III ANALYSIS AND INTERPRETATION OF FINDINGS

GENERAL

Quantitative and qualitative analysis of the collected data was made to enable the determination of the magnitude and causes of AMD discharges in the study area. The analysis included the effect of the present AMD discharges on the quality of the water in the study area streams and their effect on the quality of the Susquehanna River.

The prevailing conditions in the study area, presented in. the previous section, indicate that the major AMD discharges in the study area are the South Wilkes-Barre boreholes and the Buttonwood Tunnel in the Solomon Creek watershed, and the Askam borehole in the Nanticoke Creek watershed. Surface water losses into the deep mines thru streambeds and strip mine areas and the inflow of groundwater from above the coal measures recharge the mine pools. Since these mine pools extend beyond the study area limits, it is necessary to determine the magnitude of the surface water losses into the deep mines within, as well as outside the study area. Moreover, the allocation of surface water losses to major sub-areas in each watershed is a necessary prerequisite to the determination and the evaluation of AMD abatement measures for the study area.

PRESENT WATER QUALITY IN THE STUDY AREA

The stream flows in the study area watersheds originate in the upper portions of these watersheds, located outside of the coal measures (See Sub-Area A, FIGURE 1 -pocket). The quality of the study area streams, above the coal measures, relative to the AMD parameters is presented in TABLE V (Page 32). The presently adopted D.E.R. Water Quality Criteria for the indicated parameters in these streams is also shown in this Table.

The areas of the watersheds above the coal measures are sparsely populated (See FIGURE 1- pocket). Therefore, it is reasonable to assume that the range of water quality values, presented in TABLE V (Page 32), reflects the natural value of these

TABLE V

QUALITY OF STREAMS ABOVE COAL MEASURES

AMD PARAMETER	DER* ADOPTED STANDARDS	RECORDED RANGE OF VALUES				
		NANTICOKE CREEK WATERSHED			SOLOMON CREEK WATERSHED	
		MONITORING STATIONS			MONITORING STATIONS	
		N-8	N-9A	N-13A	S-11A	S-12
pH	6.0 - 8.5	5.87-7.3	6.42-7.85	6.0- 7.58	[1]5.65-7.45	[1]4.7- 6.85
TEMPERATURE (°F)	-	33.8-64.4	33.8-59	33.8-62.6	35.6-64.4	35.6-66.2
ACIDITY (ppm)	-	0.0-100	0.0-18	0.0-10	2.0-22	2.0-17
ALKALINITY (ppm)	> 20	0.0-200	6.0-24	0.0-16	0.0-12	0.0-26
TOTAL IRON (ppm)	< 1.5	0.0- 0.8	0.0- 0.6	[2]0.0-2.3	0.0- 0.7	[2]0.0- 3.6
SULFATES (ppm)	250 OR Natural Level	19.0-200	12.0-225	5.0-175	11.0-225	30.0-200

1 *Single Value on 1/08/74; All Other Values Above 6.0*
2 *Single Value; All Other Values Less Than 1.5 ppm*
* *TITLE 25; DER Rules & Regulations; Chapter 93, Water Quality Criteria (Adopted 9/2/71) Zone No. 0.3010.01*

streams. The low concentration of alkalinity in the streams is below the levels desired by the present Water Quality Standards. These low levels of alkalinity also indicate that alkaline salts, attributed to highway pollution sources, did not materially affect the water quality during the winter sampling dates.

After crossing the coal measures, the streams decrease in flow rate due to streambed losses into the strip mine area and the deep mines. Furthermore, these streams degrade in quality due to runoff over and AMD seepage from waste piles, accidental spills, discharges of raw sewage from unsewered communities and other factors, previously described (see PART II, Existing Conditions).

The groundwater table within the coal measures South of Middle Road (Areas C and D, Figure 1 (pocket)) is below the level of streambeds and is governed by the mine pool levels. Therefore, even if streambed losses are prevented, the recharge and base flow of the area streams is. limited to the stream recovery area North of Middle Road and to the inflow from above the coal measures (Areas E and A, respectively, Figure 1 (pocket)). If the present AMD discharges from the boreholes and the Buttonwood Tunnel were prevented from contaminating the study, area streams, the quality of the base flow in these streams would be governed by the quality of the inflow from above the coal measures and the quality of the stream recharges in Area E.

Analysis of water quality records of the streams within Area E indicates that the quality of stream recharge water does not reflect the AMD concentration of the mine pools water. Therefore, it must be concluded that the primary source of recharge to the streams in Area E is groundwater. The quality of water that recharges the base flow of the streams in Area E is presented in TABLE VI.

TABLE VI

QUALITY OF BASE FLOW RECHARGE IN THE STUDY AREA STREAMS

WATER QUALITY PARAMETER	DER ADOPTED STANDARDS	RANGE OF VALUES							
		NANTICOKE CR. WATERSHED			WARRIOR CR. WATERSHED			SOLOMON CR. WATERSHED	
		MONITORING STATIONS							
		N-1	N-2	N-3	W-1	W-2	W-3	S-10	S-9C
pH	6.0 - 8.5	6.4	5.2	6.7	7.3	7.7	7.6	6.0	
TEMPERATURE (^{0}F)		← 46.4 - 71.6 →			← 33.8 - 69.8 →			← 32 - 78.8 →	
ACIDITY (ppm)	-	53	103	54	17	7.8	6.7	4.9	
ALKALINITY (ppm)	> 20	86	18	167	153	196	143	7.5	
TOTAL IRON (ppm)	< 1.5	8.6	13.8	5.6	2.3	1.5	0.9	0.3	
SULFATES (ppm)	250 or Natural Level	408	675	356	227	307	136	71.0	

NOTE: Shaded columns indicate the highest quality base flow water that can be achieved in Area E after restoration of each of the watersheds listed.

TABLE VI indicates that although the groundwater recharge is of comparatively good quality, it does not meet all the presently adopted Water Quality Criteria for the area streams. The alkalinity of the groundwater recharge in Solomon Creek is below the presently adopted desired level of concentration, whereas the total iron concentration in the Nanticoke Creek is above the adopted standard. Consequently, the quality of the natural water inflow from above the coal basin, as well as the quality of the groundwater recharge in the lower stretches of the study area streams, do not meet all the present adopted water quality standards.

Therefore, consideration should be given to re-examining the basis by which water quality standards were adopted for the Solomon, Warrior, and the Nanticoke Creeks.

Examination of the presently proposed standards* indicates that the study area streams were grouped together with all the tributaries of the North Branch of the Susquehanna River, from its confluence with the West Branch to the Lackawanna River. The only exclusions defined are Harvey, Shickshinny, Nescopeck, Fishing, Catawissa, Roaring and Mahoning Creeks. In the present grouping of tributaries, the desired water quality in the streams within the coal measures is considered by D.E.R. to be the same as the quality desired of Toby, Abraham and other creeks where most of the watersheds area is located outside the coal measures. In addition to standard water uses adopted forr all streams in the Commonwealth, both boating and cold.water fish were added to the list of water uses for the study area streams. At present there are no fish in the study area streams (neither warm nor cold water fish). This is also reflected by the list of fishing streams in Luzerne County. The intermittent flow conditions that presently exist in the study area streams, preclude boating from being a necessary water use that requires protection. Consequently, it is possible that a review of the natural water quality in the study area streams and the desired use of these streams by the local people would enable the Water Quality Branch of D.E.R. to revise the presently proposed water quality criteria for these streams.

WATER QUALITY OF THE SUSQUEHANNA RIVER

The quality of the Susquehanna River upstream of the Wyoming Valley is not affected by AMD discharges. Unpublished records of five sampling periods between February 3, 1972 and November 28, 1972, indicate that the average alkalinity, sulfates and total iron were 43, 43 and 0.4 ppm, respectively. For these same sampling periods, the quality of the Susquehanna, immediately below its confluence with the Lackawanna River was considerably degraded. At this location, the average concentration of alkalinity was 1 ppm, sulfates

** Title 25; D.E.R. Rules & Regulations; Chapter 93, Water Quality Criteria (adopted September 2, 1971); Zone No. 0.3010.01, Table 8.*

was 201 ppm, and total iron was 9.65 ppm. These values indicate that the Lackawanna River is a major contributor of AMD to the Susquehanna River, upstream of the study area.

Monthly water quality records of the Susquehanna River, downstream of the Lackawanna confluence, are available since January, 1968. The major sampling points of the River are the Wyoming and Plymouth Bridges, upstream of the study area and the Nanticoke Bridge, downstream of the study area. These records indicate that with the exception of total iron and manganese concentration, the pH, alkalinity, dissolved solids and sulfate concentration meet the water quality standards (presently proposed by the Water Quality Branch of D.E.R.) for this stretch of the River. The relationship between the proposed water quality standards and the range of the recorded water quality of the river are as follows:

AMD PARAMETER	DER STANDARDS	RECORDED RANGE OF VALUES*		
		WYOMING BRIDGE	PLYMOUTH BRIDGE	NANTICOKE BRIDGE
pH	6.0 - 8.5	6.6 - 8.0	6.7 - 7.5	6.6 - 7.6
Alkalinity ppm	20	24 - 85	24 - 104	26 - 128
Sulfates ppm	250 or Natural Level	20 - 140	25 - 140	12 - 140
Iron ppm	1.5 Maximum	0.5 - 10	0.4 - 10	0.4 - 15
Manganese ppm	1.0	0.0 - 7.2	0.0 - 2.6	0.0 - 10.6
Total Solids ppm	-	40 - 640	40 - 600	60 - 500
Dissolved Solids ppm	500	-	-	-

* *For the sampling period 1968-1974 (D.E.R. data)*

The concentrations of the AMD parameters at selected dates of high iron concentration and the variation of these concentrations between the Wyoming Bridge and the Nanticoke Bridge, are presented in FIGURE 7 (pocket). The flow rates of the Susquehanna River at Wilkes-Barre and the Lackawanna River at Old Forge are also shown in this figure, for the aforementioned sampling dates.

Water quality records at the Wyoming and Plymouth Bridges reflect the effect of the Lackawanna discharges on the Susquehanna River. Water quality records at the Nanticoke Bridge reflect the combined effect of the Lackawanna River and the discharges from the study area. These water quality records indicate a general improvement in water quality between the Wyoming and Plymouth sampling stations. The reduced iron concentration between the confluence of the Lackawanna and the Plymouth Bridge can be attributed to the precipitation of the iron, at the pH levels of the Susquehanna River in this stretch of the River.

The major AMD discharge sources in the study area are the three South Wilkes-Barre boreholes (Station S-3), the Buttonwood Tunnel (S-2) and the Askam boreholes (N-4). The total load of acid, sulfates, and iron from these three sources during the study period sampling dates are presented in TABLE VII. The computed

TABLE VII

MAGNITUDE OF AMD DISCHARGES

SAMPLING	DISCHARGE IN CFS				TOTAL LOAD IN LBS/DAY			INCREASE IN RIVER CONCENTRATION ppm		
DATE	SUSQ. R.	S-3	S-2	N-4	ACID	SULFATE	IRON	ACID (-ALK)	SULFATE	IRON
08/09/73	2,830	30.52	17.16		120,179	549,960	73,122	7.9	36	4.5
09/10/73	2,960			0.78						
09/21/73	3,560	28.96	15.60		126,695	461,580	72,432	6.6	24	3.8
09/26/73	5,370			6.24						
10/24/73	2,020			0.58	116,573	408,930	73,145	10.7	38	6.8
10/25/73	2,010	28.96	10.03							
11/26/73	5,620	21.17	10.03		141,000	330,150	57,054	4.7	11	1.9
11/27/73	6,800			0.0						
01/07/74	14,500	33.47	27.40		171,746	738,450	86,288	2.2	9	1.1
01/09/74	11,800			14.93						
02/04/74	20,800	30.08	31.19		202,524	691,350	146,916	1.8	6	1.3
02/05/74	18,100			18.94						
03/20/74	18,100			17.60	202,788	600,570	152,638	2.1	6	1.6
03/21/74	17,800	30.08	28.96							
04/29/74	11,300	46.12	29.19		208,620	660,750	92,946	3.4	11	1.5
04/30/74	10,200			8.91						
05/29/74	8,200	38.99	25.62		131,640	726,000	70,330	3.0	16	1.6
05/30/74	7,960			3.34						
06/26/74	5,210	32.97	20.50	0.0	158,592	361,800	69,941	5.7	13	2.5
07/16/74	3,840	30.08	11.59		196,920	290,025	43,318	9.5	14	2.1
07/17/74	3,710			0.0						
08/20/74	1,750	27.63	8.20		117,660	285,765	43,012	12.5	30	4.6
08/21/74	1,700			0.0						

increase in the sulfate and iron concentration of the River and the decrease in River alkalinity due to the major AMD discharges from the study area are also presented in TABLE VII (page 36). This table indicates that the maximum increase of iron and sulfate concentration in the River, resulting from the study area. AMD discharges, are 6.8 ppm and 38 ppm, respectively. During the same study period, the maximum decrease in the River alkalinity due to these major discharges was 12.5 ppm.

The only deviation from the proposed D.E.R. Water Quality Standards is related to the concentration of iron and manganese in the River. The maximum allowable concentration of dissolved iron and manganese in drinking water* are 0.3 and 0.05 ppm, respectively. Therefore, the proposed water quality standards for these parameters indicate that the use of the Susquehanna River water for public water supply requires the removal of iron and manganese in water treatment plants. Since the Department of Environmental Resources' standards for the River are 1.5 ppm for iron and 1.0 ppm for manganese, water treatment would be required for some industrial water uses and the watering of livestock. It is therefore assumed that the proposed limits for iron and manganese concentration in the River are dictated by the aquatic life requirements of the River.

In contrast with the study area streams, the Susquehanna River throughout Luzerne County is included in the Pennsylvania Fish Commission list of fishing streams. The prevailing species are: Smallmouth Bass, Walleye, Sucker, Bullhead, Carp, Pickerel, Fallfish and Channel Catfish. The history of "fish kills" in the North Branch of the Susquehanna River indicates that since 1949, out of 13 reported cases, only five are attributed to AMD discharges. The magnitude and extent of these five cases, the reported and interpreted source of pollution, and the discharge of the Susquehanna and the Lackawanna Rivers, are presented in TABLE VIII (page 38). This table indicates that all reported "fish kills" occurred during the

U.S. Public Health Service Drinking Water Standards, 1962

TABLE VIII

SUSQUEHANNA RIVER FISH KILL

DATE	FLOW IN CFS		LIMITS OF KILL	NO. OF FISH KILLED	SOURCE OF FISH KILL
	SUSQ. R.	LACK. R.			
07/23-24/49	1,290	155	Ten miles below Pittston	Thousands	Lackawanna River*
08/07/55	732	153	Pittston to Wyoming Bridge	Not Reported	Lackawanna River*
10/09-10/61	1,570	34	W. Nanticoke to Sunbury	116,280	Deleware Pumps
08/28-9/01/62	1,200	223	Berwick to Danville	Not Reported	#5 Shaft Pumps Lackawanna River
07/28-31/66	1,670	136	Pittston to Nanticoke	100,000	Lackawanna River

* *Interpretation by GEO-Technical Services*

low flow discharges of the Susquehanna River. The 1961 "fish kill" is directly attributed to the pumping of acid mine water at the rate of 17,500 GPM from the South Wilkes-Barre No. 5 Shaft with three newly installed-pumps. A report prepared by Mr. Robert J. Bielo (12/26/61) indicates that the pumping produced a pH value of 3.8 in the River from Wilkes-Barre to Sunbury and the total iron concentration for that period approached 40 ppm. The remaining four cases are characterized by a high discharge ratio of the Lackawanna River to the Susquehanna flow rate.

1969 Value of Fish Killed, Penna. Fish Commission Reports are as follows:

Minnows (up to 2 inches)	3¢/fish
Small Bass (up to 2 inches)	16c/fish
Bullheads (6" to 9 inches)	20c/fish
Suckers (8" to 12 inches)	25c/fish
Walleyes (under 6 inches)	50c/fish

The history of "fish kills" and the water quality records of the River support the following conclusions:

1. Although the iron and manganese concentrations in the River between 1968 and 197L1 (Listed in FIGURE NO. 7, pocket) were considerably higher than the present D.E.R. Water Quality Standards; There were no reported major fish kills during the sampling dates.

2. The danger level of iron, manganese and pH values in the aforementioned stretch of the Susquehanna River are directly related to the low flow frequency of the river, as well as to the flow ratio between the Lackawanna River and the Susquehanna River at these low flow conditions.

3. Maintaining the presently proposed standards of 1.5 ppm for iron and 1.0 ppm for manganese in the Susquehanna River, if considered essential, cannot be achieved without the complete abatement of the Lackawanna AMD outfalls. A recent Susquehanna River Basin (S.R.B.) Report* indicates that the Susquehanna River is classified as an intermittently polluted stream, only from the mouth of Solomon Creek, downstream to the mouth of the Nescopeck Creek. The S.R.B. report may lead to an erroneous conclusion that the upstream AMD pollution sources affecting the River emanate from the study area and not from the mouth of the Lackawanna River.

Although the Susquehanna River below the confluence of the Solomon, Warrior and Nanticoke Creeks is suitable for fish life, there is virtually no aquatic life present in the lower stretches of these study area streams. This lack of aquatic life is attributed to the following:

a. "Base flow" is intermittent along major stretches of the study area streams within the coal measures. This condition is caused by the absence of groundwater recharge in these stream stretches, and the interception of stream flow from the upper portions of these watersheds by streambed losses and diversion into the deep mines.

b. During high runoff periods, overland flow causes AMD pollution by contact with strip mining operations, abandoned mine waste piles and from streambeds containing coal silt deposits.

c. There are large concentrated AMD discharges into Nanticoke Creek from the Askam Borehole and large discharges into Solomon Creek, from the South Wilkes-Barre three boreholes and from the Buttonwood Tunnel. These discharges are the result of the necessity to control mine pool levels; and thereby reduce the

Coal Mine Drainage in the Susquehanna River Basin; Susquehanna River Basin Commission, September, 1973.

danger of basement flooding and possible subsidence in the low-lying urban areas. However, these benefits were achieved atthe expense of water quality in the receiving streams. Elimination of these large concentrated AMD pollution sources isrequired if restoration of aquatic life in the study area streams, "from source to mouth", is desired.

Previous studies* indicate that shortening the path of water movement in the mine pools, from points of recharge to points of discharge would result in reduced concentration of AMD parameters. Since the mine pools in the study area extend into the Mill Creek Watershed, the water losses that recharge these mine pools have

the furtherest travel distance to the South Wilkes-Barre boreholes. Therefore, reduction of water losses into the deep mines in the Mill Creek Watershed is expected to considerably reduce the present concentration of AMD parameters, as well as reduce the rate of the discharge from the South Wilkes-Barre boreholes.

THE WATER QUALITY MANAGEMENT CONCEPT AND ITS EFFECT ON RIVER QUALITY

Improving the quality of the Susquehanna River by reducing the concentration of AMD parameters has long been under consideration. The Pennsylvania Sanitary Water Board, recognizing that the solution to AMD discharges. would be very complex and costly, organized an advisory committee to study the problem. A number of studies were undertaken and sponsored by the Department of Health to develop cost information for possible solutions to the AMD discharges. Flow augmentation for water quality control was one of the solutions considered**. The study concluded that maintaining a minimum low flow rate of approximately 2,500 cfs at Wilkes-Barre, for approximately 300 days annually, would be the practical limit of augmentation. In order to achieve this goal, 20 percent of the watershed above Wilkes-Barre (approximately 2,000 sq'. miles) would require control by reservoirs at an estimated cost of $120,000,000.

* *J.R. Hollowell*

** *Estimated cost of diluting Susquehanna River flows at Wilkes-Barre by augmentation from an upstream reservoir system; Pa. Dept. of Health, Pub. #20, 1965.*

Assuming that the iron concentration in the Susquehanna, at the confluence with the Lackawanna River, may reach 10 ppm at the time the natural flow rate of the river is 1,000 cfs, augmentation by additional 1500 cfs of iron-free water would reduce iron concentration to 4 ppm at a cost of $120,000,000. A similar reduction in iron concentration can be achieved by retardation of AMD discharges, in lieu of stream flow augmentation. When the Susquehanna flow rate is 1,000 cfs and the natural iron concentration of the river above the Lackawanna is 0.3 ppm, the retardation of AMD discharges of 100 cfs, with 50 ppm iron concentration, is equivalent to the augmentation off the river by 17,050 cfs. Therefore, the higher the AMD concentration at the outfalls into the Susquehanna River, the lower the ratio between the rate of retardation to the rate of augmentation.

Application of the flow retardation concept of AMD discharges to the study areas is described as follows:

ASSUMED PREVAILING CONDITIONS
(FOR ILLUSTRATIVE PURPOSES ONLY)

- AMD discharges in the Lackawanna River have been abated.
- Desired maximum level of total iron concentration in the Susquehanna River is 1.5 ppm (possible only after achievement above).
- Natural level of iron concentration, upstream of the Lackawanna confluence, is 0.3 ppm.
- Reduction of AMD discharges from the Askam borehole, the three South Wilkes-Barre boreholes and the Buttonwood Tunnel in the related watersheds. The assumed magnitude and concentration of these reduced discharges, selected to illustrate the retardation concept are as follows:

ASKAM BOREHOLE		SOUTH WILKES-BARRE BOREHOLES		BUTTONWOOD TUNNEL	
DISCHARGE	IRON CONCENTRATION	DISCHARGE	IRON CONCENTRATION	DISCHARGE	IRON CONCENTRATION
CFS	ppm	CFS	ppm	CFS	ppm
0.0	0.0	8.7	250	10	170

Based on the assumed prevailing conditions, 2,800 acre-feet of storage would be required for the retardation of AMD discharges in order to maintain the 1.5 ppm iron concentration in the Susquehanna River. A 10-year recurrence interval for low flow of the river at Wilkes-Barre was selected as the criteria for storage requirements. Computation procedures are presented in FIGURE No. 7 (pocket).

If the Lackawanna AMD outfalls are not abated, the 1.5 ppm iron concentration limit in the Susquehanna River would not be met. However, the 2,800 acre-feet storage would insure that the AMD discharges from the study area would not increase the iron concentration in the Susquehanna River by more than 1.2 ppm.

The storage required for the retardation of AMD discharges under different prevailing conditions can be computed by the same procedure as illustrated in FIGURE NO. 7 (pocket). Storage can be provided by utilizing selected existing abandoned strip pits or by newly constructed impoundments. In both cases, pumping from source to storage would be required.

Reduction of surface water losses and interception of groundwater flow into the deep mines will result in mine pool elevations that are lower than the presently prevailing mine pool levels. Analysis, presented in subsequent paragraphs and in Appendix B, indicates that approximately 2,800 acre-feet of storage is available in the study area mine pools. The rise in mine pool levels due to such storage is not expected to be sufficient to cause basement flooding problems in the area. Therefore, consideration may also be given to utilizing the available mine pool storage for the retardation concept.

For the case illustrated, storage can be provided by construction of an impoundment at one of the two locations shown in FIGURE NO. 7 (pocket). The total estimated construction cost for the impoundment and appurtenance is $2,500,000. The estimated annual operating cost is $30,000.

Abatement of present AMD discharges, both within the study area and in the adjacent watersheds, is expected to exceed the partial abatement stages assumed for the illustration of the Retardation Concept. Discharges from the present boreholes and the tunnel, during periods of no runoff are expected to be reduced by more than 90 percent. If these predictions are verified by the studies to be conducted in the watersheds, adjacent to the present study area, the illustrated principle of AMD Retardation can become a very desirable solution toward the improvement of water quality in the Susquehanna River.

ORIGIN OF MAJOR AMD DISCHARGES

The major AMD discharges in the study area are from mine pools, underlying the watersheds of Solomon, Nanticoke and Warrior Creeks. These mine pools extend beyond the study area limits to adjacent watersheds, as shown on the Geologic Map, Figure 2. Surface water losses from streambeds and the interception of watersheds runoff by strippings recharge the-underlying mine pools. The inflow of groundwater into the deep mines is another source of mine pool recharge.

The flow of water through mine workings dissolves sulfate. and iron compounds, which are acid-forming materials. Consequently, the inflow of unpolluted water into the deep mines results in the outflow of AMD from the mine pools into the study area streams.

The mine pools underlying and adjacent to the study area are grouped into two major mine pool complexes, referred to as the SouthEast Mine Pool Complex and the North-West Mine Pool Complex. THE SOUTH-EAST MINE POOL COMPLEX

This complex consists of upper and lower mine pools. The upper mine pools are located entirely within the Nanticoke and Warrior Watersheds, and are the major source of the AMD discharges from the Askam borehole. The lower pools underlay the Solomon Creek watershed and extend north-easterly into the Mill Creek watershed, beyond the present study area. These mine pools are the source of AMD discharges from the three South Wilkes-Barre boreholes. The limits of these mine pools and their flow directions are illustrated on FIGURE NO. 2 (pocket).

The magnitude of the AMD discharges from these boreholes varies with the fluctuation of mine pool levels. The higher the level of the pools, the larger are the discharge rates from the boreholes. Fluctuation of the mine pools during the study period are presented in FIGURE NO. 8 (pocket). Monthly records of discharges and AMD concentrations for the Askam and the South WilkesBarre boreholes are appended to this report (see Monitoring Stations N-4 and S-3, Appendix A). Correlation between the recorded discharges and the recorded fluctuation of the upper and lower mine pools enabled the determination of the discharge rating curves for the Askam and the South Wilkes-Barre boreholes., These rating curves and their method of derivation are also presented in FIGURE NO. 8 (pocket).

During the study period, the upper mine pools of the South-East Complex fluctuated between elevation 570' and 581'. When the water level in the Sugar Notch pool dropped below elevation 573.2 feet, there were no discharges from the Askam borehole. When the water level in the pool reached 581' (2/5/74), the discharge from the Askam borehole was 8,500 GPM.

For the same period, the lower mine pools of the South-East Complex fluctuated between the elevation 529' and 542'. These fluctuations and the discharges from the South Wilkes-Barre boreholes were affected by two improvement projects undertaken by D.E.R. during the study period. Toward the end of February, 1974, the "Plains" borehole was completed in the "Henry Prospect" mine pool, which is not part of the South-East Mine Pool Complex (for location of this borehole, see FIGURE NO. 7 - pocket). The completion of the "Plains" borehole coincided with near-maximum elevation of the lower mine pools during the study period, as shown in FIGURE NO. 8 (pocket). Although discharges from the "Plains" borehole were reported* upon its completion, flow records from this borehole are not available.

Comparison between the fluctuations of the upper and lower mine pools indicates that the lower mine pools maintained a near constant level during January and February, 1974. For the same period the Upper Mine Pools fluctuated by approximately three feet.

* *Conversation with Dr. John Demchalk, D.E.R.*

A similar phenomenon was also observed during the first two weeks of September, 1973 (See FIGURE NO. 8 - pocket). The difference in the fluctuations between the Upper and the Lower mine pools can be attributed to the possible existence of an overflow from-the Lower Mine Pools in the South-East Complex Into the Henry Prospect mine pool. Such an overflow is expected when the Lower Mine Pool levels in the South-East Complex reach elevation 536.5' $\pm$.

On March 26, 1974, the South Wilkes-Barre borehole casings were cut to elevation 527.50'. Comparison between the fluctuation of the upper mine pools, the precipitation records and the fluctuation of the lower mine pools indicate significant changes in the South-East Mine Pool Complex.

During the month of March, 1974, the upper mine pools were rising. This rise is attributed to water losses into the deep mines during the relatively high precipitation in March, as indicated in FIGURE NO. 8 (pocket). However, the levels of the lower mine pools were dropping throughout the aforementioned period. These dropping pool levels indicate that in March, 1974, the discharge from the mine pools exceeded the mine pool recharge. The completion of the "Plains" borehole and the cutting of the South Wilkes-Barre pipes coincide with the observed drop in the lower mine pools. This significant drop in the lower mine pools is attributed to the aforementioned improvement projects instituted by D.E.R..

The cutting of the South Wilkes-Barre pipes is expected to maintain the lower mine pool levels below elevation 535'. Therefore, future overflow losses. from the South-East Mine Pool Complex through the "Plains" borehole is very remote and is not anticipated. Based on the discharges recorded during the study period, the cutting of the three casings will generally maintain the lower mine pools below elevation 532'. This level amounts to dropping the lower pools by as much as 10 feet below the levels that prevailed before the pipes were cut.

With the aid of data on mine pool fluctuations and the rating: curves; the accumulative outflow from the Askam and South WilkesBarre boreholes was computed. These outflows are presented in the form of Mass Curves in FIGURE NO. 9 (p. 46A). Between August 1, 1973 and July 31, 1974, the annual discharges were 2,000 MG from the Askam borehole and 8,100 MG from the South Wilkes-Barre boreholes.

The variation of AMD concentration with the discharges from the Askam borehole is presented in FIGURE No. 10 (Page 47). Total AMD discharge loads during the 12 months study period and the mean daily loads, in pounds per day, for this borehole, are presented in TABLE IX. The variation of AMD concentration with the discharges

TABLE IX

MAGNITUDE & CONCENTRATION OF AMD DISCHARGES

ASKAM BOREHOLE

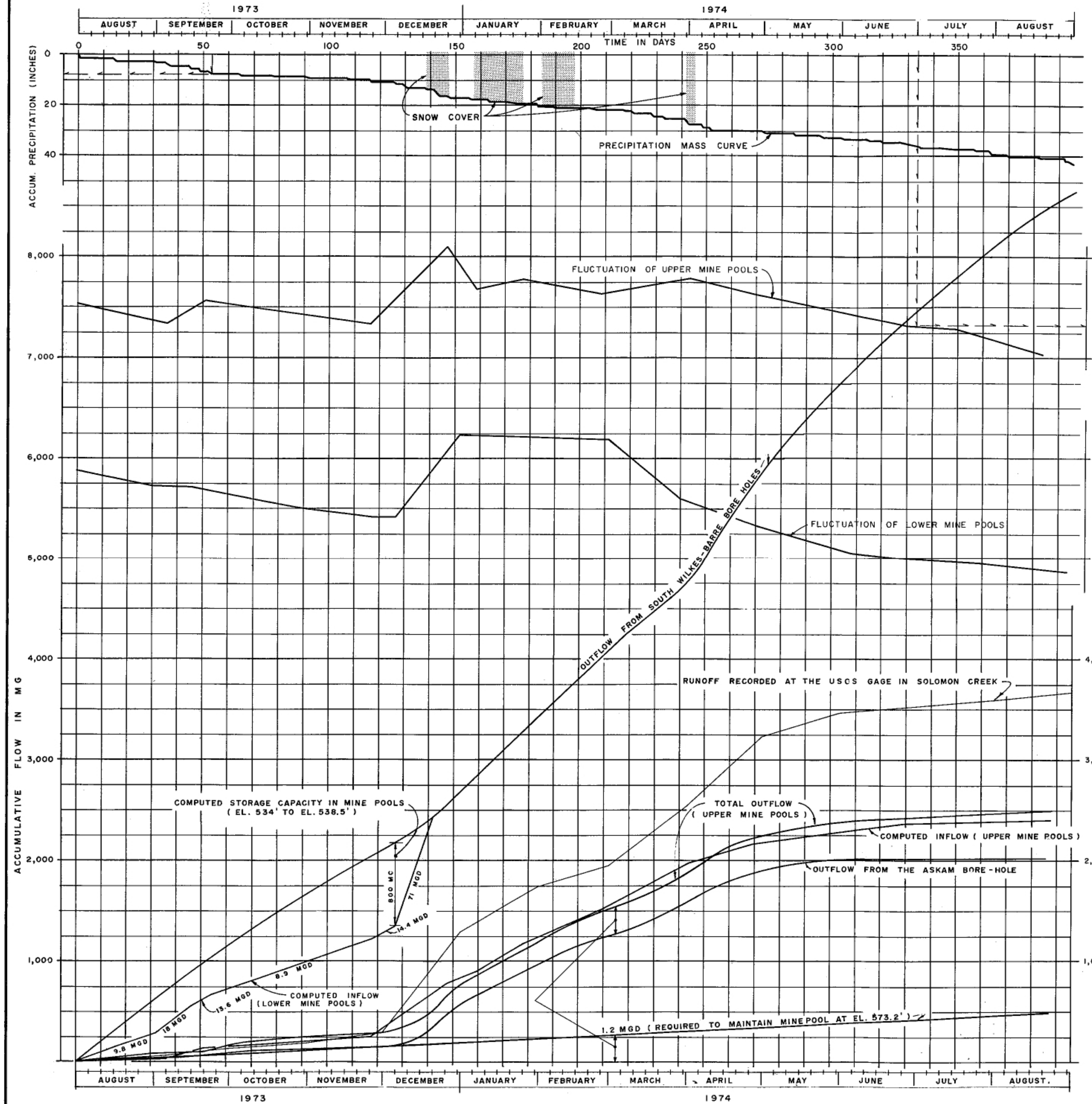
DATE	NO. OF DAYS	OUTFLOW		CONCENTRATION & LOAD OF AMD					
				ACIDITY		TOTAL IRON		SULFATES	
		MG	GPM	PPM*	LBS.	PPM*	LBS.	PPM*	LBS.
8/01/73									
9/05/73	36	37.1	715	270	83,400	200	61,780	2,370	732,050
9/20/73	15	29.6	1,370	310	76,450	220	54,250	2,320	572,100
11/25/73	66	78.7	828	280	183,620	210	137,700	2,350	1,541,070
12/26/73	31	331.0	7,414	670	1,847,870	400	1,103,200	1,920	5,295,375
1/06/74	11	193.1	12,190	950	1,528,630	550	885,000	1,500	2,413,620
1/25/74	19	221.5	8,095	700	1,291,960	420	775,180	1,820	3,359,100
2/25/74	31	336.2	7,531	670	1,877,030	400	1,120,610	1,920	5,378,940
4/02/74	35	379.7	7,534	670	2,120,070	400	1,265,710	1,920	6,075,420
4/27/74	25	215.2	5,978	580	1,040,172	360	645,620	1,970	3,533,000
6/26/74	60	190.7	2,207	360	572,050	250	397,260	2,250	3,357,340
7/14/74	20	0.1	–	–		–		–	
7/31/74	16	0.0	0	–		–		–	
	365	2,012.9			10,621,252		6,446,310		32,476,015
DAILY MEAN	1	5.51	3,830	633**	29,099	384**	17,661	1,936**	88,975

* FOR SELECTED CONCENTRATION SEE FIGURE 10

** WEIGHTED AVERAGE CONCENTRATION $= \frac{\text{DAILY MEAN LOAD \{LBS.\}}}{0.012 \times 3{,}830 \text{ GPM}}$

from the South Wilkes-Barre boreholes is presented in FIGURE NO. 11 (Page 48). Total AMD discharge loads during the study period and the mean daily loads in pounds per day, for these boreholes are presented in TABLE X (Page 49).

The observed phenomena indicates that reduction of discharges from these boreholes would not proportionately reduce the acid and



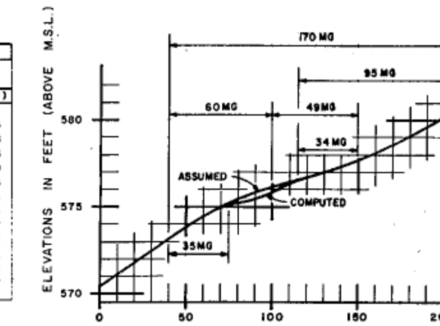
UPPER MINE POOLS

INFLOW & OUTFLOW FROM MINE POOLS FOR THE STUDY PERIOD

DATE	NO. OF DAYS	MINE POOL ELEVATION	TOTAL OUTFLOW (MG) MEASURED † ACCUM.	MEASURED † PARTIAL	UNMEASURED	TOTAL	STORAGE (MG)*	INFLOW (MG) PARTIAL	INFLOW (MG) ACCUM.
(1)	(2)	(3)	(4)	(5)	(6)=1.2x(2)	(7)=(5)+(6)	(8)	(9)=(7)±(8)	(10)=Σ(9)
8/01/73		575.2	0						0
9/05/73	36	573.2	37.1	37.1	43.2	80.3	37.0	43.3	43.3
9/20/73	15	575.5	66.7	29.6	18.0	47.6	43.4	91.0	134.3
11/25/73	66	573.2	142.9	78.7	79.2	157.9	43.4	114.5	248.8
12/26/73	31	580.5	473.9	331.0	37.2	368.2	170.0	538.2	787.0
1/06/74	11	576.7	667.0	193.1	13.2	206.3	95.0	111.3	898.3
1/25/74	19	577.7	888.5	221.5	22.8	244.3	34.0	278.3	1,176.6
2/25/74	31	576.2	1,224.7	336.2	37.2	373.4	49.0	324.4	1,501.5
4/02/74	35	577.7	1,604.4	379.7	42.0	421.7	49.0	470.7	1,971.7
4/27/74	25	576.2	1,819.6	215.2	30.0	245.2	49.0	196.2	2,167.9
6/26/74	60	573.2	2,010.3	190.7	72.0	262.7	60.0	202.7	2,370.6
7/14/74	20	572.9	2,010.4	0.1	24.0	24.1	4.0	20.1	2,390.7
8/17/74	35	570.3	2,010.4	0.0	42.0	42.0	35.0	7.0	2,397.7
						2,473.7			

* FOR SAMPLE CALCULATIONS, SEE APPENDIX B, HYDROLOGIC CONSIDERATIONS

† OUTFLOW MEASURED AT ASKAM BOREHOLE



STORAGE CAPACITY - UPPER POOLS (MG)

ANNUAL ALLOCATION OF WATER LOSS SOURCES

DESCRIPTION	WARRIOR CR. WATERSHED ABOVE COAL MEASURES	WARRIOR CR. WATERSHED WITHIN COAL MEASURES	NANTICOKE CR. WATERSHED ABOVE COAL MEASURES	NANTICOKE CR. WATERSHED WITHIN COAL MEASURES	SUB-TOTAL %	SUB-TOTAL AS SHOWN
DRAINAGE AREA (SQ. MILES)	0.17	2.95	1.85	4.02		8.99
DRAINAGE AREA (ACRES)	108.80	1,888.00	1,184.00	2,572.80		5,753.60
PERCENT OF SUB-TOTAL AREA	1.9 %	32.8 %	20.6 %	44.7 %	100	
DIVERSION BY BLUE COAL CO. FROM SOLOMON CR. WATERSHED (MG)	–	225.00	–	–	9.4	225.00
LOSSES FROM RUNOFF (MG)	42.50*	518.30	462.30*	706.40	72	1,729.50
STREAMBED LOSSES*(Base Flow)(MG)	21.75	–	236.75	–	10.8	258.50
GROUNDWATER RECHARGE (MG)	15.50	–	169.20	–	7.7	184.70
TOTAL WATER LOSSES TO MINES (MG)	79.75	743.30	868.25	706.40		2,397.70
CONTRIB. TO LOSSES IN % OF TOTAL	3.3 %	31.0 %	36.2 %	29.5 %	100	

* STREAMBED LOSSES WITHIN THE COAL MEASURES

NOTE: 22.5% OF THE WATERSHED (ABOVE THE COAL MEASURES) CONTRIBUTES 39.5% OF TOTAL LOSSES.

LOWER MINE POOLS

ANNUAL ALLOCATION OF WATER LOSS SOURCES

DESCRIPTION	SOLOMON CR. WATERSHED ABOVE COAL MEASURES	SOLOMON CR. WATERSHED WITHIN COAL MEASURES	MILL CR. WATERSHED ABOVE COAL MEASURES	MILL CR. WATERSHED WITHIN COAL MEASURES	SUB-TOTAL
DRAINAGE AREA (SQ. MILES)	9.52	6.79	18.34	11.38	46.03
DRAINAGE AREA (ACRES)	6,092.8	4,345.6	11,737.6	7,283.2	29,459.2
% OF SUB-TOTAL AREA	20.7%	14.8%	39.8%	24.7%	100.0%
TOTAL OUTFLOW FROM 3 BOREHOLES (MG)					8,106.6
RECHARGE FROM UPPER MINE POOLS (MG)					(438.0)
TOTAL RECORDED RUNOFF (INCHES)	13.16"**				
TOTAL RECORDED RUNOFF (MG)	3,582.8 **				
TOTAL WATER LOSSES INTO MINES (INCHES)	7.25"**†		(11.57")	(10.1")	
WATERSHED LOSSES INTO MINES (MG)	1,978.4		(5,690.2)		7,668.6
LOSSES FROM RUNOFF IN STRIPPING (MG)		(1,193.1)		(1,999.6)	
ALL OTHER LOSSES*(MG)	(785.3)		3,690.6		
CONTRIBUTION TO LOSSES IN % OF TOTAL	10.2%	15.6%	48.1%	26.1%	100.0%

* STREAMBED LOSSES WITHIN THE COAL MEASURES & GROUNDWATER RECHARGE
** FROM RECORDS OF USGS GAGING STATION ON SOLOMON CREEK.
† FROM COMPARISON BETWEEN THE FLOW RECORDS OF SOLOMON CREEK & TOBY CREEK
NOTE: FIGURES IN PARENTHESIS INDICATE INDIRECTLY DERIVED VALUES

SUMMARY OF FINDINGS

THE SOUTHEAST MINE POOL COMPLEX CONSISTS OF UPPER MINE POOLS AND LOWER MINE POOLS. THE UPPER MINE POOLS ARE ENTIRELY WITHIN THE STUDY AREA. INFLOW TO THESE POOLS IS ATTRIBUTED TO WATER LOSSES WITHIN THE NANTICOKE & WARRIOR WATERSHEDS. THE ALLOCATION OF ANNUAL WATER LOSSES TO THE VARIOUS WATER SOURCES IN THESE TWO WATERSHEDS IS TABULATED ABOVE. THE VISIBLE OUTFLOW FROM THE UPPER MINE POOLS IS THROUGH THE ASKAM BOREHOLE. 100% OF THE ASKAM BOREHOLE DISCHARGES ARE ATTRIBUTED TO THE LOSSES WITHIN THE STUDY AREA.

OUT OF THE TOTAL DRAINAGE AREA OF 46 SQUARE MILES THAT CONTRIBUTES TO WATER LOSSES INTO THE LOWER MINE POOLS, ONLY 16.3 SQUARE MILES OF THE SOLOMON CREEK WATERSHED (35.5%) ARE LOCATED WITHIN THE STUDY AREA. THE BALANCE OF THE DRAINAGE AREA (64.5%) IS LOCATED IN THE MILL CREEK WATERSHED. THE ALLOCATION OF ANNUAL WATER LOSSES, DURING THE STUDY PERIOD, TO THE VARIOUS WATER SOURCES IN THESE TWO WATERSHEDS IS TABULATED ABOVE. THE VISIBLE OUTFLOW FROM THE LOWER MINE POOLS IS THROUGH THE SOUTH WILKES-BARRE BOREHOLES. ONLY 24.4% OF THE DISCHARGE FROM THESE BOREHOLES IS ATTRIBUTED TO WATER LOSSES WITHIN THE SOLOMON CREEK WATERSHED, 5.4% TO THE OVERFLOW FROM THE UPPER MINE POOLS (WITHIN THE STUDY AREA) AND 70.2% TO WATER LOSSES IN THE MILL CREEK WATERSHED (OUTSIDE THE STUDY AREA).

DISTRIBUTION OF WATER LOSSES TO WATERSHEDS DURING THE STUDY PERIOD (TOTAL PRECIPITATION = 40")							
UPPER MINE POOLS				LOWER MINE POOLS			
WARRIOR CR. WATERSHED		NANTICOKE CR. WATERSHED		SOLOMON CR. WATERSHED		MILL CREEK WATERSHED	
D.A. 1,996.8AC.		D.A. 3,756.8AC.		D.A. 10,438.4AC.		D.A. 19,020.8AC.	
MG/YEAR	% OF PRECIP.	MG/YEAR	% OF PRECIP.	MG/YEAR	% OF PRECIP.	MG/YEAR	% OF PRECIP.
823.05*	37.9*	1,574.65	38.5	1,978.4	17.5	5,690.2	27.5

* INCLUDING THE DIVERSION BY BLUE COAL CO. FROM THE SOLOMON CREEK

DEFINING WATERSHED LOSSES IN PERCENT OF ANNUAL PRECIPITATION, AS TABULATED ABOVE, ENABLES THE DETERMINATION OF THE MEAN ANNUAL WATER LOSSES IN THE AFOREMENTIONED WATERSHEDS.

LEGEND

- MASS CURVES
- FLUCTUATION OF MINE POOLS
- DIRECTIONS FOR READING CURVES

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

AMD ABATEMENT STUDY

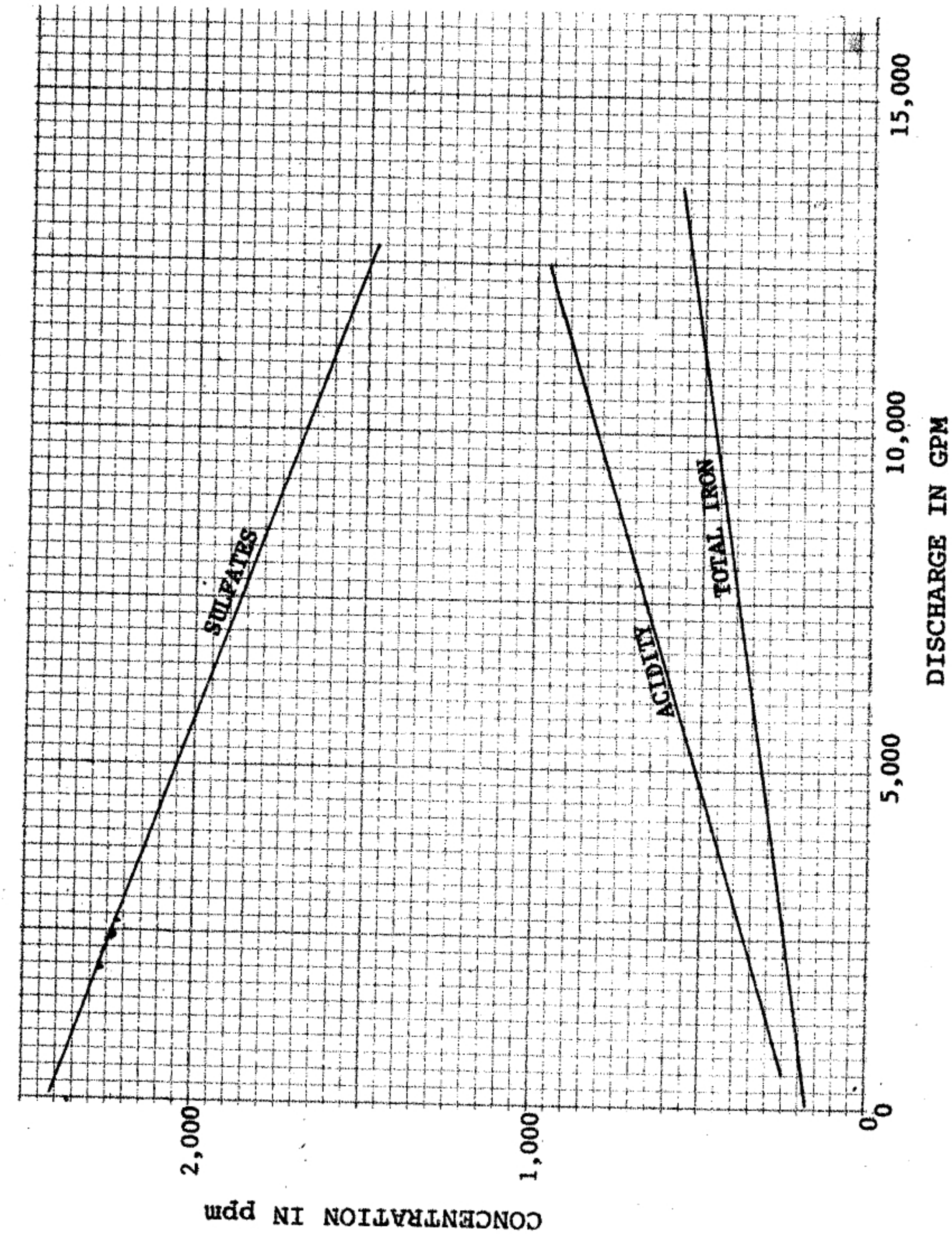
NANTICOKE, WARRIOR AND SOLOMON CREEKS
PROJECT NO. SL 181 - 3
HANOVER & WILKES BARRE TWPS. LUZERNE CO. PENNA.

SOUTH-EAST MINE POOL COMPLEX
INFLOW-OUTFLOW-STORAGE RELATIONSHIP

DATE: JAN. 1975

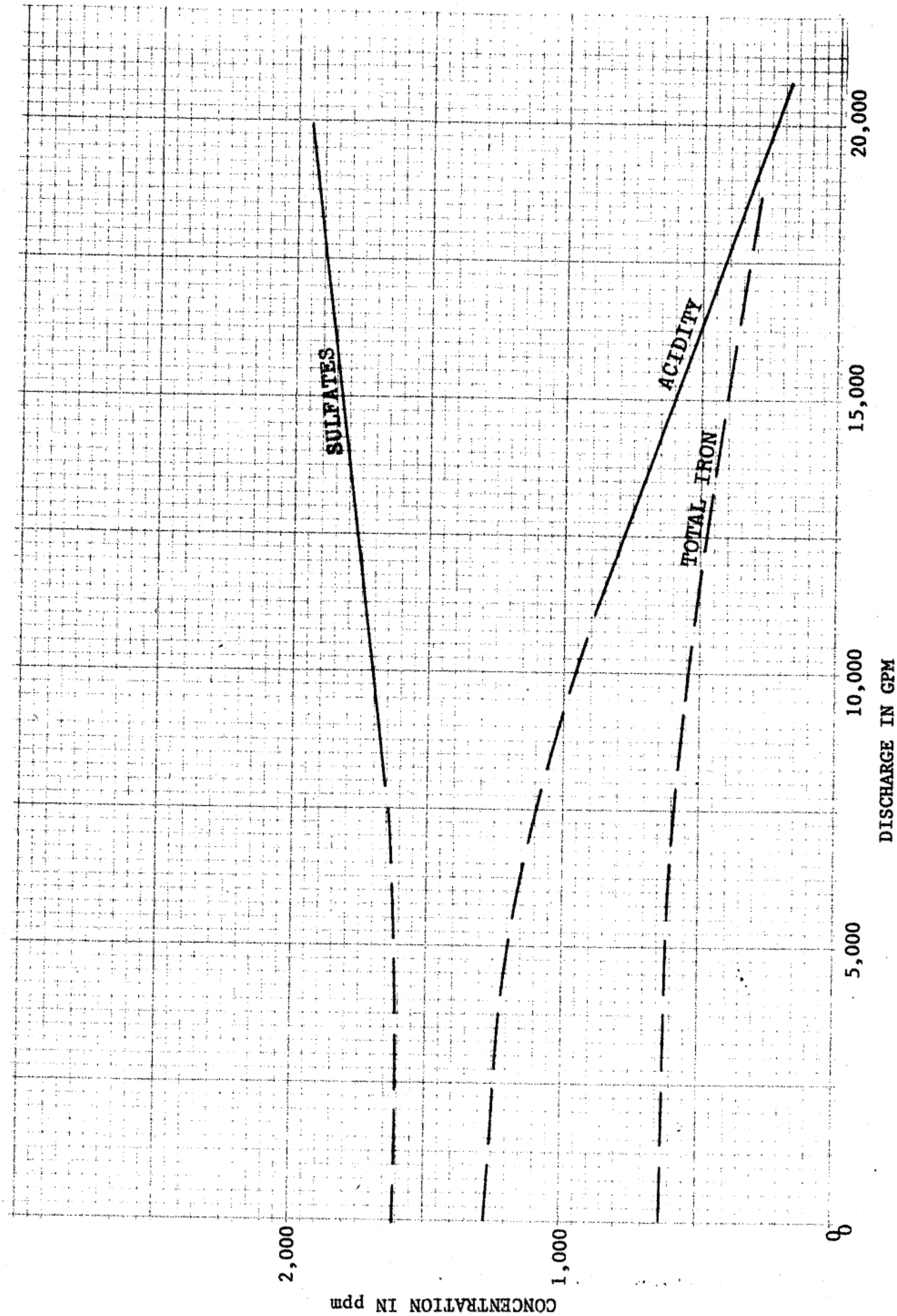
PREPARED BY
GEO - Technical Services
CONSULTING ENGINEERS & GEOLOGISTS
HARRISBURG, PENNA.

FIGURE No. 9



ASKAM BOREHOLE - Concentration of AMD Discharges

FIGURE 10



SOUTH WILKES-BARRE BOREHOLES - Concentration of AMD Discharges

FIGURE 11

TABLE X

MAGNITUDE & CONCENTRATION OF AMD DISCHARGES
SOUTH WILKES-BARRE BOREHOLES

DATE	NO. OF DAYS	OUTFLOW		CONCENTRATION & LOAD OF AMD					
				ACIDITY		TOTAL IRON		SULFATES	
		MG	GPM	PPM*	LBS.	PPM*	LBS.	PPM*	LBS.
8/01/73									
9/05/73	36	887.5	17,120	450	3,328,130	340	2,514,590	1,890	13,978,140
9/20/73	15	91.8	4,250	1,200	918,000	620	474,300	1,600	1,224,000
11/25/73	66	1,052.5	11,074	880	7,718,135	510	4,473,010	1,730	15,173,150
12/26/73	31	532.5	11,930	820	3,639,130	480	2,130,220	1,750	7,766,430
1/06/74	11	261.4	16,500	500	1,089,000	360	784,080	1,860	4,051,080
1/25/74	19	456.0	16,670	490	1,862,370	350	1,330,270	1,870	7,107,420
2/25/74	31	740.9	16,600	500	3,087,600	360	2,223,070	1,860	11,485,870
4/02/74	35	979.9	19,440	280	2,286,150	260	2,122,850	1,940	15,839,710
4/27/74	25	1,649.8	45,830	280	3,849,720	260	3,574,740	1,940	26,673,060
6/26/74	60	727.0	8,415	1,030	6,240,560	560	3,392,930	1,660	10,057,610
7/14/74	20	383.8	13,325	720	2,302,560	450	1,439,100	1,780	5,692,440
7/31/74	16	343.5	14,910	620	1,774,890	400	1,145,090	1,830	5,238,780
	365	8,106.6			38,096,245		25,604,250		124,287,690
DAILY MEAN	1	22.21	15,425	564**	104,373	379**	70,149	1,840**	340,514

* FOR SELECTED CONCENTRATION SEE FIGURE 11

** WEIGHTED AVERAGE CONCENTRATION = $\frac{\text{DAILY MEAN LOAD (LBS)}}{0.012 \times 15{,}425 \text{ GPM}}$

the iron load. On the basis of FIGURE NO. 11 (Page 48), at discharges of 15,000 GPM, the concentration of acid is 600 ppm and the iron concentration is 400 ppm. The acid and iron load would therefore be equal to 108,000* lbs/day and 72,000 lbs/day, respectively. When the discharges are reduced to 5,000 GPM, the concentration of acid is 1,180 ppm and the iron concentration is 600 ppm. The acid and iron load would therefore be equal to 70,800 lbs/day and 36,000 lbs/day, respectively. It should be noted that as the discharges from the South Wilkes-Barre boreholes decrease, there is an increase in iron and acid concentration. Consequently, a reduction of the discharges, by 66.7% would reduce acid load by only 34.4% and the iron load by only 50%.

** 15,000 GPM x 0.012 x 600 ppm = 108,000 lbs/day.*

Previous investigations*, related to the deep mines in the Wyoming Valley, concluded that the shorter the "travel path" of water in the mine pools (from the points of recharge to the points of discharge) the lower will be the concentration of AMD discharges. This conclusion is supported by the difference between the AMD concentration of the discharge at the Askam borehole and the discharges at the three South Wilkes-Barre boreholes. In the latter case, the path of water movement through the Lower Mine Pools from the Mill Creek Watershed to the three boreholes is much longer than the path of movement through the Upper Mine Pools to the Askam borehole. Therefore, the prevention of surface water losses into the deep mines in the Mill Creek watershed is expected to shorten the "travel path" and result in a reduction of AMD concentration at the three boreholes. A similar prevention of losses in the Solomon Creek watershed would have a less pronounced reduction of AMD concentration. Consequently, the reduced AMD discharge rate from the three boreholes due to prevention of surface losses would be supplemented by the additional benefits of reduced AMD concentration.

Hydrologic analysis of the Solomon Creek Watershed indicates that out of 39.87 inches of precipitation during the study period (8/l/73 - 7/31/74); 13.16 inches are runoff and 7.25 inches are water losses into the deep mines. The 3.16 inches of runoff are equivalent to 3,580 million gallons, as indicated by the mass curve of the Solomon Creek flow records, shown in FIGURE NO. 9. The 7.25 Inches of water losses in the Solomon Creek Watershed are equivalent to 1,980 million gallons. Since the total outflow from the South Wilkes-Barre boreholes was 8,100 million gallons, the water losses in the Solomon Creek Watershed account for only 24.4% of the discharges from these boreholes during the study period.

As stated earlier, the Upper Mine Pools are located entirely within the Warrior and the Nanticoke Creek Watersheds. Since the discharges from the Askam borehole can only be attributed to the Upper Mine Pools; these discharges represent the inflow into these mine pools. This inflow consists of water losses within these two watersheds (including the water diversion from the Solomon Creek

J.R. Hollowell

into the Warrior Creek Watershed, by the Huber Colliery operation of the Blue Coal Co.) and the groundwater recharge to these mine pools from outside of the Coal Measures. Examination of the outflow mass curve for the Askam borehole with reference to the fluctuations of the Upper Mine Pools (see FIGURE NO. 9 - p. 46A), indicates that an inflow at the rate of 1.2 million gallons per day (MGD) is required to maintain mine pool levels at elevation 573.2'. At this mine pool elevation there are zero discharges from the Askam Borehole, indicating the existence of additional outflow loss points from the Upper Mine Pools. These additional outflows probably recharge the Lower Mine Pools. When the Upper Mine Pools are maintained at elevation 573.2', the inflow into the mine pools is equal to the outflow from these mine pools and the recharge of the Lower Mine Pools from the Upper Mine Pools is at the rate of 1.2 MGD. When the inflow into the mine pools exceeds this outflow, the mine pool level rises and part of the outflow discharges from the Askam borehole. Due to the large discharge capacity of the Askam borehole (see FIGURE NO. 8 - pocket) the major discharge of the Upper Mine Pools is through the borehole when the pool levels are above elevation 573.2'. The total outflow from the Upper Mine Pools therefore consists of the Askam borehole discharges plus the losses that recharge the Lower Mine Pools. The mass curve of total outflow from the Upper Mine Pools and the mass curve of the precipitation during the study period are also shown in FIGURE NO. 9 (p. 46A). The relationship between inflow and outflow from the mine pools can be expressed by the following equation:

(INFLOW) - (OUTFLOW) = $\pm$ (MINE POOL STORAGE)

When the INFLOW exceeds the OUTFLOW, the mine pool level rises and the volume of water in the mine pools (+ STORAGE) is increased by the excess of the INFLOW over the OUTFLOW. Conversely, when the OUTFLOW exceeds the INFLOW into the mine pools, the mine pool level drops and the volume of water in the mine pools is decreased by the excess of the OUTFLOW over the INFLOW (-STORAGE).

The solution of the aforementioned equation requires that at least two out of three members of the equation, be known. Determination of the relationship between INFLOW, OUTFLOW and MINE POOL STORAGE, is presented in Appendix B and the results are shown in FIGURE NO. 9 (p. 46A). The analysis indicates that during the study period, the total inflow of water into the Upper Mine Pools was 2;400 million gallons, of which 225 million gallons are attributed to the water diverted by the Blue Coal Co. Prom the Solomon Creek Watershed. Therefore, the inflow into the Upper Mine Pools from sources within the Warrior and Nanticoke Watersheds are 2,400 - 225 = 2,175 million gallons. Of these, 760 million gallons (35% of the inflow) are attributed to streambed losses; 1225 million gallons (56% of the inflow) are water losses in strippings; and 190 million gallons (9% of the inflow) are attributed to groundwater recharge from outside the Coal Measures.

During the study period, the Upper Mine Pools fluctuated above elevation 573.2 for 90 percent of the time. Therefore, the overflow from the Upper Mine Pools into the Lower Mine Pools may have been considerably larger than the overflow rate of 1.2 MGD, shown on the mass curve in FIGURE NO. 9 (p. 46A). Consequently, the total water losses within the Warrior and the Nanticoke Creek Watersheds may have exceeded the computed losses by as much as 500 million gallons, for the study period.

In the first 117 days of the study period (8/1/73 - 11/25/73) the total outflow from the Lower Mine Pools was 2,030 million gallons. This outflow exceeded the inflow into these mine pools by 800 million gallons (see Appendix B). This difference represents the volume of water retained in these mine pools, between elevation 538.5' and elevation 534.2' (4.3 foot drop in mine pool level), as shown in FIGURE NO. 9 (p. 46A). This difference is 39.4% of the total outflow $(_2{}^{8}03_0$ x 100 = 39.4%) and represents water drawn from mine pool storage, whose detention time in the mine pools reached 117 days at the end of the period. Therefore, the concentration of the AMD discharges toward the end of the period was increased due to the long detention time of the mine pool water. Flow and quality records for

South Wilkes-Barre boreholes (see Monitoring Station S-3, Appendix A) indicate that on August 9, 1973 the rate of outflow from the boreholes was 13,700 GPM and the acid and iron concentration was 590 ppm and 350 ppm, respectively. On November 26, 1973, which was the end of 117-day period, the rate of outflow was 9,500 GPM, whereas the acid and iron concentration increased to 1,000 ppm and 419 ppm, respectively.

From November 26, 1973 to January 1, 1974 (a period of 36 days) the INFLOW exceeded the OUTFLOW from the mine pools and the volume of storage, previously withdrawn, was replenished. The mine pool levels rose to elevation 542', resulting in freshly augmented storage in the mine pools. Flow and quality records of Monitoring Station S-3 indicate that on January 7, 1974, the rate of outflow from the boreholes was 15,000 GPM, whereas the acid and iron concentration dropped to 500 ppm and 248 ppm, respectively. A similar relationship between the rate of outflow and acid concentration and the AMD discharges occurred toward the end of the study period, when the mine pool levels dropped from elevation 542' to elevation 529'. However, after February, 1974, the outflow from the boreholes was influenced by the opening of the "Plains" borehole and the cutting of the casings at South Wilkes-Barre boreholes. As a result of these changes and influences, mine pool detention, rate of outflow and AMD concentration could not be directly compared with the respective relationship at the beginning of the study period. The cutting of the pipes reduced the available mine pool storage for similar fluctuations (changes in height) of the mine pools that occurred at the beginning of the study period. The cutting of the pipes also enabled an increase in the rate of discharge from the boreholes and resulted in maintaining lower pool levels than the levels attained prior to the cutting. Therefore, for similar inflows that occurred prior to the cutting of the pipes, the detention time in the mine pools after the pipes were cut is considerably shorter, due to reduced storage capacity. Consequently, a lower concentration of AMD discharges is anticipated.

The aforementioned analysis indicates that in addition to alleviating the flooding conditions in the urban areas and reducing subsidence, the cutting of the South Wilkes-Barre pipes is expected to reduce the concentration of AMD discharges from these boreholes.

THE NORTH-WEST MINE POOL COMPLEX

Analysis of water quality in the Susquehanna River required the determination of river discharges, upstream and downstream ofthe study area. A plot, showing discharge records of the USGS Gaging Station at Danville versus the discharges- at the Wilkes-Barre Station, for the same days of record, is presented in FIGURE NO. 12 (pocket). This plot indicates that for similar river discharges at Danville, the recorded discharges at Wilkes-Barre were higher prior to 1970 and lower after 1970. The reduction in the river discharges at Wilkes-Barre, after 1970, is indicated only when the river discharges at Wilkes-Barre exceeded 1,700 cubic feet per second (cfs). The drainage area of the Susquehanna River, upstream of the Danville and Wilkes-Barre Stations, is 11,220 square miles and 9,960 square miles, respectively. If the changes in the flow of the river shown in FIGURE NO. 12 (pocket) are due to changes in the precipitation pattern or changes in runoff conditions, after 1970; then the increase in flow from the drainage area downstream of Wilkes-Barre Station, should correspond to the decrease in flow from the drainage area, upstream of the Wilkes-Barre station. Denoting the reduced flow in CSM*, upstream of the Wilkes-Barre Station as Aq1 and the increased flow between Danville and Wilkes-Barre as Aq_2; then, 9,960 Aq1 = 1,260 Aq2.

This implies that after 1970, the increase of flow in CSM below Wilkes-Barre gaging station is approximately eight times the decrease in flow in CSM, upstream of the Wilkes-Barre gaging station. This increase in the river flow, below Wilkes-Barre is significantly larger than can be attributed to change's in precipitation pattern or land use, within the 1,260 square miles of the drainage area, between these two gaging stations.

Deep mining and pumping from the mines in the Wyoming Valley stopped in 1967, causing mine pools to rise and overflow into the Susquehanna River. The indicated increase in river flow in CSM.*

**Cubic feet per second per Square Mile (CSM)* below the Wilkes-Barre gaging station, is attributed to large overflows from these mine pools into the river downstream of the gaging station.

Mine drainage from the North-West Mine Pool Complex has been discharging into the Solomon Creek through the Buttonwood Tunnel since the Fall of 1967. Mine drainage into Solomon Creek from the South-East Mine Pool-Complex began when the mine pool was penetrated by the construction of three drainage relief boreholes in South Wilkes-Barre. The South Wilkes-Barre boreholes were completed in September 1, 1971, and started discharging after the June 1972 floods. Discharges from the Upper Mine Pools of the South-East Mine Pool Complex into Nanticoke Creek, through the Askam Borehole, also began after the 1972 floods. The confluences of the Solomon and Nanticoke Creeks with the Susquehanna River are downstream of the Wilkes-Barre Gaging Station. In the past, pumping discharges from mines and mine pools into the river were predominantly upstream of the Wilkes-Barre station (prior to completion of the Buttonwood Tunnel and the aforementioned boreholes). The present discharges from these mine pools into the river are predominantly downstream of this station (see Plan, FIGURE NO. 12 (pocket).

The maximum discharge from the Buttonwood Tunnel, during the study period was 14,000 GPM, recorded on February 4, 1973. On that date the Askam borehole and the South Wilkes-Barre boreholes discharged 8,500 GPM and 13,500 GPM, respectively. Therefore, the total mine pool discharges from these three sources into the Susquehanna River on February 4, 1973 were 36,000 GPM, or the equivalent of 80.2 cfs. Of these total discharges, 38.9 percent was contributed by the Buttonwood Tunnel. The recorded flow of the River on February 4, 1973 at the Wilkes-Barre station was 20,800 cfs.

The minimum discharge from the Buttonwood Tunnel was 3,750 GPM, recorded on August 20, 1974. On that date, the total discharges from the Tunnel and the boreholes were 16,150 GPM (36 cfs). Therefore, the Buttonwood Tunnel discharge on August 20, 1974 was 23.2 percent of the total discharges. The recorded flow of the River on August 20, 1974 at the Wilkes-Barre Station was 1,750 cfs. The minimum AMD discharges from all sources were recorded on November 26, 1973. Flow conditions during the aforementioned three dates of record are summarized below

DATE	SUSQ. RIVER AT WIL.BAR. FLOW (CFS)	MINE POOL DISCHARGES TOTAL		NW COMPLEX TUNNEL		SE COMPLEX BOREHOLES	
		GPM	% OF TOTAL	GPM	% OF TOTAL	GPM	% OF TOTAL
2/04/73	20,800	36,000	100	14,000	38.9	22,000	61.1
8/20/73	1,750	16,150	100	3,750	23.2	12,400	76.8
11/26/73	5,620	14,000*	100*	4,500	32.1	9,500	67.9

* *MINIMUM OF TOTAL MINE POOL DISCHARGE*

Examination of these flow conditions indicates that the discharges from the North-West Mine Pool Complex reflect the variation in the flow of the River to a significantly larger degree than the discharges from the South-East Mine Pool Complex. Since water levels in the Upper Mine Pools of the South-East Complex are at least sixty feet higher than the bottom of the River, these mine pools cannot materially be affected by the fluctuation in the river stages. Therefore, the previous analysis was repeated by comparing the discharges from the Buttonwood Tunnel with the discharges from the Lower Mine Pools in the South-East Complex, as tabulated below:

DATE	SUSQ. RIVER AT WIL.-BAR.	NW COMPLEX TUNNEL		SE COMPLEX LOWER MINE POOLS S. W-B BOREHOLES		SUB-TOTAL	
	FLOW (CFS)	GPM	% OF FLOW	GPM	% OF FLOW	GPM	% OF FLOW
09/21/73	3,560	7,000	35.0	13,000	65.0	20,000	100
10/25/73	2,010	4,500	25.7	13,000	74.3	17,500	↓
11/26/73	5,620	4,500	32.1	9,500	67.9	14,000	↓
01/07/74	14,500	13,300	47.0	15,000	53.0	28,300	↓
02/04/74	26,800	14,000	51.0	13,500	49.0	27,500	↓
03/21/74	17,800	13,000	49.0	13,500	51.0	26,500	↓
04/29/74	11,300	13,100	38.8	20,700*	61.2*	33,800*	↓
05/29/74	8,200	11,500	39.7	17,500*	60.3*	29,000*	↓
06/26/74	5,210	9,200	38.3	14,800	61.7	24,000	↓
07/16/74	3,840	5,200	27.8	13,500	72.2	18,700	↓
08/20/74	1,750	3,750	23.2	12,400	76.8	16,150	↓

* *Affected by cutting of the South Wilkes-Barre Casings*

The latter analysis indicates that, while the Tunnel discharges have a direct relationship to the magnitude of the discharges in the River, there is no direct relationship between the discharges from the South Wilkes-Barre boreholes and the magnitude of flow in the River.

If the Susquehanna River is losing water into the North-West Mine Pool Complex, the cause of the correlation of the Buttonwood Tunnel discharges with the flow in the River can readily be explained. Moreover, if the rate of River losses into the North-West Mine Pools is higher than the discharges from the Buttonwood Tunnel, there must be additional discharge points from these mine pools than those recorded at the Buttonwood Tunnel. Furthermore, if the aforementioned additional discharges from the North-West Complex into the River are located downstream of the Wilkes-Barre gaging station, these River losses bypass the gaging station. Consequently, the previously mentioned changes (since 1970) in the relationship between the records at the Wilkes-Barre and Danville River stations can readily be explained.

The inflow of river water into the mine pools can only be located in areas where the level of the river is higher than the level of the mine pools. A profile of the Susquehanna River is presented in FIGURE NO. 12 (pocket)., Also shown on the profile are the high and low mine pool levels, recorded by D.E.R. during the study period. The river profile shows that adjacent to Scovell Island, River Mile 196, the river bottom is approximately at elevation 535'. Projecting the recorded river stages at the Wilkes-Barre station upstream to Scovell Island, indicates that most of the projected river stages are higher than the elevations of the Stevens and Clear Spring Mine Pools. The fluctuation of all the mine pools, shown on the profile, are also plotted in relationship to the projected river stages at River Mile 196, as shown in FIGURE NO. 1.2 (pocket). Since the river bottom is approximately at elevation 535' and within the coal measures in this area, water losses from the river into the deep mines can occur in the proximity of River Mile 196.

Losses from the river into the deep mines have been known to occur in the past. In February 1959, the bottom of the river caved into deep mining operations (now Ewen Mine Pool) at River Mile station 193.7, as shown on the plan in FIGURE NO. 12 (pocket). This cave-in is known as the "Pittston Disaster".

The "Pittston Disaster" occurred at a time when many of the mines were still in operation and the water levels in the deep mines were kept much lower than the level of the river by pumping. The river cave-in was plugged and a grout curtain between the river and the mine was constructed to prevent water losses from the river into the mine. However, deep mining discontinued soon after completion of the remedial measures due to the prohibitive cost of pumping required to lower the mine pools to the levels that existed prior to the Pittston Disaster.

The present levels of the mine pools in the vicinity of River Mile station 193.7 are higher than most of the river stages at this station. Consequently, river losses into the deep mines are not expected to occur near this location at the present time.

If the magnitude of river losses into the deep mines is larger than the discharges recorded from the Buttonwood Tunnel, the existence of other additional discharge points from the mine pools into the river should be expected. Examination of the mine pool levels, shown on the Profile and on the Stage Discharge Curves in FIGURE NO. 12 (pocket), indicates the following:

> When the flow of the river at Wilkes-Barre is less than 6,500 cfs, the Lance and Loree Mine Pools are the lowest mine pools in the entire North-West Mine Pool Complex. Therefore, the movement of water in this Mine Pool Complex is from the higher level mine pools to the Lance and Loree Pools. The general direction of flow in the North-West Mine Pool Complex is indicated by arrows on the Plan in FIGURE NO. 12 (pocket). These mine pool levels and flow conditions indicate that the discharge from the Buttonwood Tunnel can only be attributed to the Avondale - Grand Tunnel and the Nottingham -- Buttonwood Mine Pools. The maximum expected discharge from the Buttonwood Tunnel related to the fluctuation. of these latter mine pools is 8 MGD
> (see Buttonwood Tunnel Rating Curve, FIGURE NO. 12 - pocket).
> When the levels of the Nottingham -- Buttonwood mine pools are higher than the Loree and Lance Mine Pools; drainage of mine water from the remaining pools in the North-West Complex

cannot reach the Button Tunnel by gravity. Consequently, the drainage must flow to the Loree and Lance Mine Pools. The suspected location of discharges from these latter mine pools into the river is shown on the plan and profile in FIGURE NO. 12 (pocket). The geologic conditions, as well as the flow pattern through the North-West Mine Pool Complex, supports the suspected existence of discharges into the river at the indicated location.

When the flow of the river at Wilkes-Barre is more than 6,500 cfs, the levels of the Lance and Loree pools rise above the level of the Nottingham - Buttonwood Pool. Under these conditions, the discharges from the Buttonwood Tunnel are more than 8 MGD, and the discharges in excess of 8 MGD are attributed to the drainage of mine water from the entire North-West Mine Pool Complex.

The rise in the level of the Lance and Loree pools, above the level of the Nottingham - Buttonwood Pool, indicates that the rate of inflow into the mine pool complex exceeds the discharge capacity of the river outlet points, previously described. Therefore, the Tunnel discharges in excess of 8 MGD represent only the excess flow that cannot be discharged through all other discharge points in the North-West Complex.

The duration of daily flow in the Susquehanna River at, the Wilkes-Barre U.S.G.S. gaging station is shown in TABLE XI. This

TABLE XI

SUSQUEHANNA RIVER AT WILKES-BARRE
DURATION OF DAILY FLOW (1899-1963)*

DISCHARGE IN CFS WHICH WAS EQUAL TO OR LESS THAN THAT SHOWN FOR THE INDICATED % OF TIME							
%	2	5	10	20	30	40	50
CFS	1,000	1,300	1,600	2,600	3,800	5,200	7,000
%	60	70	80	90	95	98	
CFS	9,500	14,000	20,000	32,000	46,000	68,000	

* ADOPTED FROM WATER RESOURCES BULLETIN NO. 1; PA. STREAM FLOW CHARACTERISTICS, LOW FLOW FREQUENCY AND FLOW DURATION; U.S.G.S. AND D.E.R., 1966.

table indicates that the rate of flow in the river, in excess of 6,500 cfs, occurs approximately 50 percent of the time. On the basis of TABLE XI, the Buttonwood Tunnel Rating Curve and the StageDischarge relationship, shown in FIGURE NO. 12 (pocket), the mean annual distribution of the Tunnel discharges was computed, as shown in TABLE XII.

TABLE XII

MEAN ANNUAL DISTRIBUTION OF
BUTTONWOOD TUNNEL DISCHARGES

% OF TIME	FLOW DURATION {DAYS}	SUSQUEHANNA RIVER FLOW {CFS}	DISCHARGE IN MGD AND ACCUMULATIVE FLOW IN MG FROM THE INDICATED SOURCES					
			TOTAL		AVONDALE AND NOTTINGHAM POOLS		FROM ALL OTHER MINE POOLS	
			MGD	MG	MGD	MG	MGD	MG
47%	172.0	6,500	6.5	1,118.0	6.5*	1,118	0.0	0.0
13%	47.0	9,500	13.5	634.5	8.0	376	5.5	258.5
10%	36.5	14,000	15.0	547.5	8.0	292	7.0	255.5
10%	36.5	20,000	16.5	602.3	8.0	292	8.5	310.3
10%	36.5	32,000	22.0	803.0	8.0	292	14.0	511.0
10%	36.5	60,000	44.0	1,606.0	8.0	292	36.0	1,314.0
100%	365.0			5,311.3		2,662		2,649.3
MEAN DAILY	1		14.6		7.3		7.3	

* ASSUMED AVERAGE DISCHARGE FOR THE DURATION SHOWN

If the discharges of more than 8 MGD from the Buttonwood Tunnel are attributed to river losses into the deep mines, then the rate of outflow from the mine pools into the river.,, through any other existing discharge points, is expected to be much higher than the discharge from the Tunnel.

It has been reported* that when most of the mines in the Wyoming Valley were in operation, an average of 125,000 GPM (180 MGD was continually pumped to the surface. Water losses into the deep mines at the time these mines were in operation also consisted of streambed losses, losses of surface runoff in strip mine operations and groundwater recharge. Although the deep mining operations have

** J.R. Hollowell; Hydrology of the Abandoned Coal Mines in the Wyoming Valley, Pennsylvania (unpublished).*

ceased, strip mining is still in progress. Therefore, the present streambed losses and the losses of surface runoff into the abandoned deep mines through strippings is equal to or greater than the losses that occured during the period of active deep mining in the basin. Due to an increase in subsidence since the cessation of deep mining activities and the removal or destruction of numerous flumes (constructed to reduce streambed losses into the deep mines), the present surface water losses are probably greater than those occurring in the past.

The rising of the mine pools after the cessation of pumping from the deep mines, greatly reduced the gradient (slope of the water surface) between the water table outside of the coal measures and the mine pool levels.

Therefore, the recharge of mine pools by groundwater sources from outside of the coal measures is the only mine pool water source that is expected to be less at the present time than it was during the period of deep mining.

Comparison between the reported average pumping rate of 180 MGD during deep mining and the present known discharges from the mine. pools (less than 70 MGD), indicates that the additional 110 MGD (180 - 70 = 110 MGD) or 170 cfs, cannot be attributed to losses into the mines from the normal hydrologic cycle In the Wyoming Valley. Neither can the majority of these additional losses be attributed to the increased recharge of groundwater during the period of deep mining.

During the period of deep mining in the valley, and excluding the draught years (1961-1966), the mean annual total runoff was approximately 20 inches (see TABLE B-1, Appendix B from the beginning of records to 1961). The total drainage area of all tributary streams that cross the Wyoming Valley is approximately 140 square miles, of which 70 square miles are entirely within the coal. basin. If the water levels In the deep mines were lowered by pumping throughout the entire 70 square miles of the coal basin, and the 110 MGD is attributed to groundwater recharge from the remaining 70 square miles of watershed, then the following would apply:

a. The area contributing to groundwater recharge is 140-70 = 70 square miles, or 44,800 acres.

b. The annual recharge in terms of inches per year contributed by the above area is

However, the 70 square miles cannot contribute 33 inches of recharge into the deep mines when the entire runoff (including the base flow of the streams) in this same area is only 20 inches. Moreover, if the pumping would have lowered the groundwater table below the streambeds, the base flow of the streams would have stopped. Available records from the area streams (see Toby Creek in TABLE B-1, Appendix B) indicate that such conditions did not exist during the deep mining period.

The aforementioned analysis strongly supports the argument against attributing the entire additional daily losses of 110 MGD to groundwater recharge, during the period the deep mines were being pumped. Consequently, it must be concluded that losses from the Susquehanna River into the deep mines has occured and were apparent prior to the cessation of pumping in the Wyoming Valley. If the daily average rate of such losses is 110 MGD (170 cfs), and these river losses are confined to the North-West Mine Pool Complex, then the pumping from these mine pools should also have averaged 110 MGD. Since the mean discharge from the Buttonwood Tunnel is 14.6 MGD TABLE XII (p. 60), of which only 7.3 MGD is attributed to the Avondale and Nottingham Mine Pools; then the magnitude of the discharges from all other mine pools in this complex into the river is 110 - 7.3 = 102.7 MGD (159 cfs). If discharges into the river do occur at the location indicated in FIGURE NO. 12 (pocket), dis-. charges of such magnitude could have started only after pumping from mines was discontinued, and the levels in the mine pools rose (1968-1970) above the riverbed. The dating of these probable discharges is in fair agreement with the flow relationship of the river at Danville and Wilkes-Barre, presented in FIGURE NO. 12 (pocket).

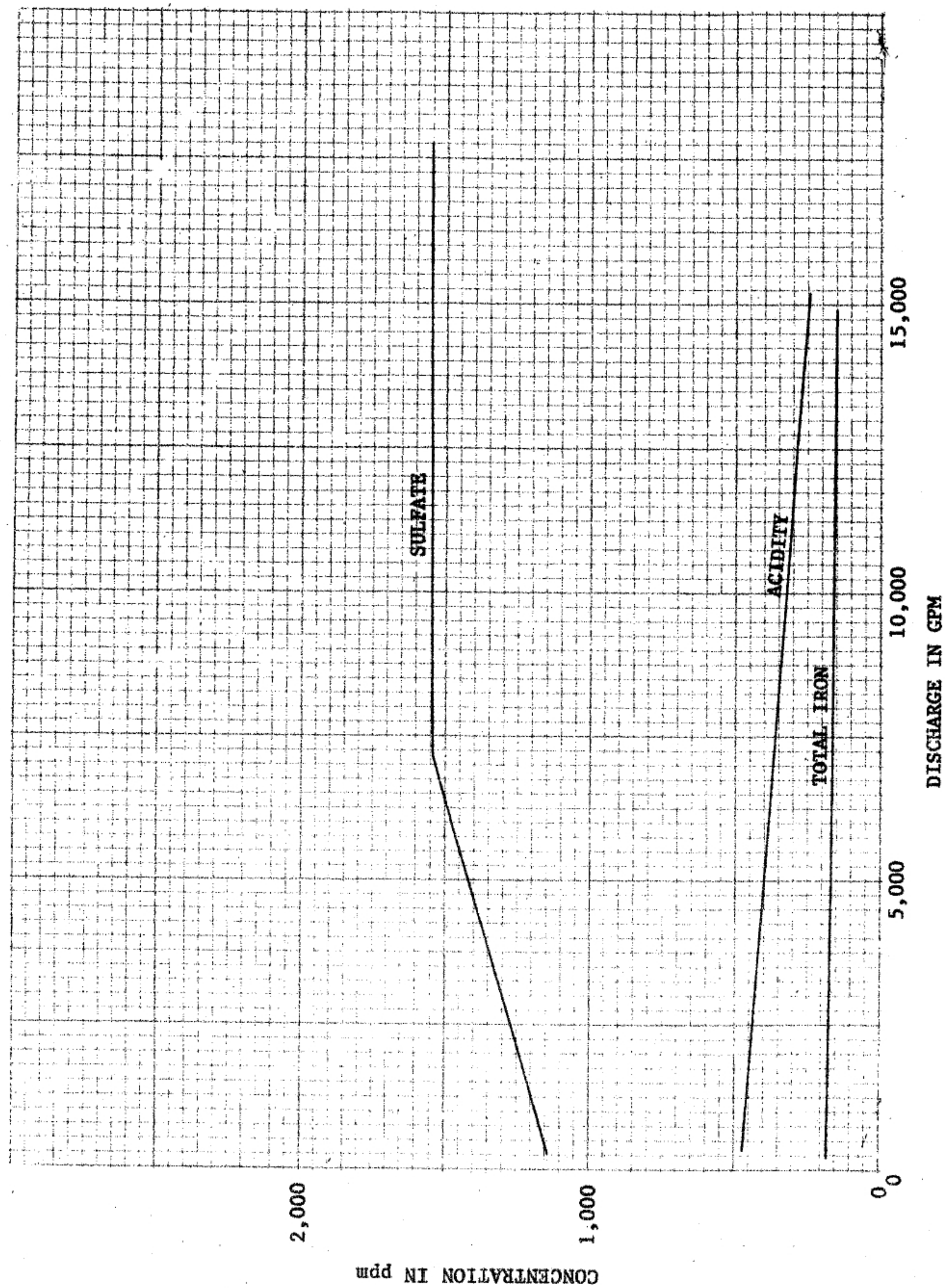
The average discharge of 110 MCD implies that during high flow stages in the river, losses of river water into the deep mines and subsequent discharge from the mine pools into the river may exceed the average discharge. This is also supported by pumping records during deep mining operations in the valley. It has been reported* that the capacity of the pumps provided by most of the mining companies was ten times the annual average rate of pumping. This was needed to provide sufficient pumping capacity during periods of large inflow into the deep mines. When high inflow continued for several days, the monthly average pumping rate would be 3 to 4 times the annual rate.

During low flow stages in the river, the discharges from the mine pools are expected to be considerably less than 110 MGD. Although the minimum recorded discharges from the Avondale and Nottingham pools was 3,750 GPM (5.4 MGD), the discharges into the river from all other pools in the North-West Complex, through outlets that are lower than the Buttonwood Tunnel, are expected to be many times larger than the flow from the Tunnel.

Therefore, even during extreme tow flow periods in the river when river tosses into the deep mines are insignificant or do not exist, the total discharges from the North-West Complex into the river may still exceed all the presently known discharges from the tunnel and the boreholes.

Verification of the magnitude of such additional discharges from the North-West Complex into the river is essential for the evaluation of the effect of AMD discharges on the quality of the Susquehanna River. The AMD concentration in the Buttonwood Tunnel discharges is shown in FIGURE NO. 13 (Page 64). For discharges above 8,000 GPM, the average concentrations of acid, total iron and sulfates are 300 ppm, 150 ppm and 1,550 ppm, respectively. Therefore, if the additional discharges from the North-West Complex into the river are at the average rate of 110 MGD, the additional daily loads of acid, iron and sulfates are 275,220 lbs, 137,610 lbs and 1,421,970 lbs, respectively. The additional acid load alone is more than double the average daily acid load from the tunnel and the

** J.R. Hollowell; Hydrology of the Abandoned Coat Mines in the Wyoming Valley, Pennsylvania (unpublished).*



BUTTONWOOD TUNNEL - Concentration of AMD Discharges

FIGURE 13

boreholes. *Consequently, if the existence and magnitude of these additional discharge points into the river are verified, the presently know discharges from the study area represent only about one-third of the total AMD discharges into the Susquehanna River from all mine pools in the Wyoming Valley. Therefore, the major AMD pollution sources affecting river quality are the suspected large additional discharges into the river from the North-West Complex.*