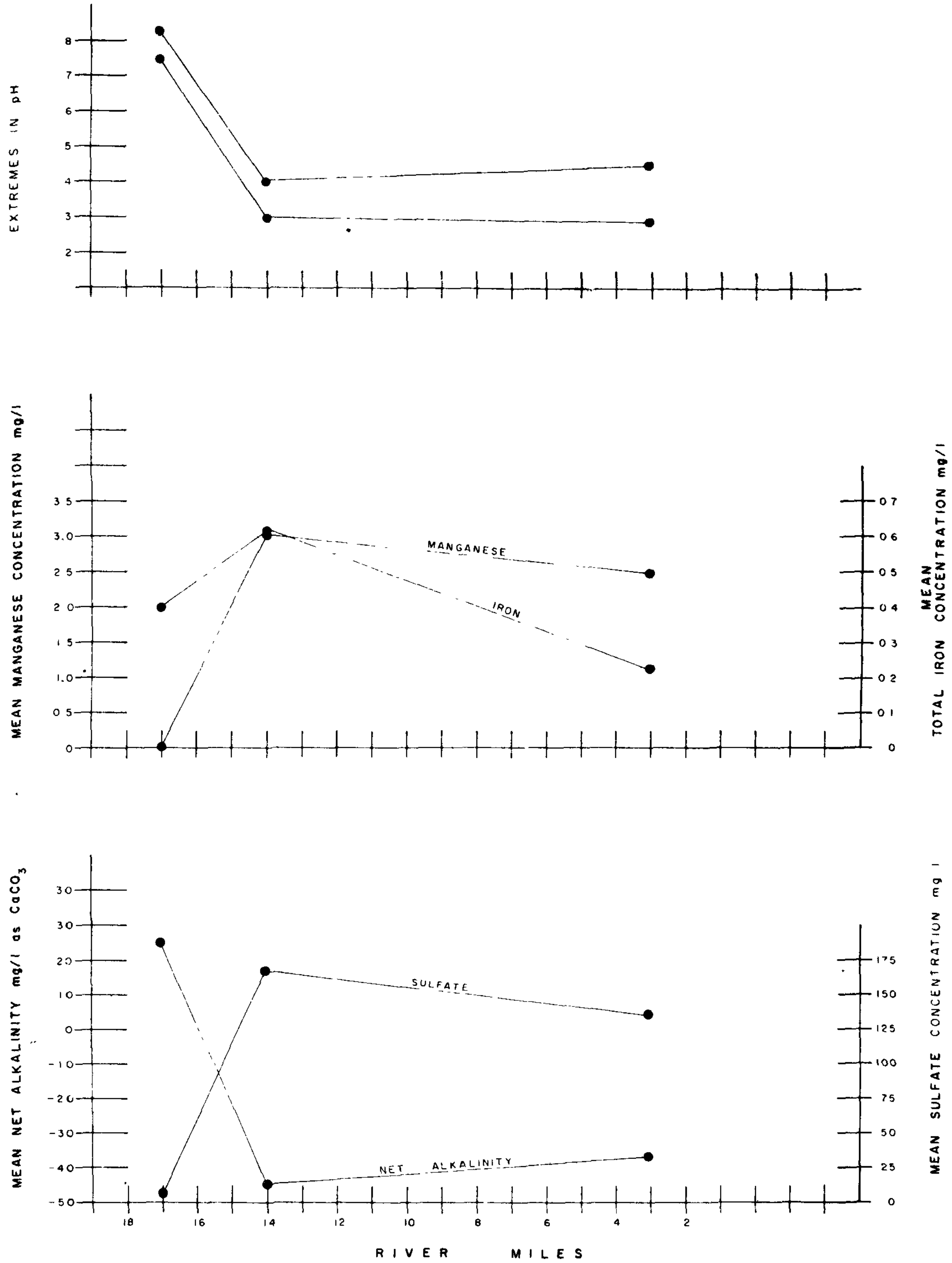
FIGURE 16-B



PROFILE OF FLOW, NET ALKALINITY OF MAHANTANGO CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY

JULY - 1965

FIGURE 17-A

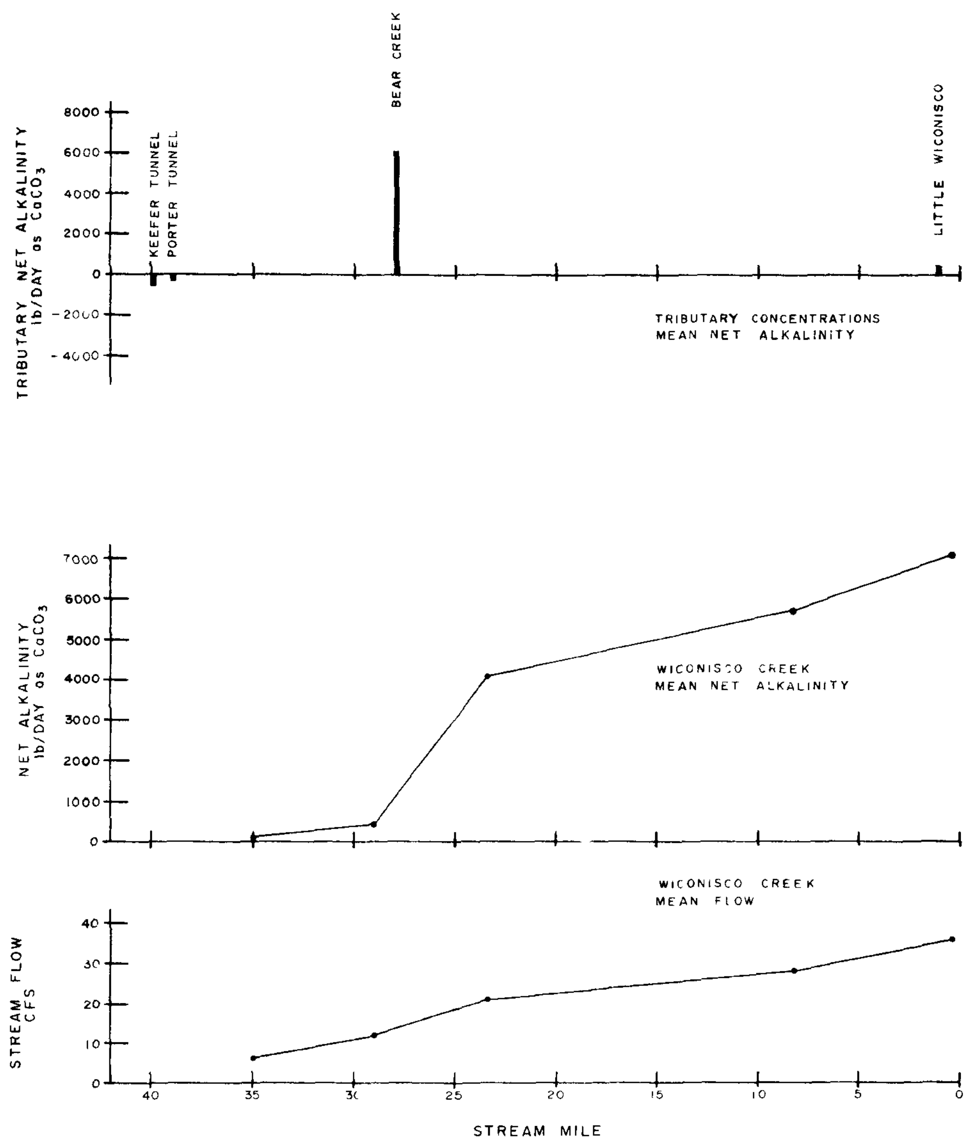


PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

MAHANTANGO CREEK

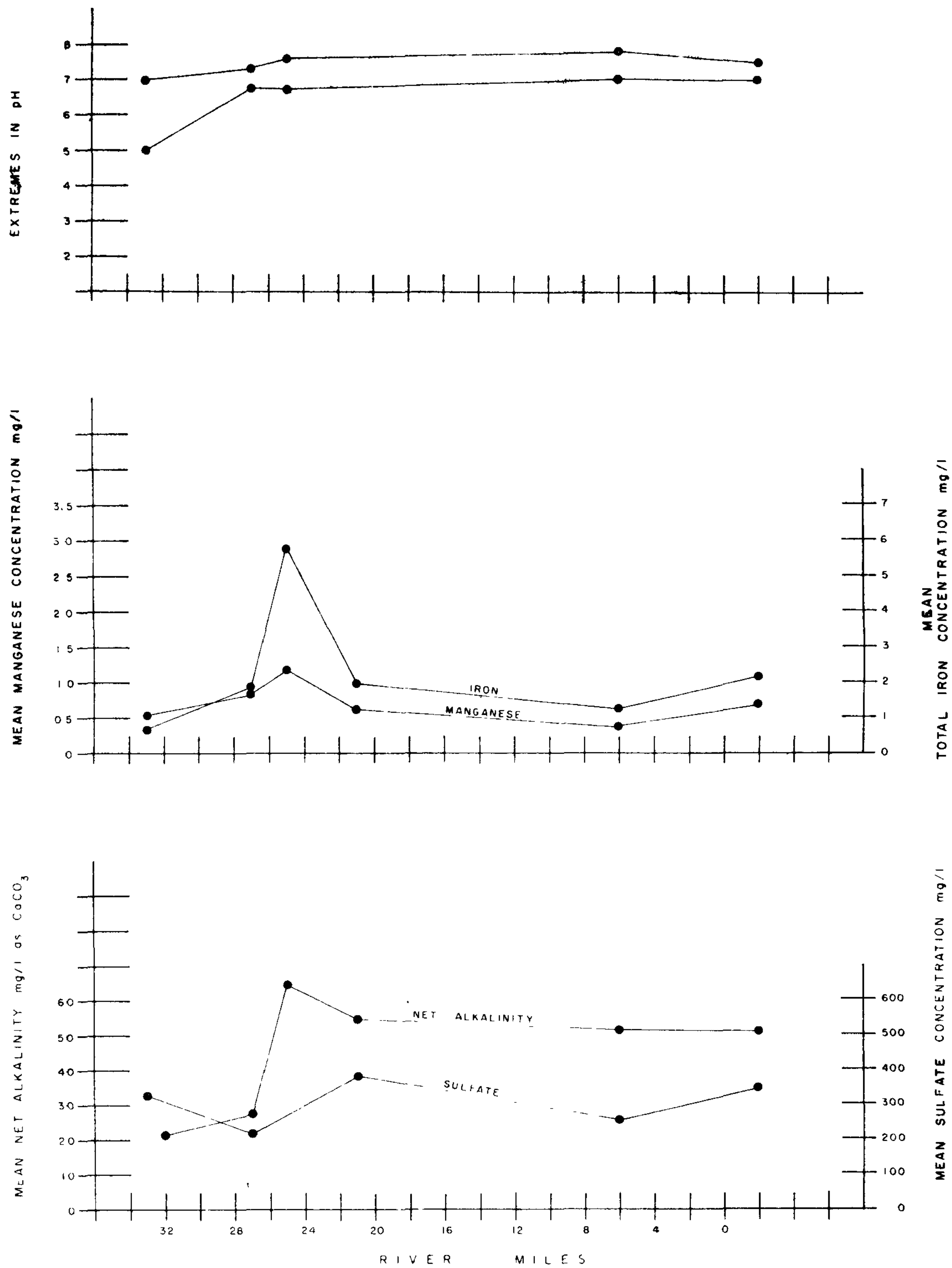
JULY - 1965

FIGURE 17-B



PROFILE OF FLOW, NET ALKALINITY OF WICONISCO CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
JULY - 1965

FIGURE 18-A

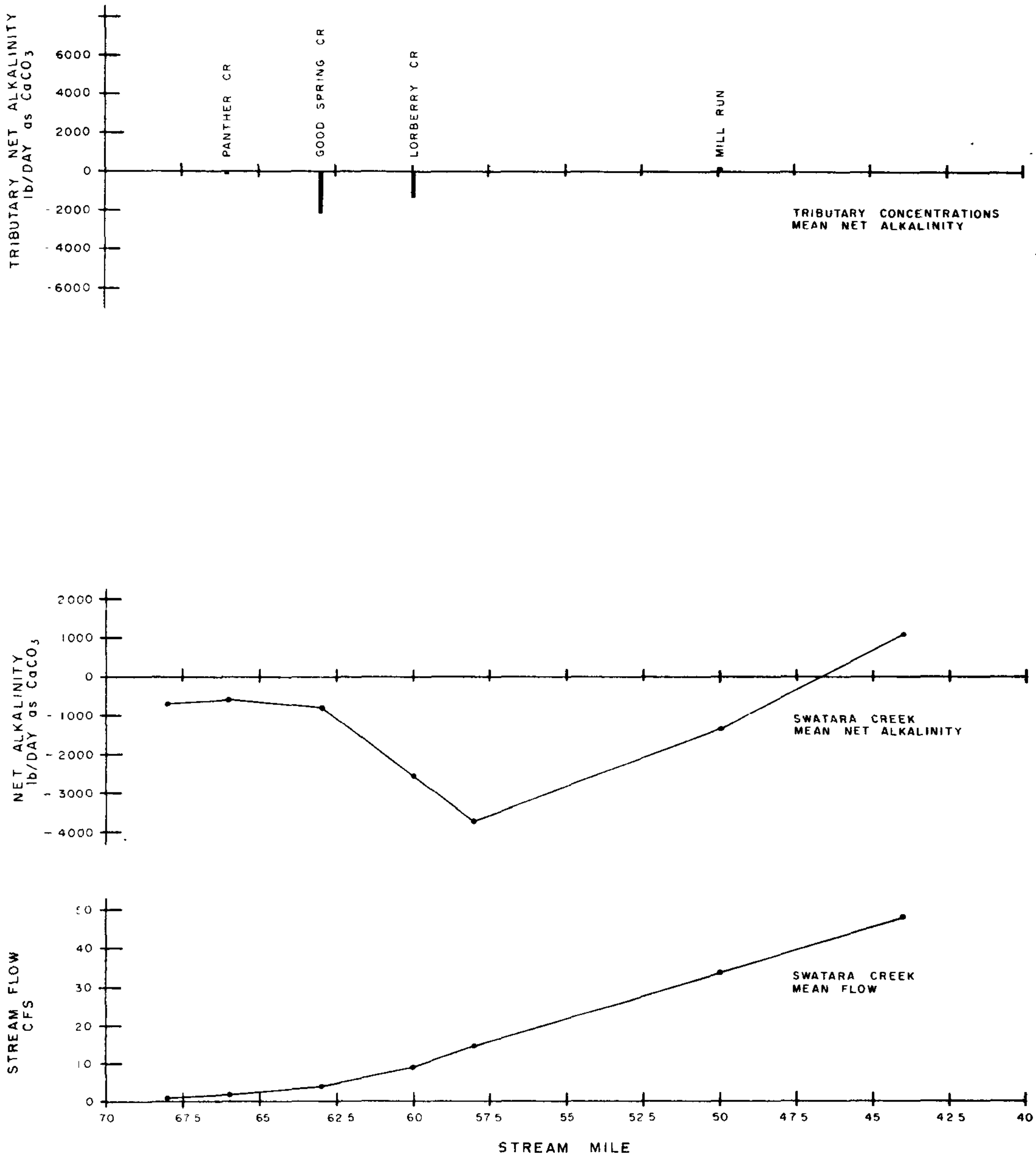


PROFILE OF pH, MANGANESE, IRON & SULFATE CONCENTRATION AND NET ALKALINITY

WICONISCO CREEK

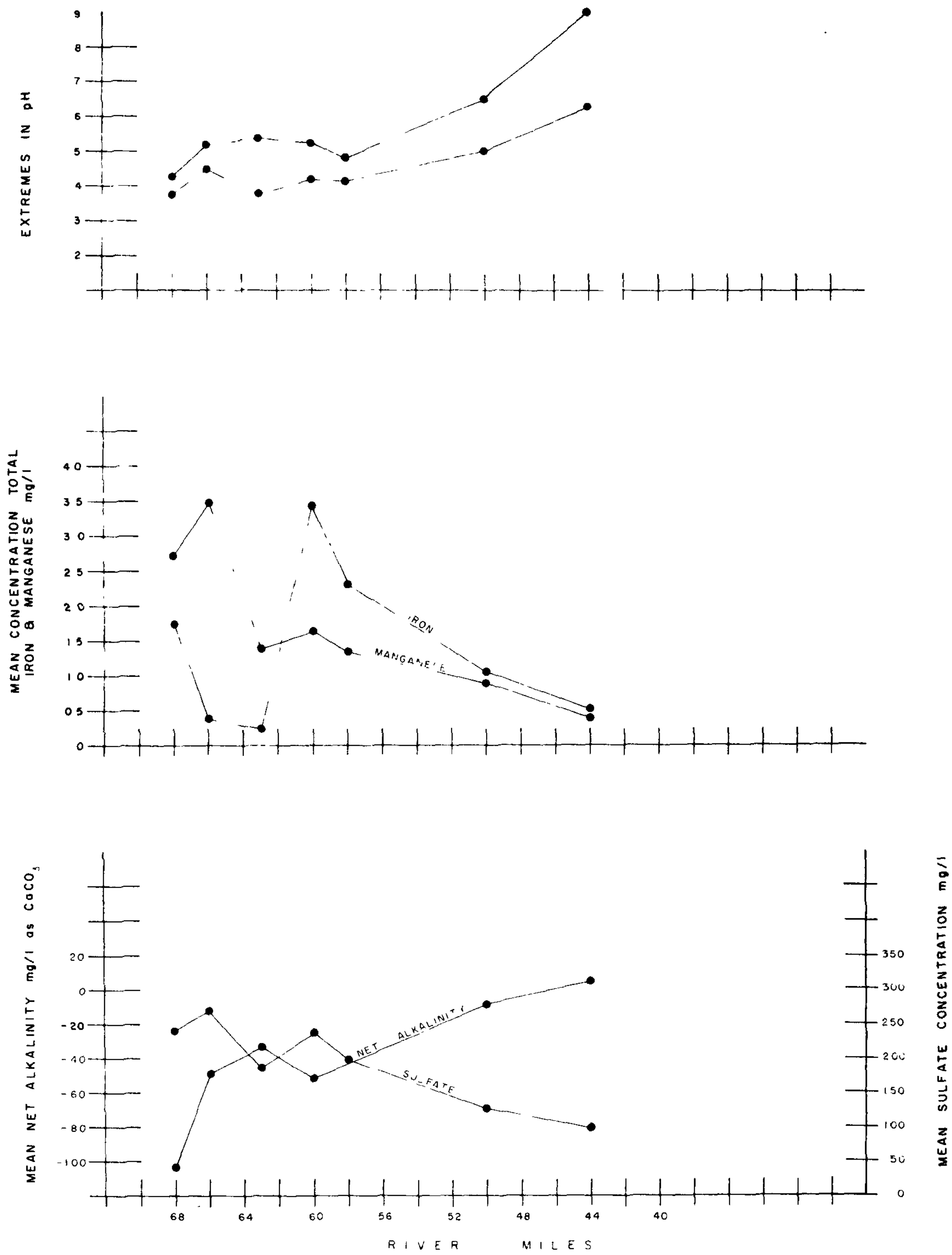
JULY - 1965

FIGURE 18-B



PROFILE OF FLOW, NET ALKALINITY OF SWATARA CREEK
AND
TRIBUTARY CONTRIBUTIONS OF NET ALKALINITY
OCTOBER – NOVEMBER, 1965

FIGURE 19-A



PROFILE OF pH, MANGANESE, IRON & SULFATE
CONCENTRATION AND NET ALKALINITY

SWATARA CREEK

OCTOBER – NOVEMBER, 1965

FIGURE 19-B