III. ANALYSIS AND INTERPRETATION OF FINDINGS

GENERAL.

The major purpose of this study was to evaluate the magnitude of the AMD discharges from the South Wilkes-Barre Boreholes that can be attributed to water losses in the Mill Creek watershed. The "existing conditions" in the study area presented in Section II, indicate no major AMD discharges within the Mill Creek watershed. Nevertheless, water quality records indicate a general, slight degradation in the quality of the streams after entering the study area coal basin. Therefore, future abatement measures in the study area should serve the following purpose:

a. Reduce AMD discharges from the South Wilkes-Barre Boreholes located in the adjacent Solomon Creek watershed, and

b. Improve the quality of the streams within the Mill Creek watershed.

In order to allocate the discharges from the South Wilkes-Barre Boreholes (Station S-3, Figure 4, page 13) to the respective recharge sources, the relationship between "inflow" into the mine pools and the "outflow" from Station S-3 must be established. This requires the use of data obtained in the previous study of Nanticoke, Warrior and Solomon Creeks.

PRESENT WATER QUALITY IN THE STUDY AREA.

The flow in Mill Creek originates in the upper reaches of the Main Stem, Gardner Creek and Laurel Run. The upper portions of these sub-watersheds are located outside of the coal measures (see Sub-Area A, Figure 1, page 5). The quality of the study area streams, above the coal measures, is presented in TABLE V, page 44. The presently adopted DER Water Quality Criteria relative to AMD parameters obtained during the study period, are also shown in this TABLE.

The areas of the watershed above the coal measures are sparsely populated (see Figure 1). 'Therefore, it is reasonable to assume that the range of water quality values presented in TABLE V reflects the natural quality of these streams.

TABLE V
QUALITY OF STREAMS ABOVE THE COAL MEASURES

AMD PARAMETERS	D.E.R.* ADOPTED STANDARDS	RECORDED RANGE OF VALUES						
		GARDNER CREEK			MAIN STEM	LAUREL RUN & COAL BROOK		
		G-12	G-13	G-9	M-19	L-21A	C-31	C-30
pH	6.0 - 8.5	5.5-7.8	5.6-8.2	5.4-6.4	5.4-6.5	5.8-7.9	5.7-7.2	6.1-8.2
Temperature (C)		2-26	2-26	2-26	2-23	1-21	3-21	2-21
Acidity (ppm)	—	0-8	0-8	0-8	0-8	0-8	2-12	0-8
Alkalinity (ppm)	> 20	8-32	8-32	4-18	8-26	10-28	6-40	6-40
Total Iron (ppm)	< 1.5	0-0.8	0-0.4	0.3-1.0	0-0.2	0-0.2	0-0.1	0-2.3**
Sulfates (ppm)	250 or Nat. Lev.	37-55	12-50	28-60	8-55	4-30	20-33	8-33

* *Title 25; DER Rules & Regulations; Chapter 93, Water Quality*

** *Single Value on 8/27/75. All other values less than 1.5*

The range of alkalinity in the streams include values that are lower than the level desired by the present Water Quality Standards. A similar observation can be made relative to the pH values of these streams. The 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 deep mines, resulting in intermittent flow along many stretches (see Figure 3). Furthermore, these streams slightly degrade in quality due to runoff over waste piles, limited AMD seepage from deep mines and waste piles, discharge of raw sewage from unsewered communities and other specific factors previously described (see Section II - Existing Conditions).

The present uses of stream water within the coal basin is limited to industrial users and waste assimilation. The intermittent flow along many stretches preclude propagation of fish. The study area streams are not included in the Fish Commission List of Fishing Streams in Luzerne County. However, if. the base flow of the streams is reestablished as a result of abatement measures, it may be desirable to extend the presently limited water uses in these streams. Therefore, it may also be desirable to ensure that the good quality of the reestablish streams is maintained throughout their entire length, "from source to mouth". At present, the major contributors to stream pollution are in Gardner Creek (see quality records, stations G-11, G-8A and G-7; Appendix B). This pollution in turn affects water quality in the Main Stem of Mill Creek (see records, M-4A, M-4 and M-2; Appendix B). Downstream of the confluence with Laurel Run, a considerable improvement in the quality of Mill Creek was recorded. This is attributed to the dilution effect of Laurel Run. Field observations and water quality records indicate that, should the base flow of the presently intermittent flow reaches of the streams be maintained by reducing streambed losses, the quality of the streams would also be upgraded.

BOREHOLE AMD DISCHARGES.

The mine pools underlying and adjacent to the study area are grouped into two major mine pool complexes referred to as the South-East and North-West Mine Pool Complexes. Approximate limits of the colliery barrier pillars and the major mine pool complexes are shown on Figure 4. Most of the surface water losses in the study area are recharging the South-East Complex, as indicated in Figure 3. However, water losses in Gardner Creek watershed are recharging mine pools that are isolated or contribute to the North-West Pool Complex.

The South-East Mine Pool Complex consists of "lower" and "upper" pools. The "lower" mine pools are recharged partly by the aforementioned water losses within the study area and partly by water losses in the adjacent Solomon Creek watershed. The three South Wilkes-Barre Boreholes (S-3; Figure 4, page 13) were drilled into the South WilkesBarre mine pool, which is presently the lowest pool in the South-East Complex. The main purpose of the boreholes is to limit the rise of the pool levels and thereby prevent flooding of basements in the low lying urban areas. Similarly, the Askam Borehole (N-4; Figure 4, page 13) was drilled into the "upper" mine pools to reduce flooding of low lying areas in the Askam locale caused by rising pool levels.

The Buttonwood Tunnel (S-2; Figure 4, page 13) and the Plainsville Borehole (Plains; Figure 4, page 13) are the major outlets that regulate the mine pool levels in the North-West Mine Pool Complex.

The relationship between AMD discharges from the borehole outlets and the Buttonwood Tunnel and the fluctuation of the mine pool levels in the respective pool complexes was discussed in a previous study (SL181-3, 1975). Monitoring of the AMD discharges from these pool outlets continued during the present study.

The concentration of AMD parameters in the discharges from the South Wilkes-Barre Boreholes during the 1973 - 1974 sampling period (SL 181-3) and the concentrations obtained during the present study are presented in TABLES VI and VII, respectively. Comparison between the two periods of records indicate a demarked reduction of Acid and Iron concentration in the AMD discharges. Similar comparisons between the '73 - '74 and '75 - '76 records for the Askam Borehole (TABLES VIII and IX) and the Buttonwood Tunnel (TABLES X and XI) also indicate a reduction in Acid and Iron concentration. The average concentration of AMD parameters at these mine pool discharge points for. the two recording periods is summarized as follows:

The reduction of AMD concentration in the discharges from the South Wilkes-Barre Boreholes and the Buttonwood Tunnel were predicted in previous studies. The improvement was anticipated for the following reasons:

South Wilkes-Barre Boreholes: On March 26, 1974, the borehole casings were cut to elevation 527.50'. The cutting of the pipes resulted in maintaining lower pool levels. Therefore,

DISCHARGE POINT		CONCENTRATION OF AMD IN ppm*					
STA.	DESCRIPTION	ACID		TOTAL IRON		SULFATE	
		73/74	75/76	73/74	75/76	73/74	75/76
S-3	S. Wilkes-Barre Boreholes	638	360	390	182	1,855	1,717
N-4	Askam Borehole	579	256	344	192	1,904	1,818
S-2	Buttonwood Tunnel	293	182	154	109	1,335	1,212

** Weighted Average Values*

for inflows (water losses into the mine pools) similar to those occurring prior to the cutting of the pipes, the detention time in the pools became considerably shorter due to reduced storage capacity. Consequently, a lower concentration of AMD discharges was anticipated (SL 181-3 Report; p. 53).

TABLE VI

AVERAGE CONCENTRATION OF AMD DISCHARGES
South Wilkes-Barre Boreholes (S-3)
Previous Study (1973-1974)

DATE	Q GPM	CONCENTRATION (ppm) ACID	TOTAL IRON	SO_4	Q x CONCENTRATION/1,000 ACIDITY	TOTAL IRON	SO_4
08/09/73	13,700	590	350	2,400	8,083	4,795	32,880
09/21/73	13,000	600	320	2,000	7,800	4,160	26,000
10/25/73	13,000	600	389	2,050	7,800	5,057	26,650
11/26/73	9,500	1,000	419	2,150	9,500	3,980.5	20,425
01/07/74	15,000	500	248	2,050	7,500	3,720	30,750
02/04/74	13,500	500	400	1,650	6,750	5,400	22,275
03/21/74	13,500	574	531	1,725	7,749	7,168.5	23,287.5
04/29/74	20,700	650	274	1,700	13,455	5,671.3	35,190
05/29/74	17,500	500	246	2,200	8,750	4,305	38,500
06/26/74	14,800	520	290	1,480	7,696	4,292	20,720
07/16/74	13,500	1,100	210	1,450	14,850	2,835	19,575
08/20/74	12,400	700	234	1,550	8,680	2,901.6	19,220
SUM	170,100	7,834	3,911	22,325	108,613	54,286.9	315,472.5
NO. OF RECORDS	12	12	12	12			
MEAN	14,175	653	326	1,860			
SUM "Q"					170,100	170,100	170,100
WEIGHTED AVERAGE = $\frac{\Sigma Q \times Conc. \times 1,000}{SUM"Q"}$ =					638	319	1,855

TABLE VII

AVERAGE CONCENTRATION OF AMD DISCHARGES
South Wilkes-Barre Boreholes (S-3)
Present Study (1975-1976)

DATE	Q GPM	CONCENTRATION (ppm) ACID	TOTAL IRON	SO_4	Q x CONCENTRATION/1,000 ACIDITY	TOTAL IRON	SO_4
06/25/75	18,682	346	185	1,562	6,464	3,456.2	29,181.3
07/23/75	16,711	780	170	1,496	13,034.6	2,840.9	24,999.7
09/30/75	21,654	352	232	1,500	7,622.2	5,032.7	32,481
10/29/75	21,847	320	200	1,825	6,991	4,369.4	39,870.8
11/25/75	18,187	276	181	2,175	5,019.6	3,291.8	39,556.7
12/30/75	16,274	290	139	2,075	4,719.5	2,262.1	33,768.6
02/11/76	23,377	294	167	1,625	6,872.8	3,904	37,987.6
02/26/76	24,588	330	177	1,650	8,114	4,352.1	40,570.2
04/28/76	17,433	308	156	1,963	5,369.4	2,719.5	34,221
05/27/76	14,364	364	200	1,313	5,228.5	2,872.8	18,850
SUM	193,117	3,660	1,807	17,184	69,435.6	35,092.5	331,496.9
NO. OF RECORDS	10	10	10	10			
MEAN	19,312	336	181	1,718			
SUM "Q"					193,117	193,117	193,117
WEIGHTED AVERAGE = $\frac{\Sigma Q \times Conc, \times 1,000}{SUM "Q"}$ =					360	182	1,717

TABLE VIII

AVERAGE CONCENTRATION OF AMD DISCHARGES
ASKAM BOREHOLE (N-4)
PREVIOUS STUDY (1973-1974)

DATE	Q GPM	CONCENTRATION (ppm)			Q x CONCENTRATION/1,000		
		ACID	TOTAL IRON	SO_4	ACIDITY	TOTAL IRON	SO_4
09/10/73	350	240	190	1,800	84	66.5	630
09/26/73	2,800	410	270	2,500	1,148	756	7,000
10/24/73	275	440	342	2,173	121	94.1	597.6
01/09/74	6,700	466	261	2,025	3,122.2	1,748.7	13,567.5
02/05/74	8,500	750	530	1,975	6,375	4,505	16,787.5
03/20/74	7,900	760	367	1,700	6,004	2,899.3	13,430
04/30/74	4,000	262	175	1,775	1,048	700	7,100
05/30/74	1,500	420	166	1,250	630	249	1,875
SUM	32,025	3,748	2,301	15,198	18,532.2	11,018.6	60,987.6
NO. OF RECORDS	8	8	8	8			
MEAN	4,003	469	288	1,900			
SUM "Q"					32,025	32,025	32,025
WEIGHTED AVERAGE = $\frac{\Sigma Q \times Conc. \times 1,000}{SUM\ "Q"}$ =					579	344	1,904

TABLE IX

AVERAGE CONCENTRATION OF AMD DISCHARGES
ASKAM BOREHOLE (N-4)
PRESENT STUDY (1975-1976)

DATE	Q GPM	CONCENTRATION (ppm)			Q x CONCENTRATION/1,000		
		ACID	TOTAL IRON	SO_4	ACIDITY	TOTAL IRON	SO_4
06/26/75	1,700	286	178	1,734	486.2	302.6	2,947.8
09/30/75	12,000	328	259	1,850	3,936	3,108	22,200
10/29/75	7,500	240	220	2,250	2,806	1,650	18,875
11/25/75	1,480	230	170	2,175	340.4	251.6	3,219
01/06/76	500*	214	124	1,975	107	62	987.5
01/29/76	800*	220	149	1,925	176	119.2	1,540
02/26/76	7,270	230	149	1,550	1,672.1	1,083.2	11,268.5
03/30/76	3,275	180	118	1,275	589.5	386.5	4,175.6
04/28/76	1,300	152	118	1,438	197.6	153.4	1,869.4
05/27/76	4,220	228	133	1,825	928.4	561.3	7,701.5
SUM	40,045	2,308	1,618	17,997	10,233.2	7,677.8	72,784.3
NO. OF RECORDS	10	10	10	10			
MEAN	4,005	231	162	1,800			
SUM"Q"					40,045	40,045	40,045
WEIGHTED AVERAGE = $\frac{\Sigma Q \times Conc. \times 1,000}{SUM\ "Q"}$ =					256	192	1,818

* *Estimated Value*

TABLE X

AVERAGE CONCENTRATION OF AMD DISCHARGES
BUTTONWOOD TUNNEL (S-2)
PREVIOUS STUDY (1973-1974)

DATE	Q GPM	CONCENTRATION (ppm) ACID	TOTAL IRON	SO_4	Q x CONCENTRATION/1,000 ACIDITY	TOTAL IRON	SO_4
08/09/73	7,700	240	160	1,600	1,848	1,232	12,320
09/21/73	7,000	230	160	1,700	1,610	1,120	11,900
10/25/73	4,500	400	211	1,525	1,800	949.5	6,862.5
11/26/73	4,500	500	172	1,575	2,250	774	7,087.5
01/07/74	13,300	300	140	1,400	3,990	1,862	18,620
02/04/74	14,000	268	167	1,325	3,752	2,338	18,550
03/21/74	13,000	242	204	1,025	3,146	2,652	13,325
04/29/74	13,100	220	102	975	2,882	1,336.2	12,772.5
05/29/74	11,500	160	114	1,750	1,840	1,311	20,125
06/26/74	9,200	600	167	1,025	5,520	1,536.4	9,430
07/16/74	-	-	-	-	-	-	-
08/20/74	3,750	300	149	1,225	1,125	558.8	4,593.8
SUM	101,550	3,460	1,746	15,125	29,763	15,669.9	135,586.3
NO. OF RECORDS	11	11	11	11			
MEAN	9,232	315	159	1,375			
SUM "Q"					101,550	101,550	101,550
WEIGHTED AVERAGE = $\frac{\Sigma Q \times Conc. \times 1,000}{SUM "Q"}$ =					293	154	1,335

TABLE XI

AVERAGE CONCENTRATION OF AMD DISCHARGES
BUTTONWOOD TUNNEL (S-2)
PRESENT STUDY (1975-1976)

DATE	Q GPM	CONCENTRATION (ppm) ACID	TOTAL IRON	SO_4	Q x CONCENTRATION/1,000 ACIDITY	TOTAL IRON	SO_4
06/25/75	8,453	178	114	1,144	1,504.6	963.6	9,670.2
07/23/75	6,256	162	96	1,496	1,013.5	600.6	9,359
08/27/75	4,790	300	134	1,342	1,437	641.9	6,428.2
09/30/75	20,905	200	130	1,000	4,181	2,717.7	20,905
11/25/75	11,478	166	96	1,150	1,905.3	1,101.9	13,199.7
12/30/75	7,204	154	86	1,375	1,109.4	619.5	9,905.5
02/11/76	12,371	180	112	1,500	2,226.8	1,385.6	18,556.5
03/26/76	16,569	200	106	1,150	3,313.8	1,756.3	19,054.4
03/30/76	10,952	156	88	1,050	1,708.5	963.8	11,499.6
04/28/76	8,901	170	100	1,350	1,513.2	890.1	12,016.4
05/27/76	9,227	152	120	1,225	1,402.5	1,107.2	11,303.1
SUM	117,106	2,018	1,182	13,782	21,315.6	12,748.2	141,897.6
NO. OF RECORDS	11	11	11	11			
MEAN	10,646	183	107	1,253			
SUM "Q"					117,106	117,106	117,106
WEIGHTED AVERAGE = $\frac{\Sigma Q \times Conc. \times 1,000}{SUM "O"}$ =					182	109	1,212

Buttonwood Tunnel: In February 1974, the Plainsville Bore
hole (Henry mine pool; Figure 4, page 13) outfall was completed
and discharges from this borehole occurred during high pool levels. Since the discharges from the Plainsville Borehole are attributed to the North-West Mine Pool Complex, the outflow from this borehole was expected to cause the following changes in the North-West Complex:

a. Reduce the concentration from the Buttonwood Tunnel (S-2; Figure 4, page I3) by shortening the water flow path and detention time within the mine pools. (Verified in TABLE X and TABLE XI).

b. Maintain lower level of mine pools in proximity to the Plainsville Borehole.

Askam Borehole: The reduction of AMD concentration in the discharges from the Askam Borehole cannot be attributed to changes in flow pattern. The considerable reduction in the concentration of AMD discharges during the present study period might indicate a general improvement with time, but it cannot be readily explained.

PRECIPITATION-RUNOFF-WATER LOSS RELATIONSHIP.

LONG TERM RECORDS: The National Climatic Center of the U.S. Department of Commerce maintains a Meteorological Station at the WilkesBarre-Scranton Airport near Avoca. Climatolgical records are available since 1936 and include precipitation, temperature and wind velocity. Precipitation data is recorded on an hourly basis whereas observations of temperature and wind velocity are made daily at 3 hour intervals.

The U.S. Geologic Survey (USGS) maintains stream flow gaging stations on the Solomon Creek, Toby Creek and the Susquehanna River at Wilkes-Barre. At this writing, published records are available from the beginning of records at each station through September 1974.

In a previous study, a comparison was made between the USGS records of the gaging stations (SL 181-3; TABLE C-1, Appendix C). It was assumed that due to the proximity of Toby Creek to Solomon Creek, the annual precipitation over these two watersheds was similar. The watershed above Toby Creek is outside of the coal measures, whereas a large portion of the Solomon Watershed is within the coal mining area. On the basis of the aforementioned comparison, the following conclusions were reached:

A pronounced difference between consecutive runoff records is very apparent in the "water year"*of 1968 and the difference continues to the present time. This 1968 date coincides with the termination of deep mine pumping in the Solomon Watershed.

From the beginning of records to 1961, the mean annual runoff in Toby Creek (33 years) was the equivalent of 20.15 inches. The mean annual runoff in the Solomon Creek (34 years) was 20.84 inches. The similarity between the annual runoff in the mined and unmined watersheds was attributed to the fact that runoff losses into the mines was balanced by pumping into the streams from the mines. The balance was necessary to prevent flooding of the deep mines. Since the USGS gaging station on Solomon Creek is located on the lower stretch of the stream, the records reflect the pumping from the mines into the Creek upstream of the gaging station.

After the termination of pumping from the deep mines (1968), surface runoff in the Solomon Watershed averaged 12.26 inches or 30.4% of the mean annual precipitation from 1968 td 1973. For the same period, the runoff in Toby Creek averaged 19.89 inches, or 49.4% of the mean annual precipitation.

Assuming that the runoff in Toby Creek represents the premining conditions in Solomon Creek, the annual surface runoff losses into the deep mines for the period 1968 - 1973 was 19.89" - 12.26" = 7.63 inches. The mean average precipitation over the Solomon Creek watershed for the same period was 40.3". Consequently, the 7.63 inches of annual water losses into the mines represented 7.63 x 100/40.3 = 18.9% of the mean annual precipitation, or 7.63 x 100/19.89 = 38.4% of the total watershed runoff.

Previous data and analysis of losses and mine pool discharges in the Nanticoke, Warrior S and Solomon Creek watersheds indicated that the discharges from the South Wilkes-Barre Boreholes can be attributed to surface water losses into the South-East Mine Pool Complex that underlies the three watersheds and the adjacent Mill Creek watershed.

** "Water Year" records commence on October 1st and end on September 30th.*

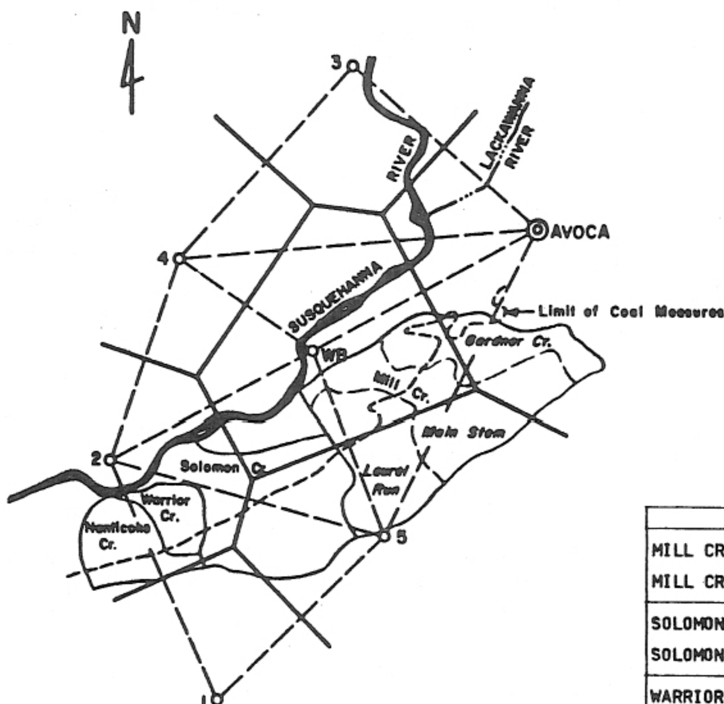
STUDY PERIOD RECORDS: During the 1975 - 1976 study period, two continuous recorders were installed in the Mill Creek watershed. The location of these recorders is shown on Figure 3, page 11. Station M-2 represents the flow in the Main Stem of Mill Creek and Station L-23 represents the flow in Laurel Run, a major tributary to Mill Creek. During the same period, the discharges from the three South WilkesBarre Boreholes and the Askam Borehole were monitored. AMD discharges from the Askam Borehole represent upper mine pool discharges from the South-East Mine Pool Complex. These upper pools are recharged by surface water losses within the coal measures and groundwater flow from areas above the coal measures in the Warrior and Nanticoke watersheds. Flow records in Solomon Creek were obtained from the USGS gaging station.

The four watersheds encompass approximately 55 square miles, consisting of forested , hilly terrain in the headwaters of the watersheds and relatively flat urban areas in the flood plains of the Susquehanna River. The topographic relief in the Mill Creek watershed varies from elevation 520' at the mouth of the Creek to elevation 2,160' along the drainage divide. Within the limit of the coal measures, the area has been extensively disturbed by deep and strip mining operations. The wide variation in topography, surface cover, soil conditions and mining activities results in a variation of runoff conditions.

Review of available information revealed that, in addition to the first order climatological station at Avoca, daily precipitation records are also available from six rain gages in the area. The locations of these gages are shown on Figure 6* Distribution of the precipitation over the watersheds that contributes to surface water losses into the deep mines was made by means of a Theissen Diagram. The method of distribution and the derived factors are also indicated on Figure 6.* Daily precipitation records from each station are presented in Appendix C. These records indicate that the annual precipitation over the headwaters of the watersheds, outside of the coal measures, exceeds the precipitation over the flood plain of the Susquehanna River.

* *Page 53*

PRECIP. STATION	AREA IN SQUARE MILES	REMARKS
	MILL CREEK	
	A. ABOVE COAL MEASURES	
AVOCA	5.40	GARDNER CREEK
	4.29	MAIN STEM
	9.69	
#5	4.76	MAIN STEM
	7.14	LAUREL RUN
	11.90	
W.B.	0.95	LAUREL RUN
	2.14	MAIN STEM
	1.67	GARDNER CREEK
	4.76	
	26.35	SUB-TOTAL
	B. WITHIN COAL MEASURES	
W.B.	1.90	GARDNER CREEK
	4.05	MAIN STEM
	2.86	LAUREL RUN
	8.81	
	35.16	TOTAL MILL CREEK
	SOLOMON CREEK	
#5	7.62	ABOVE COAL MEASURES
#2	1.90	ABOVE COAL MEASURES
	9.52	SUB-TOTAL
#2	4.75	WITHIN COAL MEASURES
#5	1.43	WITHIN COAL MEASURES
	6.18	SUB-TOTAL
	15.70	TOTAL SOLOMON CREEK
	WARRIOR CREEK	
#2	0.17	ABOVE COAL MEASURES
	2.95	WITHIN COAL MEASURES
	3.12	TOTAL WARRIOR CREEK
	NANTICOKE CREEK	
#2	1.85	ABOVE COAL MEASURES
	4.02	WITHIN COAL MEASURES
	5.87	TOTAL NANTICOKE CREEK



THIESSEN DIAGRAM

CLIMATOLOGICAL STATIONS

#1	MOUNTAIN TOP
#2	WEST NANTICOKE
#3	EXETER
#4	SHAVERTOWN
#5	BEAR CREEK
W.B.	WILKES-BARRE
◉	1st ORDER STATION

DISTRIBUTION OF PRECIPITATION

WATERSHED	ALLOCATION TO PRECIP. STATIONS
MILL CREEK TOTAL	0.28 AVOCA + 0.34 #5 + 0.38 W.B.
MILL CREEK ABOVE COAL M.	0.37 AVOCA + 0.45 #5 + 0.18 W.B.
SOLOMON CREEK TOTAL	0.58 #5 + 0.42 #2
SOLOMON CR. ABOVE COAL M.	0.80 #5 + 0.20 #2
WARRIOR CREEK	USE STATION #2 (100%)
NANTICOKE CREEK	

AMD ABATEMENT STUDY
MILL CREEK
PROJECT NO. SL 181-4
LUZERNE CO., PENNA.

PRECIPITATION DISTRIBUTION

FIGURE 6

The monthly precipitation in the watersheds that overlie the South-East Mine Pool Complex is indicated below. During the study period, the precipitation over Solomon and Warrior/Nanticoke Creeko each exceeded the precipitation over the Mill Creek watershed.

TABLE XII

MONTHLY PRECIPITATION OVER THE SOUTH-EAST MINE POOL COMPLEX

YEAR	MONTH	PRECIPITATION IN INCHES			
		AVOCA AIRPORT	WARRIOR & NANTICOKE (1)	SOLOMON CREEK (2)	MILL CREEK (3)
1975	MAY	4.01	3.74	4.34	4.27
	JUNE	5.64	5.26	6.11	5.98
	JULY	3.85	6.03	5.22	4.24
	AUGUST	2.78	3.59	3.58	2.98
	SEPTEMBER	6.10	8.05	7.73	7.71
	OCTOBER	3.29	4.08	3.73	3.60
	NOVEMBER	3.00	3.53	3.88	3.36
	DECEMBER	1.84	2.40	2.97	2.33
1976	JANUARY	3.25	4.33	5.90	3.75
	FEBRUARY	2.14	2.52	2.47	2.27
	MARCH	2.18	2.62	2.96	2.53
	APRIL	2.27	2.63	2.76	2.52
	TOTAL	40.35	48.78	51.65	45.54

(1) Precipitation Station #2 (West Nanticoke)

(2) $0.58 \times i_5 + 0.42 \times i_2$

(3) $0.28 \times i_{Avoca} + 0.34 \times i_5 + 0.38 \times i_{W.B.}$

NOTE: *For values of "i", see Precipitation Records, Appendix C.*

LIMITATION OF STUDY PERIOD RECORDS: Interruptions in operation of the continuous recorders occurred due to flooding, acts of vandalism and malfunctions of the recorders. The gaps in the records for the study period are shown in Figure 7*. Data required for the analysis of water losses consisted of flow records, as well as records on fluctuations of mine pools. Review of the recorder charts indicated that low temperatures (winter period) have a significant effect on the time scale of these charts. Recorded chart time lagged behind actual time by as much as three days per month. Therefore, computational adjustments were necessary to compensate for time lag distortions in the analysis of the chart records.

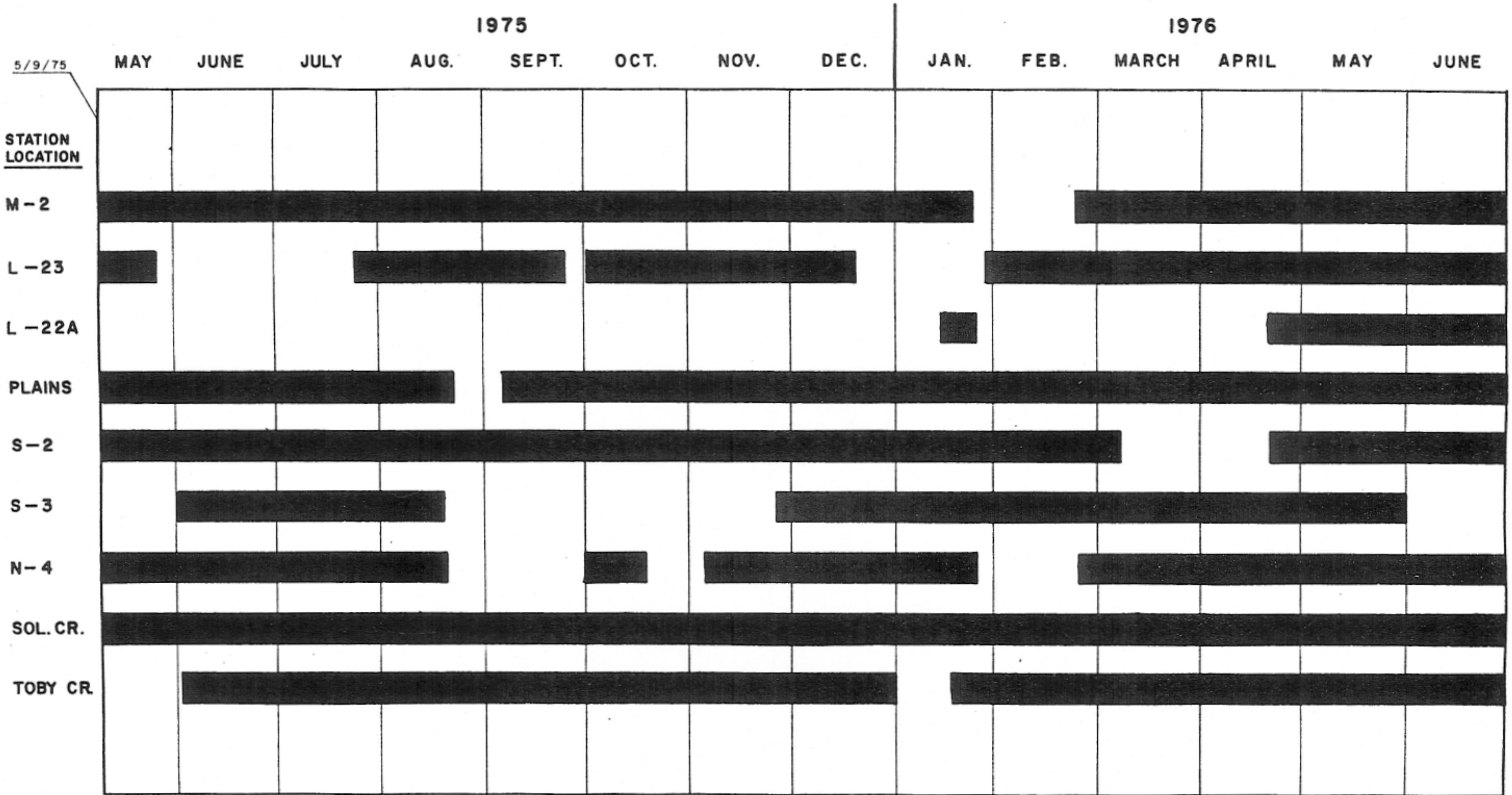
Stage/discharge relationship had to be determined for each stream flow recorder in order to convert time/stage scales into time/flow charts or hydrographs. Due to observed changes in stream-bed and flow patterns at Station M-2, a correlation between actual current meter measurements and recorded stream stages was required to affect computational adjustments for stream flow analysis.

Backwater effect during high stages in Solomon Creek had to be taken into consideration in the preparation of Stage/Discharge rating curves for Station S-3 (South Wilkes-Barre Boreholes).

Despite these limitations, data obtained through the use of continuous monitoring recorders permitted a more reliable analysis of water losses than that previously obtained by monthly readings, This is particularly significant for the correlation between mine pool fluctuations and the discharges from the boreholes.

TOTAL SURFACE WATER LOSSES INTO THE DEEP MINES: Surface water losses in the watershed consist of streambed losses and surface area infiltration of precipitation within the coal basin. Out of the 36.6 square miles of the Mill Creek watershed, approximately 68% (25 sq.mi.) are located above the coal measures (see Area A, Figure I"** With the exception of limited areas immediately adjacent to the coal measures, there are no surface water losses in Area A. Runoff from precipitation directly contributes to Area A stream flow and infiltration recharges the groundwater table which in turn contributes to the base flow of the Area A streams. As the streams increase in length,

** Page 56*   [1] ** Page 5*



STATION	LOCATION
M-2	Mill Creek at confluence with Laurel Run
L-23	Laurel Run at Mouth
L-22A	Laurel Run at Colebrook Dam
PLAINS	Plainsville Borehole Outfall (Henry Pool)
S-2	Buttonwood Tunnel Outfall
S-3	South Wilkes-Barre Boreholes Outfall
N-4	Askam Borehole Outfall
SOL. CR.	Solomon Creek USGS Gaging Station
TOBY CR.	Toby Creek USGS Gaging Station

AMD ABATEMENT STUDY

MILL CREEK
PROJECT NO. SL 181-4
LUZERNE CO., PENN.

PERIODS OF CONTINUOUS RECORDS

FIGURE 7

they increase in flow rate until they cross the limit of the coal measures into the coal basin. Within the coal basin, some stream flow, area runoff and infiltration is lost directly into the deep mine pools that are below the level of the stream channels. Similarly, groundwater is lost to the deep mines by recharge through fracture zones from the elevated water table that surrounds the coal basin. Consequently, there is no contribution to "base flow" from groundwater into the stream reaches from 32% of the watershed that is within the coal basin. Subsidence depressions, strippings, mine waste piles and lack of vegetation decreases surface runoff and evapotranspiration in Area C, which in turn increases the rate of infiltration into the deep mines. After crossing the coal measures, the difference between the water surface elevation of the Mill Creek tributaries and the elevation of the mine pools is such that these streams become exfluent streams with flow losses into the underlying deep mine pools. Consequently, the rate of stream flow per square mile of drainage area within the coal basin differs substantially from the rate of stream flow outside of the coal measures, However, if all surface water losses were to be prevented (a condition that existed prior to deep and strip mining in the basin), the flow per square mile throughout the entire watershed would be essentially the same. Under the latter condition, the flow per square mile at the mouth of Mill Creek will be similar to the flow per square mile in the headwaters of the watershed. Therefore, the total surface water losses into the deep mines during the study period can be derived by the following procedures:

a. Determine the present flow at station M-l, which is the sum of the recorded flow at M-2 and L-23. (see Figure 3, page 11).

b. Determine the relationship between flow per square mile at M-1 to the flow per square mile of the watershed above the coal measures.

c. Subtract the flow recorded at M-1 from the anticipated flow at this station if there were no water losses to the mines.

As previously described, the outflow from the three South WilkesBarre Boreholes is attributed to the surface water losses, leaking sewer and water lines, and groundwater inflows which recharge the

South-East Pool Complex. Consequently, any reduction of these mine pool recharge sources in the Mill Creek watershed (and the adjacent Solomon, Warrior and Nanticoke watersheds) will abate AMD pollution
by reducing the rate of discharge from the Three Boreholes. Therefore, the contribution of these recharge sources of water losses within each watershed is needed in order to evaluate the degree of abatement that can be achieved by feasible water loss prevention methods.

Fluctuation of mine pool levels in the South-East Pool Complex
is reflected by the records of the Stanton and Delaware Pools, shown in Figure 5, page 17. If the inflow into the mine pools is equal to the. outflow from the pool, the level of the pool will remain unchanged. This fundamental relationship between inflow and outflow from the mine pools can be expressed by the following equation:

(INFLOW) - (OUTFLOW) _ ± (MINE POOL STORAGE)

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

<u>ILLUSTRATIVE EXAMPLE:</u> The procedure used to determine total surface water losses into the South-East Complex is as described below:

From 11/25/75 to 1/10/76, the Stanton Mine Pool dropped from elevation 530.5' to elevation 529.2' - a drop of 1.3' in forty-six days. From 1/10/76 to 1/28/76, the Stanton Pool then rose from elevation 529.2' to elevation 530.5' (same elevation as on 11/25/75), or a rise of 1.3' in eighteen days. Denoting the periods of "drop" and "rise" in mine pools by subscripts (1) and (2) the following INFLOW/OUTFLOW relationship can be derived:

Falling: INFLOW $_{(1)}$ - OUTFLOW (1) = -(MINE POOL STORAGE)

Rising: INFLOW (2) - OUTFLOW (2) _ +(MINE POOL STORAGE)

{INFLOW $_{(1)}$ + INFLOW (2)}-{OUTFLOW $_{(1)}$ + OUTFLOW $_{(2)}$} = 0

Therefore, for the period of sixty-four days (11/25/75 to

1/28/76), the inflow into the mine pools was equal to the outflow from the pools.

Applying this technique to other time intervals of mine pool fluctuations, the magnitude of inflow into the pools can be determined by measuring the volume of outflow from the Three Boreholes for the selected time interval.

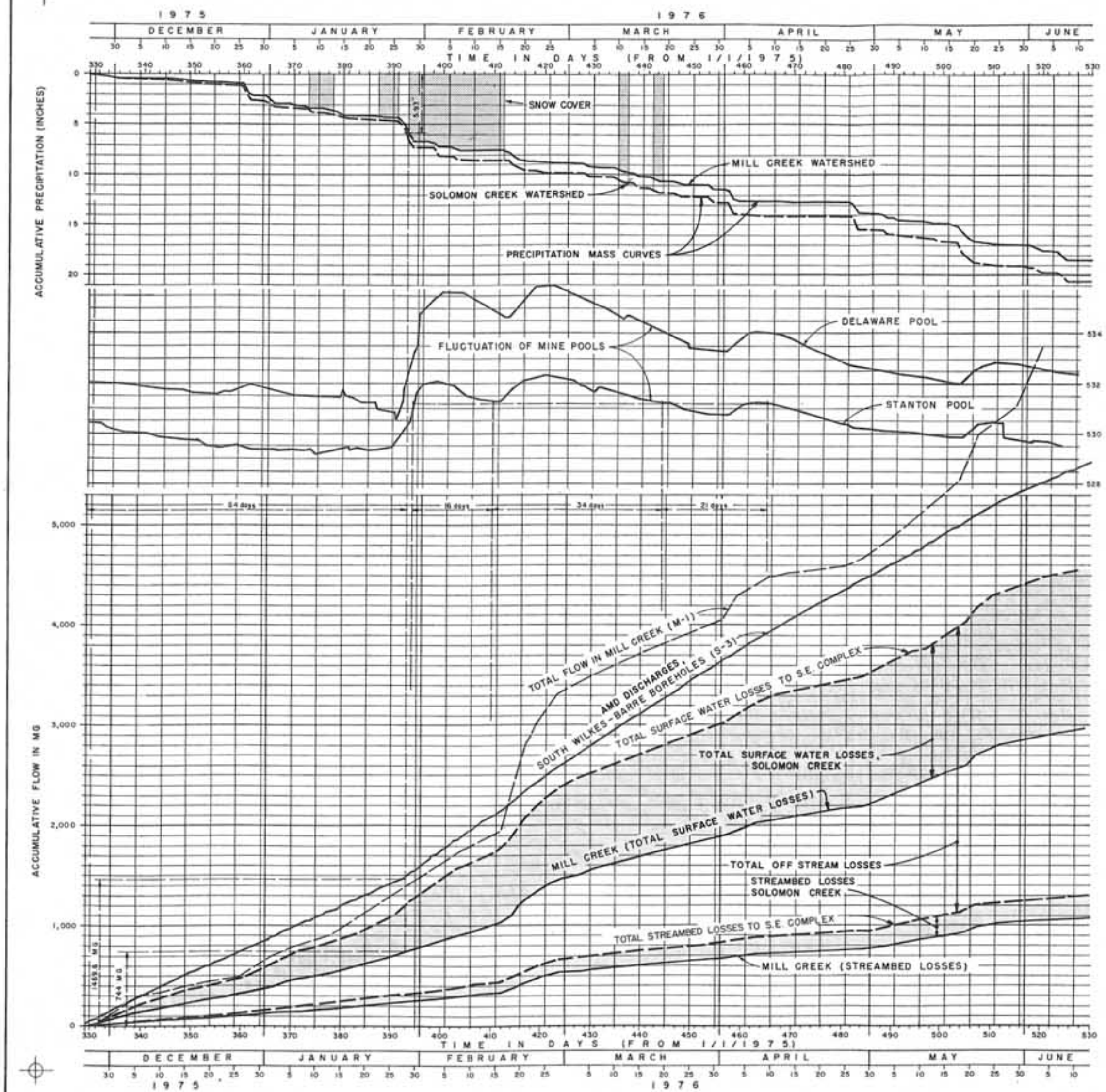
Since surface water losses in Gardner Creek do not recharge the South-East Complex, they do not contribute to the discharge at the South Wilkes-Barre Boreholes. Consequently, the Gardner Creek losses were deducted from the total losses in Mill Creek. Similarly, some of the water losses in Sugar Notch Run (a subwatershed of Solomon Creek) were deducted from the total water losses of Solomon Creek which contribute to the South-East Complex. (The upper portion of Sugar Notch Run provides direct recharge to the Upper Mine Pools).

For the sixty-four day period (11/25/75 - 1/28/76), the level of the Stanton Pool at the beginning of the period was equal to the Pool level at the end. On that basis, the OUTFLOW from the South Wilkes-Barre Boreholes should equal the INFLOW into the South-East Mine Pool Complex.

Outflow from the South-East Mine Pool Complex: From the flow data recorded at the three South Wilkes-Barre Boreholes (S-3), a mass curve was drawn (see Figure 8*). The cumulative flow for the sixty-four day period was 1,469.6 million gallons which converts to 22.96 MGD or 35.55 cfs.

Inflow (Losses) to the South-East Mine Pool Complex: Since the Complex underlies several different watersheds, the contribution of each watershed was derived to determine the total inflow as follows:

Mill Creek - Laurel Run Losses: Flow relationship between stream inflow into the coal basin and the flow near the mouth of Mill Creek (Sta. M-1) is presented in Figure 9A)"* Since M-1 is the sum of the flow at Stations L-23 and M-2 (see Figure 3), the use o f M-1 records was limited to the period o f records where the flow records at M-2 overlapped the records at L-23. * page 61 * page 63



SUMMARY OF FINDINGS

SURFACE WATER LOSSES INTO THE LOWER MINE POOLS

FLOW CONDITIONS FOR PERIODS WHERE INFLOW INTO MINE POOLS = OUTFLOW FROM MINE POOLS

PERIOD	NO. OF DAYS	BOREHOLES DISCHARGE STA. S-3 (MG)	TOTAL LOSSES (MG) SOLOMON WATERSHED	TOTAL LOSSES (MG) MILL CR. WATERSHED	TOTAL LOSSES (MG) TOTAL	EXCESS DISCHARGE MG	STREAMBED LOSSES (MG) SOLOMON CREEK	STREAMBED LOSSES (MG) MILL CREEK	STREAMBED LOSSES (MG) TOTAL	STREAM FLOW (MG) SOLOMON CREEK	STREAM FLOW (MG) MILL CREEK
(1)	(2)	(3)	(4)	(5)	(6)=(4)+(5)	(7)=(3)-(6)	(8)	(9)	(10)=(8)+(9)	(11)	(12)
06/14/75-09/27/75	105	2,524.4	383	965	1,348	1,176.4	53	250	303	546	1,146
11/23/75-01/28/76	64	1,469.6	461	735	1,196	273.6	67	237	304	663	1,387
01/29/76-02/14/76	16	556.4	217	231	448	108.4	27	80	107	335	476
02/14/76-03/19/76	34	1,176.5	343	734.5	1,077.5	99.0	49	289	338	499	1,920
03/19/76-04/09/76	21	668.9	191	319	510	158.9	29	115	144	265	660
	240	6,395.8	1,595	2,984.5	4,579.5	1,816.3	225	971	1,196	2,308	5,589

EVALUATION AND PROJECTION OF FLOW (05/01/75-04/30/76)

DESCRIPTION										
% OF AMD DISCHARGE	100%	24.9%	46.7%	71.6%	28.4%	3.3%	15.2%	18.7%	36.1%	87.39%
DRAINAGE AREA (SQ.MI.)	(52.3)	15.7	36.6	52.3	52.3	15.7	36.6	52.3	15.7	36.6
RUNOFF EQUIV. (INCH)	7.04"	3.85"*	4.69"*	5.04"	2.00"	0.82"*	1.53"*	(1.32")	8.46"	8.79"
PRECIPITATION (INCH)	(30.45")	32.68"	29.50"			32.68"	29.50"		32.68"	29.50"
% OF PRECIPITATION	(23.1%)	17.90%	15.90%*			2.5%*	5.2%*		25.9%	29.8%
TOTAL PRECIP. (INCH)**	(47.37")	51.65"	45.54"			51.65"	45.54"		51.65"	45.54"
PROJECTED FLOW (INCH)**	10.9"	9.24"*	7.24"*			1.29"*	2.37"*		13.37"	13.57"
PROJECTED FLOW (MG)**	9,903 MG	2,522 MG	4,603 MG	7,125 MG	2,778 MG	351 MG	1,507 MG	1,858 MG	3,647 MG	8,629 MG
COMP./RECORDED VALUES	(10,680 MG)†	2,859 MG	4,788 MG	7,647 MG	(3,033 MG)	393 MG	1,608 MG	2,001 MG	4,212 MG	9,197 MG
RUNOFF EQUIV. (INCH)	(11.75")	10.48"*	7.53"*	(8.42")	(3.33")	1.44"*	2.53"*	(2.20")	15.44"	14.46"

* ONLY LOSSES INTO THE SOUTH-EAST MINE POOL COMPLEX (LOWER POOLS)
** FOR THE 12 MONTH PERIOD 5/1/75-4/30/76, USING PREVIOUSLY DERIVED % OF PRECIPITATION
† 7,647 + 3,033 = 10,680

RECHARGE-DISCHARGE BALANCE IN THE SOUTH-EAST MINE POOL COMPLEX

UPPER MINE POOLS *

NANTICOKE, WARRIOR AND SUGAR NOTCH WATERSHEDS

	MINE POOL RECHARGE	ANNUAL INFLOW (MG) 5/1/75 to 4/30/76	ANNUAL INFLOW (MG) MEAN YEAR	% OF TOTAL
SOURCE	1 STREAMBED LOSSES	1,180	1,040	15.5
	2 OFF-STREAM LOSSES	3,891	3,440	51.5
	3 TOTAL SURFACE LOSSES	5,071	4,480	67.0
	4 GROUNDWATER RECHARGE	1,460	1,290	19.4
	5 PIPELINE LEAKAGE	910	910	13.6
	6 TOTAL SOURCES	7,441	6,680	100.0

AMD DISCHARGES	ANNUAL OUTFLOW (MG) 5/1/75 to 4/30/76	ANNUAL OUTFLOW (MG) MEAN YEAR	% OF TOTAL
7 ASKAM BOREHOLE	1,673	1,440	21.6
8 BALANCE (6) - (7)	5,768	5,240	78.4

TO NANTICOKE CREEK & SUSQUEHANNA RIVER

* From Fig. 12, Page 79

MEAN ANNUAL VALUES

THE MEAN ANNUAL PRECIPITATION AT THE FIRST ORDER CLIMATOLOGICAL STATION AT AVOCA IS 35.65". THE PRECIPITATION AT THE AVOCA STATION FOR THE 12-MONTH PERIOD OF THE STUDY (5/1/75 - 4/30/76) IS 40.35". THEREFORE, THE MEAN ANNUAL AMD DISCHARGES AND SURFACE WATER LOSSES ARE:

$$\frac{35.65"}{40.35"} \times \text{(STUDY PERIOD VALUES)}$$

LOWER MINE POOLS

SOLOMON CREEK AND MILL CREEK WATERSHEDS

	MINE POOL RECHARGE	ANNUAL INFLOW (MG) 5/1/75 to 4/30/76	ANNUAL INFLOW (MG) MEAN YEAR	% OF TOTAL
SOURCE	1 STREAMBED LOSSES	2,001	1,770	14.5
	2 OFF-STREAM LOSSES	5,646	4,990	40.9
	3 TOTAL SURFACE LOSSES	7,647	6,760	55.4
	4 GROUNDWATER RECHARGE	2,920	2,580	21.2
	5 PIPELINE LEAKAGE	2,850	2,850	23.4
	6 TOTAL SOURCES	13,417	12,190	100.0

AMD DISCHARGES	ANNUAL OUTFLOW (MG) 5/1/75 to 4/30/76	ANNUAL OUTFLOW (MG) MEAN YEAR	% OF TOTAL
7 SOUTH W-B BOREHOLES	10,680	9,400	77.1
8 BALANCE (6) - (7)	2,737	2,790	22.9

UNACCOUNTED FOR DISCHARGES

TO SOLOMON CREEK & SUSQUEHANNA RIVER

AMD DISCHARGES FROM SOUTH WILKES-BARRE BOREHOLES
COMPARISON BETWEEN ANNUAL AND LOW FLOW PERIODS

AMD DISCHARGES AND SOURCE OF MINE POOL RECHARGE	STUDY PERIOD: 366 DAYS 5/1/75-4/30/76 MGD	366 DAYS TOTAL	30 CONSECUTIVE LOW FLOW DAYS 8/26-9/25/75 MGD	30 CONSECUTIVE LOW FLOW DAYS TOTAL
AMD DISCHARGES	29.18	100.0%	21.80	100.0%
STREAMBED LOSSES	4.23	14.5%	1.50	6.9%
OFF-STREAM LOSSES	11.93	40.9%	6.24	28.6%
Sub-Total Surface Losses	16.16	55.4%	7.74	35.5%
GROUNDWATER RECHARGE	6.19	21.2%	7.13	32.7%
PIPELINE LEAKAGE	6.83	23.4%	6.93	31.8%

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

AMD ABATEMENT STUDY
MILL CREEK
PROJECT NO. SL 181 - 4
LUZERNE CO., PENNA.

MILL CREEK & SOLOMON CREEK WATERSHEDS
PRECIPITATION - INFLOW - OUTFLOW RELATIONSHIP
LOWER MINEPOOLS - S.E. MINEPOOL COMPLEX

DATE: DEC. 1976

FIGURE NO. 8

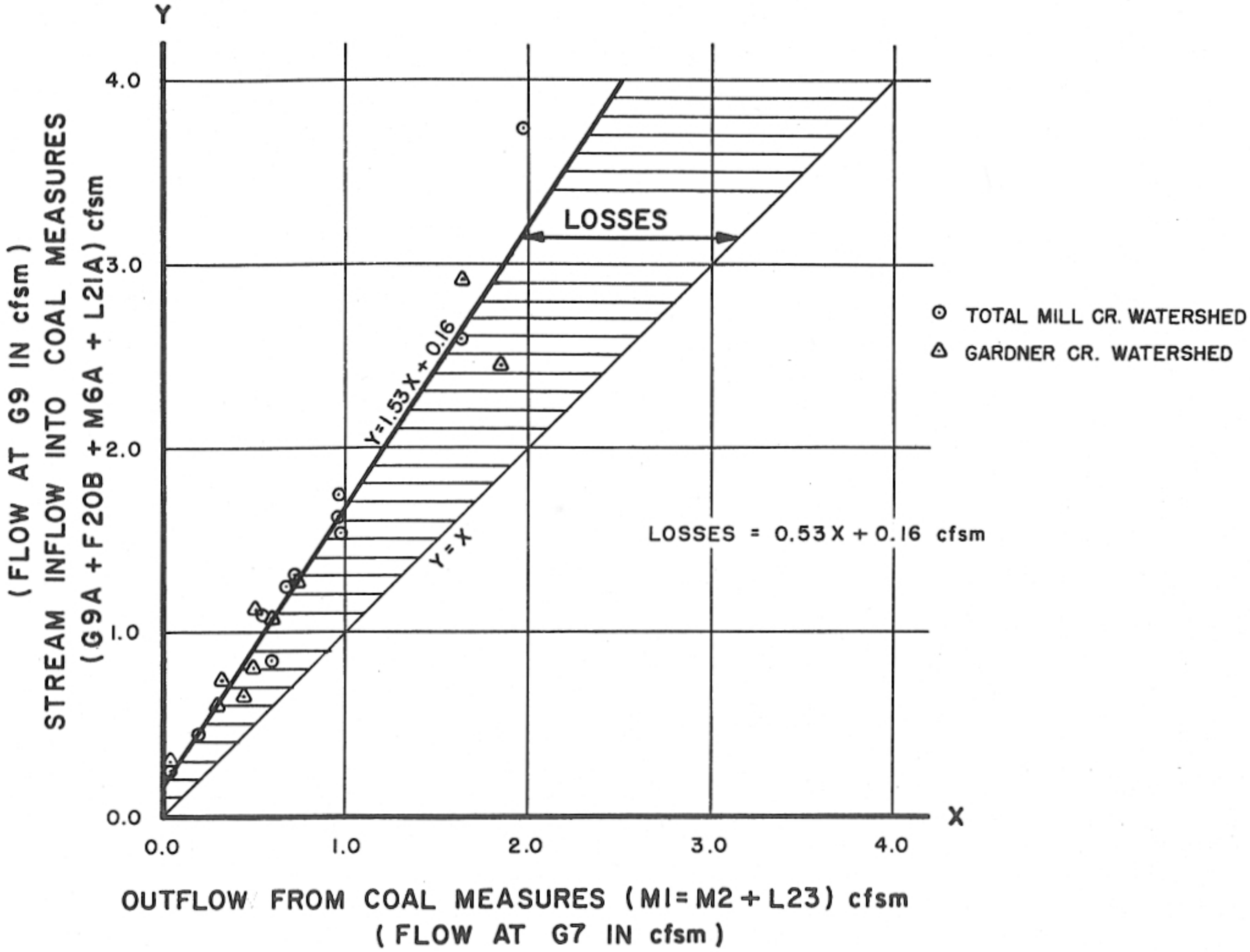


FIGURE 9A

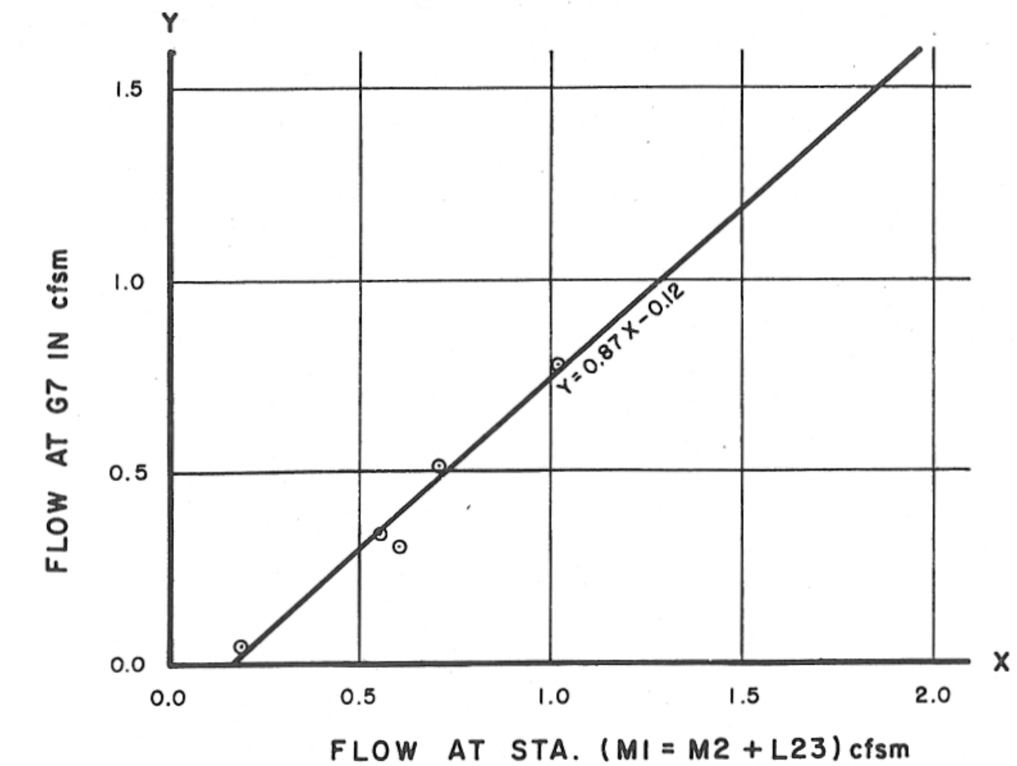


FIGURE 9B

SURFACE WATER LOSSES IN THE MILL CREEK WATERSHED

The data overlap periods are shown on Figure 7, page 56.

The recorded values from M-1 were compared to the USGS records at Solomon and Toby Creeks. A good correlation was obtained between the flow at M-1 in cfsm (cubic feet per second per square mile of drainage area) and that of Toby Creek, as shown in Figure 10, page 65. Therefore, for the periods when flow records were not available at M-1, the flow was computed from this relationship.

For the illustrative 64 day period, the flow at M-1 was derived as follows:

The recharge of the South-East Complex from water losses in the Mill Creek watershed are the total watershed losses less the losses in Gardner Creek. Correlation between the flow in cfsm at Station G-7 and that at M-1 is shown in Figure 9B'** and is

Flow in Toby Creek Drainage Area 32.4 Sq. Miles	Period	Flow in Mill Creek (M-1) Drainage Area 36.6 Sq. Miles	
11/25-30/75 $\frac{41.5\ cfs}{32.4\ Mi^2} = 1.28$ cfsm	6 days	1.02 cfsm*	223.9 CFS days
12/01-31/75 $\frac{31.7\ cfs}{32.4\ Mi^2} = 0.98$ cfsm	31 days	0.78 cfsm*	885.0 CFS days
01/01-28/76 $\frac{31.5\ cfs}{32.4\ Mi^2} = 0.97$ cfsm	27 days	0.78 cfsm*	770.8 CFS days
	64 days		1,879.7 CFS days

1,879.7 CFS days x 0.646 = 1,214.3 MG → → → → → → → → → →

* From correlation with Toby Creek (see Fig. 10, page 65).

From Figure 9A; $q_J = (1.53\ q_o + 0.16)$ *cfsm, where*

q_J = *inflow of stream into the coal basin in cfsm*

q_o = *flow of stream at Station M-1 in cfsm*

Therefore, the total expected flow at M-1 if total water losses were prevented (assuming pre-mining conditions) would have been:

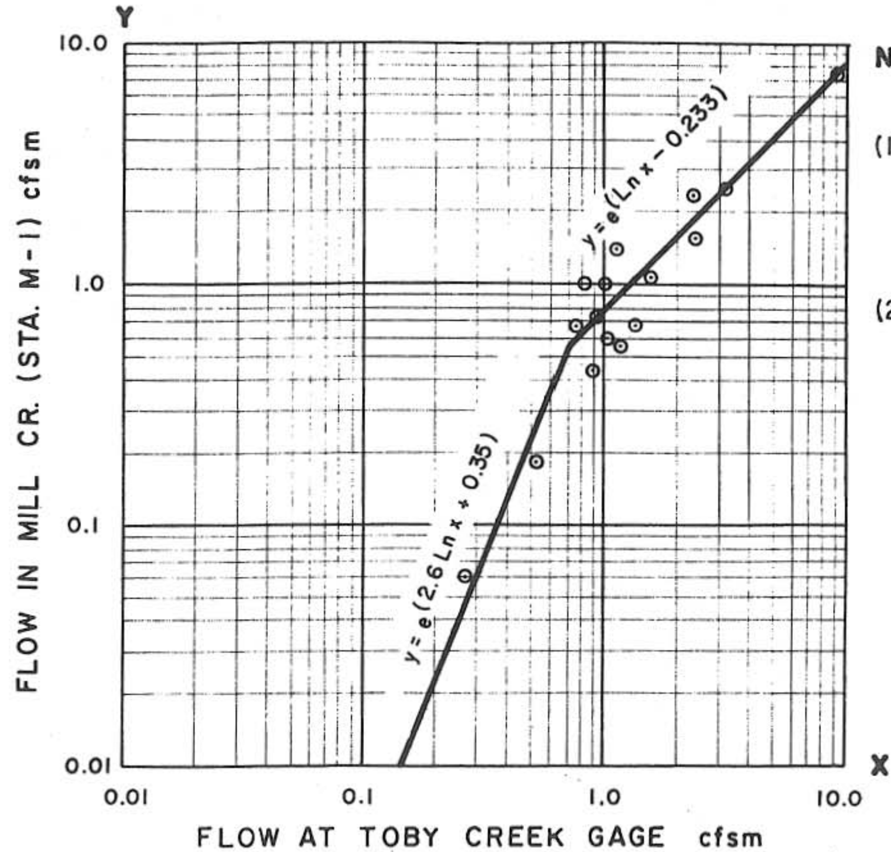
{(1.53x1.02cfsm+0.16)x6days+(1.53x0.78cfsm+0.16)x58days}x0.646x36.6 = 2,100.0 MG

Cumulative Flow at M-1 (accounting for losses) . . . . = 1,214.3 MG ← ←

Total losses in Mill Creek Watershed (including Gardner Creek) . . = 885.7 MG

expressed by the equation $q_{g\text{-}7} = (0.87 \times q_{m\text{-}1} - 0.12)$cfsm.

The relationship between the flow at G-7 in cfsm and the inflow ** page 63.



NOTES:

(1) for $.15 < q_{Toby} < .70$ cfsm

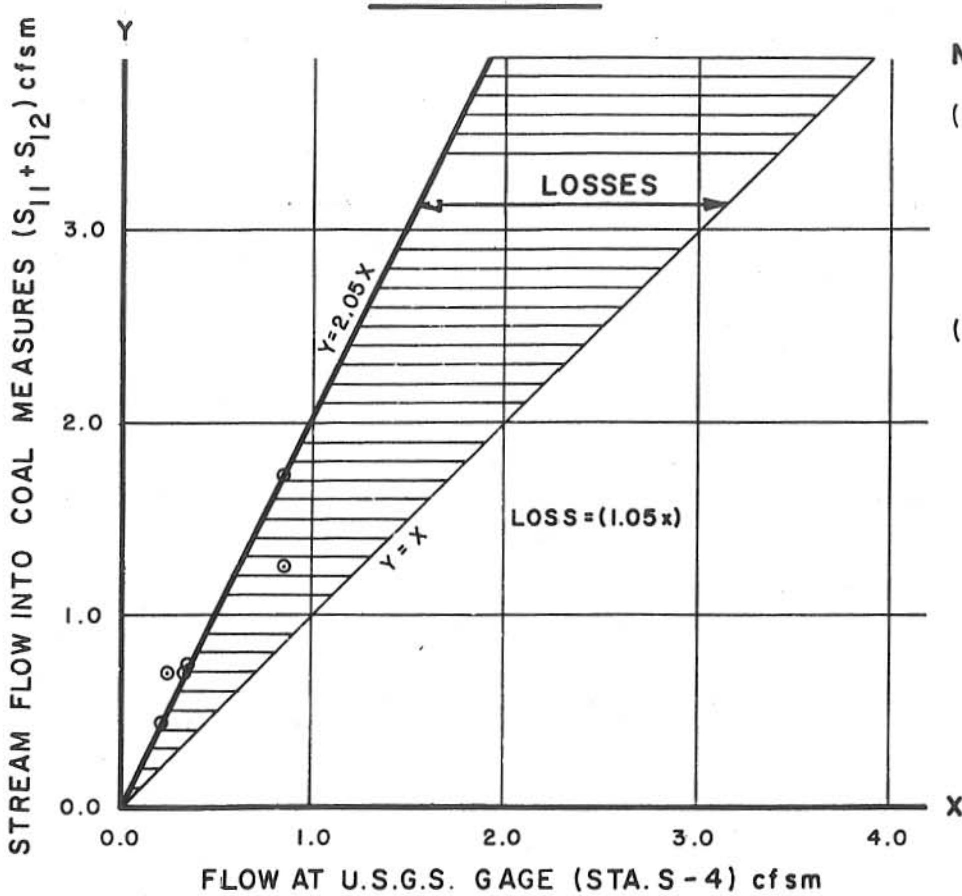
$q_{M-1} = y = e^{(2.6 \, Ln \, x + .35)}$ cfsm

(2) for $q_{Toby} > .70$ cfsm

$q_{M-1} = y = e^{(Ln \, x - .233)}$ cfsm

FLOW CORRELATION (TOBY CR. Vs. MILL CR.)

FIGURE 10



NOTES:

(1) Data obtained from a previous study in Nanticoke, Warrior and Solomon Creek watersheds (SL 181-3).

(2) Flow in Solomon Creek is being recorded at the U.S.G.S. Gaging Station (see Fig. 4, Sta. S-4).

SURFACE WATER LOSSES IN SOLOMON CR. WATERSHED

FIGURE 11

of Gardner Creek from outside the coal basin (G-9) is identical to the relationship shown on Fig. 9A, p. 63. Therefore, the flow at G-7, if losses in Gardner Creek were prevented, can be expressed by the following relationships:

{{1.53x(0.87x1.02-0.12)+0.16}x6 days + {1.53x(0.87x0.78-0.12)+0.16}x58 days}
x 0.646 x 9.7 mi^2 = ... 419.2 MG

Flow at G-7 accounting for losses:

{(0.87x1.02-0.12)x 6 days +
(0.87x0.78-0.12) x 58 days} x 0.646 x 9.7 mi^2 = ... 232.0 MG

Total losses in Gardner Creek to North-West Complex . . . . 187.1 MG

Therefore, total Mill Creek losses into the South-East Complex are: 885.7 MG (page 64) - 187.1 MG . . . . 698.6 MG

<u>Solomon Creek Watershed Losses</u>: From flow records at the USGS gaging station on Solomon Creek (Station S-4, Fig. 4, p. 13), the accumulative flow of Solomon Creek for the 64 day period (11/25/75 to 1/28/76) was 550.3 million gallons which converts to 8.6 MGD or 13.3 cfs. The mean flow per square mile = $\frac{13.3 \text{ cfs}}{15.7 \text{ mi}^2}$ = 0.85 cfsm.

The flow relationship between stream inflow into the basin and the flow at the USGS gage within the coal basin is presented in Figure 11, page 65, and can be expressed as follows: $q_J = 2.05\ q_0$; where q_J = rate of stream inflow in the coal basin in cfsm, and q_0 = recorded flow at the USGS gage in cfsm. Therefore, the total expected flow for the 64 day illustrative period at the USGS gage (S-4), if water losses were prevented is:

2.05 x 0.85 cfsm x 0.646 x 15.7 mi^2 x 64 days . . . 1,131.0 MG

Total accumulative flow recorded at S-4 . . . . . . 550.3 MG

Total losses in Solomon Creek (incl. Sugar Notch Run) 580.7 MG

Accounting for the 2.33 sq.mi. of Sugar Notch Run watershed that recharge the upper pools, the direct recharge of the lower mine pools is $\frac{(15.7-2.33)mi^2}{15.7mi^2}$ x 580.7 MG = 494.5 MG

From a previous study of the Solomon Creek watershed (SL181-3), the minimum recharge of the "Lower Mine Pools" from the "Upper Mine Pools" was determined to be 1.2 MGD. Therefore, the additional recharge for the 64 day period is 1.2 MGD x 64 days, or 76.8 MGD.

Consequently, total losses to the Lower Mine Pools from all of Solomon Creek sources amount to 494.5 + 76.8 (1.2 x 64 days) = ... 571.3 MG

<u>Water Balance for 64 day Period</u>: Based on the INFLOW/OUTFLOW values derived from the illustrative example, water balance for the 64 day period is as follows:

Outflow from the South Wilkes-Barre Boreholes . . . 1,469.6 MG

Inflow losses to the South-East Pool Complex:

Mill Creek Watershed 698.6

Solomon Creek Watershed 571.3

Total Surface Water Losses . . . . 1,269.9 MG

Excess Outflow (not accounted for) . . . . 199.7 MG

Assuming that all discharges from the Lower Mine Pools in the South-East Mine Pool Complex emanate from the South Wilkes-Barre Boreholes, the 199.7 MG of excess outflow is attributed to other mine pool recharge sources (pipeline losses and groundwater recharge).

DISTRIBUTION OF 64 DAY LOSSES (RECHARGE) TO THE SOUTH-EAST MINE POOL COMPLEX

DESCRIPTION	SURFACE WATER LOSSES		OTHER SOURCES	TOTAL
	SOLOMON CREEK	MILL CREEK		
Volume (MG)	571.3	698.6	199.7	1,469.6
% of Total	38.9%	47.5%	13.3%	100.0%
Contributing Drainage Area in Square Miles	13.37	26.9	—	40.27
Losses in Inches of Runoff	2.46"	1.49"	—	2.10"
Precipitation (inches)	6.53"	5.64"	—	5.94"
Losses; % Precipitation	37.7%	26.4%	—	(35.4%)
Recorded Stream Flow (MG)	550.3	1,214.3	—	—
Drainage Area (Sq.Mi.)	15.7	36.6		(52.3)
Runoff (inches)	2.02"	1.91"	—	(1.94")
Runoff + Losses (inches)	4.48"*	3.4"*		(4.04")
% of Precipitation	68.6%	60.3%		(68.0%)

* Expected runoff if total losses were prevented

A similar procedure was applied to all other periods (total of 240 days) where the inflow into the mine pools was equal to the outflow from the mine pools. The relationship between precipitation, mine pool fluctuations, surface water losses, and AMD discharges from the South Wilkes-Barre Boreholes is presented in the mass curves in Figure 8, page 61. The mass curve of total losses is based on generation of inflow into the basin, using hourly flow recorded at Station M-1. Since the outflow from the South Wilkes-Barre Boreholes is specifically related to the South-East Mine Pool Complex, the "total loss" mass curve is the accumulative surface water losses into the South-East Complex. In addition to the above losses, the Gardner Creek branch of Mill Creek is losing to and recharging the NorthWest Mine Pool Complex.

To facilitate data processing and computational procedures, a computer program was prepared to generate the hourly surface water inflow into the coal basin. Input data consisted of the hourly records from Station M-1 in the Mill Creek watershed and Station S-4 (USGS gage) in the Solomon Creek watershed. Relationship between the inflow into the coal basin and the flow records at stations M-1 and S-4 is presented in Appendix D.

Water balance for the 240 day period indicates that the discharge from the Three Boreholes exceeded the computed surface water losses into the deep mines. The excess discharge of 1,816 MG or 7.57 MGD (1,816 MG : 240 days = 7.57 MGD) from the boreholes is attributed to pipeline leakage and groundwater recharge of the South-East Complex, as discussed in subsequent sections.

For the 240 day period, the computed surface water losses in the Mill Creek watershed contribute 46.7% of the borehole discharges, whereas surface water losses in the Solomon Creek watershed are approximately 25% of the borehole discharges. A breakdown of losses for the aforementioned period and projected losses for the 12 month period (5/1/75 - 4/30/76) are presented in the tabulated Summary of Findings on Figure 8, page 61.

LIMITATION OF THE TOTAL. WATER LOSS METHOD. OF ANALYSIS. The method of deriving the surface water losses, by comparing the present runoff conditions with the runoff that prevailed in the pre-mining period, results in an underestimate of the total losses.

The mining in the watershed has considerably altered the hydrologic cycle over the mined area. Strip mining has destroyed vegetation areas causing a reduction in evapotranspiration and an increase in runoff and infiltration. Much of the increased runoff is trapped by strip pits, waste piles and subsidence depressions further increasing infiltration into the mines and virtually eliminating runoff from strip areas to streams. Consequently, during present periods of precipitation, the rate of infiltration (surface water losses to the deep mines) within the coal basin greatly exceeds the infiltration rate that prevailed prior to coal mining operations in the area.

Within the deeply mined portion of the coal basin, the present groundwater table is represented by the deep mine pools which are substantially lower than the level of the streambeds. However, outside of the mined areas, the groundwater table is at or above the streambed levels and the groundwater recharges the "base" flow of the surface streams. Therefore, along the rim of the coal basin, there is a large difference in elevation between the groundwater table outside the coal basin and the mine pool levels within the coal basin. This increased differential in groundwater levels (head) increases the rate of groundwater inflow into the coal basin and recharges the mine pools.

Subsidence within the coal basin is attributable to the deep mining and extreme fluctuations of mine pool water levels in the abandoned mines. Such subsidence in urban and suburban areas is one of the major contributors to leakage from water mains, sanitary and storm sewers. Consequently, losses from these pipelines are an additional significant source of recharge to the mine pools underlying the study area.

These additional recharge sources indicate that the method of analysis used to derive "total water loss" results in a conservative estimate of water losses to the mine pools. On the basis of the aforementioned additional losses, and assuming the Three Boreholes are the major outlet for mine pool discharges*, the discharges from the boreholes can be expected to exceed the conservative estimate of water losses that were computed by the "total loss" method. As previously described, the sources of these excess borehole discharges are the increased infiltration in stripped areas, leakage from pipelines and increased groundwater recharge. Therefore, strip area restoration, the elimination of pipeline leakage and the interception of groundwater recharge is expected to considerably reduce the AMD discharges from the South Wilkes-Barre Boreholes. The significance of the latter mine pool recharge sources is described in the following paragraphs.

<u>STREAMBED LOSSES.</u> Water losses through streambeds were evaluated from monthly stream flow measurements using the following procedures:

1. Stream flow at individual monitoring stations was compared with appropriate upstream and downstream stations and gains or losses are tabulated in Appendix A, Flow Comparison. Stream loss reaches are identified on these Tables and are shown in Figure 3, page 11.
2. From this tabulation, log-log regression curves of upstream flow versus loss were prepared (see Appendix D, Flow/Loss Curves).
3. Correlation of monthly flows with Toby Creek flows on a per square mile basis were made (see Appendix D, Toby Creek Flow Correlation Curves).
4. Using the flow correlation of Toby Creek with individual stations, and the average annual flow distribution of Toby Creek **, a yearly flow distribution was generated for each permanent monitoring station.
5. Based on the generated annual flow, annual losses were computed using the previously mentioned flow/loss curves. The loss computations are given in Appendix A and tabulated as depicted overleaf:

It should be noted that additional discharges from the South-East Mine Pool Complex into the Susquehanna River are possible through undetected "point" and "non-point" sources.

** Water Resources Bulletin No, 1, Pennsylvania Department of Environmental Resources*

STREAMBED LOSSES

STREAM	UPSTREAM STATION	DOWNSTREAM STATION	ANNUAL LOSS IN MG
Mill Creek	M-4	M-2	598
Mill Creek	M-6 & G-7	M-4A	410
Mill Creek	M-6A	M-6	485
Gardner Creek	G-9	G-8A	401
Flume	F-20	F-21	120
Laurel Run	L-23C	L-23	540
TOTAL STREAMBED LOSSES (ANNUAL)			2,554

All of the streambed losses tabulated above do not recharge the South-East Mine Pool Complex. An estimated distribution of the losses to each Complex is as follows:

DISTRIBUTION OF ANNUAL STREAMBED LOSSES

STREAM	SE COMPLEX	NW COMPLEX
Mill Creek	1,043 MG	450 MG
Gardner Creek	0	401 MG
Flume	120 MG	0
Laurel Run	540 MG	0
TOTAL	1,703 MG	851 MG

Based on an estimated annual discharge of 1,640 MG from the Plainsville Outlet, the losses to the North-West Complex represent 58% of the discharge from this borehole. Correspondingly, the annual discharge from the three South Wilkes-Barre Boreholes is estimated to be 9,400 MG, of which the computed streambed losses (1,703 MG) represent approximately 18% of the total AMD discharges.

OFF-STREAM LOSSES. Computed water losses for a 365 day period in the entire Mill Creek watershed are summarized as follows:

WATER LOSSES IN MG		
TOTAL	STREAMBED	OFF-STREAM
7,885	2,554*	5,331

The recorded flow at M-1 for the 365 day period was 9,197 MG (14.46"). Therefore, the expected runoff at M-1, if losses were prevented, is * See tabulation above, "Total Streambed Losses (Annual)"

$$\frac{(7{,}885\ MG + 9{,}197\ MG) \times 3.07\ ac.ft./MG}{36.6\ mi^2 \times 640\ ac/mi^2} \times 12'' = 26.87''$$

Surface water losses over the entire 36.6 square mile watershed are equivalent to

$$\frac{26.87''}{(7{,}885 + 9{,}197)} \times 7{,}885 = 12.40''$$

"Off-stream" losses, derived by the "total loss" method, can only be attributed to runoff losses within the 8.9 square miles of the mined areas in the watershed. The runoff losses consist of losses due to direct precipitation over the 8.9 square miles of the mined areas (Areas C & D) and additional losses from runoff sources in the 0.8 square miles of Area B (Figure 1, page5). For 26.87" of annual runoff, the off-stream losses are equivalent to:

$$\frac{\left(5{,}331\ MG \times 3.07\ ac.ft/MG - \frac{26.87''}{12''} \times (0.8\ mi^2 \times 640\ ac/mi^2)\right) \times 12''}{8.9\ mi^2 \times 640\ ac/mi^2} = 32.1''$$

The precipitation over Mill Creek watershed for the 365 day period (5/1/75 - 4/30/76) was 45.54". Runoff, total losses and "off-stream" losses as a percentage of this precipitation is as follows:

PRECIPITATION	RUNOFF				LOSSES			
	PRE-MINING*		PRESENT		TOTAL		OFF-STREAM	
INCHES	INCHES	% OF PRECIP.	INCHES	% OF PRECIP.	INCHES	% OF PRECIP.	INCHES	% OF PRECIP.
45.54	26.87	59.0	14.46	31.8	12.40	27.2	32.1	70.5

** If losses were prevented*

The 32.1" of annual "off-stream" losses are attributed to strip mining, both active and abandoned. Land reclamation consisting of regrading and revegetation would reestablish normal runoff and increase the rate of evapotranspiration, thereby reducing the present high rate of infiltration into the mine pools. The base flow of streams in,

unmined watersheds is directly related to groundwater recharge of stream flow during periods of no precipitation. Since infiltration in unmined watersheds is the source of groundwater recharge, the long term base flow in the streams is equivalent to the long term rate of infiltration. Therefore, if the annual "base flow" of the streams in unmined watersheds can be determined, the annual infiltration can be evaluated.

Flow records in Toby Creek (USGS gage) represent the total runoff over an unmined watershed. Accounting for the discharges resulting from precipitation runoff, the derived base flow for Toby Creek is equivalent to 1 cfsm, or $\frac{2 \text{ ac.ft. x } 365}{640 \text{ Acres}}$ x 12" = 13.69" of runoff. Assuming that the infiltration in Toby Creek watershed represents the "pre-mining" infiltration conditions in the study area, reclamation could provide the following AMD abatement benefits:

PRECIPITATION INCHES	OFF-STREAM LOSSES (INFILTRATION)					
	PRESENT		AFTER LAND RECLAMATION		AMD ABATEMENT	
	INCHES	% OF PRECIP.	INCHES	% OF PRECIP.	INCHES	% OF PRECIP.
45.54	32.1	70.5	13.7	30.1	18.4	40.4

The present acid concentration in the AMD discharges from the South Wilkes-Barre Boreholes is 360 ppm. Therefore, the expected abatement in terms of acid load removal is:

$$\left(\frac{18.4}{12} \times \frac{1}{3.07}\right) \text{MGD} \times 8.33 \times 365 = 1{,}519 \text{ Lbs/Acre/year}$$

or 1,519 ÷ 365 = 4.2 lbs of acid per day per acre of strip mine area reclaimed.

At the present writing, approximately 500 acres of strip mined land over the South-East Mine Pool Complex has been reclaimed by local interests for shopping centers, industrial and residential developments,. The land restored represents an AMD abatement value of 4.2 lbs/acre/day x 500 acres = 2,100 lbs of acid per day. The full abatement benefits of land reclamation by local interests can only be realized after the implementation of streambed loss prevention measures proposed in this Report. To ensure that the runoff from these reclaimed areas is conveyed without loss into the restored streams, the integrity of the storm drainage system should be verified and corrected if necessary.

Approximately 1,470 acres of urban area overlies the South-East Pool Complex in the study area. Runoff from these areas contributes to the stream flow through the existing storm drainage sewer systems. However, if the storm sewers are affected by subsidence resulting in leakage, the loss of collected urban runoff into the deep mines will contribute directly to the recharge of the underlying mine pools.

Assuming that the annual runoff over the urban areas is 70.5% of the precipitation and that only 50% of this runoff is being lost through defective storm sewers into the mines, the annual contribution of runoff from the urban areas to the surface water losses into the South-East Complex is as follows:

DESCRIPTION	WATERSHED		
	MILL CREEK	SOLOMON CREEK	TOTAL
URBAN AREAS (Acres)*	1,470.0	670.0	2,140
Avg. Annual Precip. (in.)**	40.3	45.6	—
Avg. Annual Runoff (in.)	28.4	32.1	—
Avg. Annual Runoff (MG)	1,133.0	584.0	1,717
50% LEAKAGE LOSSES (MG)	566.5	292.0	858.5

* *Excluding Urban Areas overlying "permanent" or "perched" groundwater conditions, where losses from Storm Sewers would directly recharge the groundwater table.*

** *Mean annual precipitation at Avoca is 35.65". Precipitation over Mill and Solomon Creeks is respectively 1.13 and 1.28 times larger than that at Avoca.*

It should be noted that runoff producing precipitation* was limited to 146 days for the period 5/1/75 - 4/30/76. However, the runoff produced and the resulting mine pool recharge extended beyond the 146 days of precipitation. Therefore, it is reasonable to assume that 146 days of precipitation would reflect mine pool fluctuation for a longer duration than the 146 days, The effect of combined storm and sanitary sewers that flow 365 days of the year are discussed in a subsequent paragraph.

On the basis of the above assumption, the magnitude of losses from the urban areas represents 8.8% of the borehole discharges, derived as follows:

(1) Accumulative discharges from the South Wilkes-Barre Boreholes for the period of records is tabulated overleaf:

Assumed as daily precipitation over 0.01 inches (an exaggerated assumption).

PERIOD	NO. OF DAYS	BOREHOLE DISCHARGE		PRECIPITATION (INCHES)					
		MG	MGD	AVOCA	W.B.	#5	#2	SOLOMON CREEK*	MILL CREEK*
06/04/75-8/20/75	77	2,004.4	26.03	9.86	10.67	13.06	12.50	12.82	11.26
11/25/75-6/25/76	214	5,903.6	27.59	19.09	20.03	26.62	23.88	25.47	22.01
SUB-TOTAL	291	7,908.0	(27.18)	28.95	30.70	39.68	36.38	38.29	33.27
05/01/75-4/30/76	366	(11,022.0)**	(30.11)	40.35	-	-		51.65	45.54

* *For distribution of precipitation, see TABLE XII, page 54.*

** $\frac{7,908 \text{ MG}}{28.95''} \times 40.35'' = 11,022.03 \text{ MG}$

(2) Borehole discharge for average year (precipitation at Avoca = 35.65") = $\frac{7,908}{28.95} \times 35.65 = 9,738$ MG*

(3) Annual runoff losses of 859 million gallons, represent $\frac{859}{9,738} \times 100 = 8.8\%$ of the mean annual borehole discharge, or the equivalent of $\frac{859}{365} = 2.35$ MGD.

The assumed urban runoff contribution to borehole discharges is equivalent to 7,047 pounds of acid production per day (2.35 MGD x 8.33 x 360 ppm = 7,047 lbs/day). Assuming that the average cost of repair and replacement of leaky storm sewers is S50 per foot, and that as much as ten (10) miles of storm sewers in the study area will require corrective measures, then the total cost of sewer loss prevention is $50 x 10 miles x 5,280' = S2,640,000. Implementation of such corrective measures would prevent the daily production of 7,047 pounds of acid at a cost of $2,640,000 : 7,047 = S375/lbs of acid removed.

The above discussion indicates that verification of the locations and magnitude of storm sewer losses into the deep mines is highly desirable for the AMD abatement program. Storm sewer losses can be accurately determined by means of simple "on site" test procedures.

* Compares favorably to the mean annual discharge of 9,400 MG derived in Figure 8, page 61.

SURFACE WATER LOSSES INTO THE UPPER MINE POOLS.

AMD discharges from the Askam Borehole are attributed to surface water losses into the upper mine pools of the South-East Mine Pool Complex. The upper mine pools underlie the Warrior and Nanticoke Creek watersheds (Figure 4, page 13). Surface water losses in the headwaters of Sugar Notch Run in the Solomon Creek watershed (drainage area 2.33 square miles) also recharge the upper mine pools. Water losses in the Nanticoke and Warrior Creek watersheds and AMD discharges from the Askam Borehole were reported in a previous Study (SL 181-3; August 1973 through September 1974). Monitoring of AMD discharges from the Askam Borehole was also included in the scope of the present Study.

Surface water losses into the upper mine pools during the present study period were computed by a method similar to that employed for the determination of water losses into the lower mine pools and is as follows:

> The relationship between the flow at the USGS gaging station in Solomon Creek and the recorded flow at the Nanticoke and Warrior Creeks monitoring stations was established in the previous study and is presented in Appendix D. The monitoring stations represent the flow in the stream stretches of Nanticoke and Warrior Creeks that overlie the upper mine pools. Therefore, the surface water Losses derived from the foregoing relationship recharge the upper mine pools.
>
> In the 1973-1974 study period (SL 181-3), water Losses (inflow into mine pools) were equated to the AMD discharges from the Askam Borehole (outflow from mine pools). Since the streambed Losses were directly evaluated by flow measurements within stream stretches, the difference between AMD discharges from the Askam Borehole and the recorded streambed Losses for each selected time period was attributed to "off-stream" surface water Losses.

The aforementioned method of analysis is valid if all water losses into the upper mine pools are discharged from the Askam Borehole. However, if there are other discharge points in addition to the Askam Borehole, the method of analysis employed in the previous study results in an underestimate of "off-stream" losses*.

Updated total surface water losses into the upper mine pools is presented in Figure 12, page 79. Mass curves of surface water losses, streambed losses and the AMD discharges from the Askam Borehole were plotted for the same time period that was selected for the plotting of the lower pools mass curves (see Figure 8, page 61).

Surface water losses in the Nanticoke, Warrior and Sugar Notch Run watersheds that recharge the upper mine pools for the period 5/1/75-4/30/76 are tabulated in Figure 12, page 79 and are summarized below:

(1) Drainage Area above Coal Measures		2 Square miles
(2) Drainage Area within Coal Basin†		6 Square miles
(3) Total Drainage Area		8 Square miles
	MG	**Runoff Equiv. (inch)**
(4) Streambed Losses	1,132	8.15"
(5) Off-stream Losses	(3,755)	27.02" (36.02")††
(6) Total Surface Water Losses	4,887	35.17"
(7) Askam Borehole AMD Discharges	1,573	11.32"
(8) Excess Losses (6) - (7)	3,314	23.85"

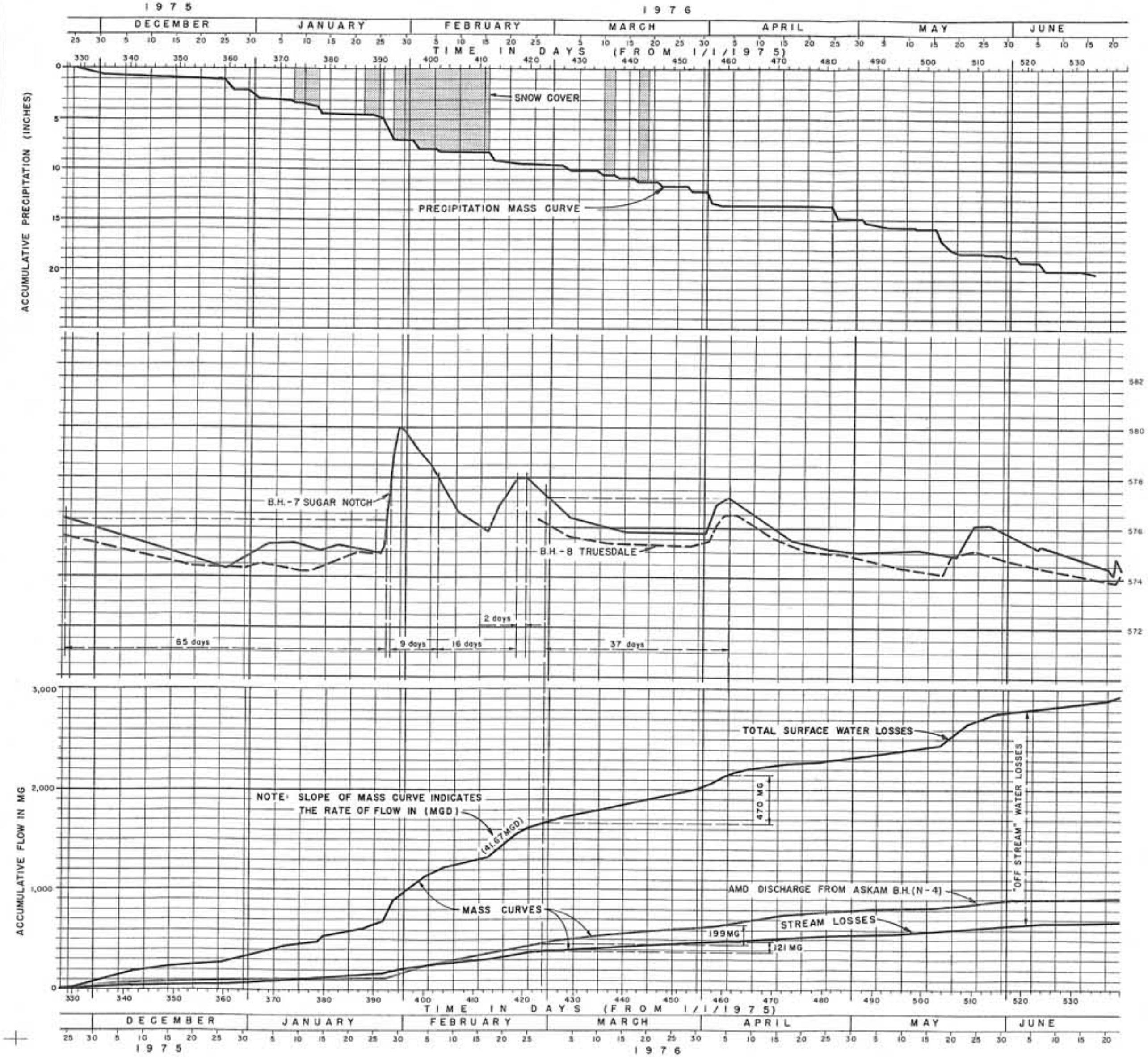
† *Underlain by the Upper Mine Pools*

†† $27.02'' \times \frac{8\ sq.mi.}{6\ sq.mi.} = 36.02''$

It should be noted that the relationship between the flow in Solomon Creek and that of the inflow of Nanticoke Creek, Warrior Creek and Sugar Notch Run into the coal basin is based on the 1973/1974 records from the previous Study (SL 181-3). Precipitation records over the upper mine pools and the flow records of Solomon Creek for the period shown in Figure 12, page 79, and for a similar perion in 1973/1974 are tabulated as follows:

PERIOD	ACCUMULATIVE FLOW IN SOLOMON CREEK MG		PRECIP. OVER UPPER MINE POOL INCHES	
	1973/74	1975/76	1973/74	1975/76
11/25-1/28	1,412	663	11.94"	7.07"
01/29-2/14	161	335	0.97"	1.29"
02/14-3/19	405	499	4.06"	2.93"
03/19-4/09	634	265	5.05"	2.29"
TOTAL	2,612	1,762	22.02"	13.58"

* *A summary of surface water losses in the Nanticoke and Warrior Creek watersheds is presented in SL 181-3 Report; Figure 9, page 46A.*



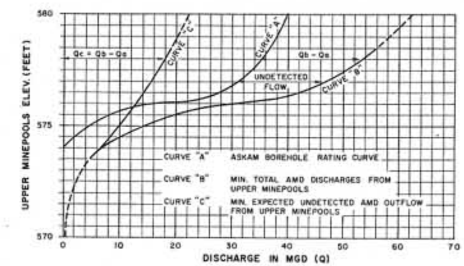
SUMMARY OF FINDINGS

SURFACE WATER LOSSES INTO THE UPPER MINE POOLS
FOR PERIODS WHEN INFLOW = OUTFLOW FROM MINEPOOLS

PERIOD	NO. OF DAYS	TOTAL SURFACE WATER LOSSES MG	BOREHOLE DISCHARGE STATION N-4 MG	EXCESS LOSSES	STREAMBED LOSSES	OFF-STREAM LOSSES
(1)	(2)	(3)	(4)	(5)=(3)-(4)	(6)	(7)=(3)-(6)
06/18/75-07/22/75	34	220	57	163	54	166
07/22/75-09/25/75	65	270.5	21	249.5	60.5	210
09/25/75-10/18/75	22	369	209	160	82	287
10/18/75-11/24/75	24	492	206	286	110	382
11/24/75-01/28/76	65	817	106	711	194	623
01/28/76-02/06/76	9	354	138.5	215.5	75	279
02/06/76-02/22/76	16	368	148	220	85	283
02/22/76-02/24/76	2	65	17.5	47.5	14	51
02/28/76-04/05/76	37	470	199.5	270.5	121	349
	274	3,425.5	1,102.5	2,323	795.5	2,630

EVALUATION AND PROJECTION OF AMD DISCHARGE (5/1/75-4/30/76)

DESCRIPTION					
% OF TOTAL SURFACE WATER LOSSES	100%	32.2%	67.8%	23.2%	76.8%
DRAINAGE AREA (SQ.MI.)	←	—	8.0	—	→
RUNOFF EQUIV. (INCH)	24.64"	7.93"	16.71"	5.72"	18.92"
PRECIPITATION (INCH) (6/18/75-4/05/76)	←	—	34.16"	—	→
RUNOFF EQUIVALENT IN % OF PRECIPITATION	72.1%	23.2%	48.9%	16.7%	55.4%
TOTAL PRECIP. (INCH) (5/1/75-4/30/76)	←	—	48.78"	—	→
PROJECTED AMD DISCHARGE	35.17" 4,887 MG	11.32" 1,573 MG	23.85" 3,314 MG	8.15" 1,132 MG	27.02" 3,755 MG
COMPUTED OR RECORDED VALUES 5/1/75-4/30/76	5,071 MG	1,673 MG	3,398 MG	1,180 MG	3,891 MG



EXPECTED OUTFLOW FROM UPPER MINEPOOLS (APPROX.)

NOTE:
THE SUMMARY OF TOTAL WATER LOSSES INTO THE SOUTH-EAST MINE POOL COMPLEX IS SHOWN ON FIG. 8, PAGE 61.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

AMD ABATEMENT STUDY

MILL CREEK
PROJECT NO. SL 181-4
LUZERNE CO., PENNA.

WARRIOR, NANTICOKE & SUGAR NOTCH RUN WATERSHEDS

PRECIPITATION-INFLOW-OUTFLOW RELATIONSHIP UPPER MINEPOOLS – S.E. MINEPOOL COMPLEX

DATE	FIGURE NO.
JAN. 1977	12

Comparison between Solomon Creek flow and precipitation during the present study with that of the previous study indicate the following:

$$\frac{\text{FLOW (1975/76)}}{\text{FLOW (1973/74)}} = \frac{1{,}762 \text{ MG}}{2{,}612 \text{ MG}} = 0.67$$

$$\frac{\text{PRECIP. (1975/76)}}{\text{PRECIP. (1973/74)}} = \frac{13.58''}{22.02''} = 0.62$$

The comparison above indicates that the precipitation over the upper mine pools and the recorded flow at the USGS gage are closely related. Therefore, the relationship obtained between the flow in Solomon Creek and that of the Nanticoke Creek, Warrior Creek and Sugar Notch Run watersheds holds true for both of the previous and present study periods.

GROUNDWATER RECHARGE.

Due to the large "head differential" between the groundwater table outside of the coal measures and the mine pool levels, the rate of groundwater flow into the coal basin is expected to be a significant source of mine pool recharge. Data obtained within the scope of this study is insufficient for a quantitative estimate of mine pool recharge from groundwater recharge. Proposed methods for evaluating the extent of groundwater recharge are described in a previous study (SL 181-3).

In the absence of essential data to document groundwater flow, the estimated flow into the coal basin was based on the concept of "groundwater interception". This concept was used to derive the following estimate of groundwater recharge to the South-East Mine Pool Complex.

At least twelve lineaments* or fracture zones cross the rim of the coal basin on the southern side of the South-East Mine Pool Complex. Eight of these lineaments traverse the Solomon and Mill Creek watersheds (lower mine pools) and four traverse the Nanticoke and Warrior Creek watersheds (upper mine pools). These lineaments are linear features on the earth's surface that express possible zones of intense jointing of the bedrock. Such zones below the groundwater table are desirable locations for moderate to high yield, drilled water wells.

* ARC Report 73-111-2554, April 1975. Use of Photo Interpretation and Geological Data to Identify Surface Damage and Subsidence in Northern Anthracite Coal Field

Although the rim of the coal basin within the aforementioned watersheds is more than 12 miles long, the rate of groundwater inflow to the basin is expected to be greatest along these major fracture zones. This groundwater inflow is believed to be a significant part of the total mine pool recharge. Therefore, interception of groundwater flow within these fracture zones is expected to reduce the recharge of mine pools.

Assuming the the rate of groundwater interception in each major fracture zone is at least 0.5 MGD (approximately 350 GPM), the resulting recharge to the South-East Pool Complex would be 6 MGD.

(0.5 MGD x 12 fracture zones = 6 MGD). This intercepted amount is equivalent to 20% of the mean annual AMD discharge from the Askam and South Wilkes-Barre Boreholes.

The interceptable water represents only part of the total groundwater recharge into the mine pools. The balance of groundwater recharge is widely distributed in the less fractured areas between the major fractured zones. If the balance of the groundwater inflow is assumed to be equal to the interceptable flow, the total annual groundwater recharge would be as follows:

DESCRIPTION		SE MINE POOL COMPLEX		
		UPPER POOLS	LOWER POOLS	TOTAL
(1)	Interceptable Groundwater Inflow into Coal Basin (MGD)	2	4	6
(2)	Annual Interceptable Flow for Study Period (MG)	730	1,460	2,190
(3)	Assumed Total Groundwater Recharge (3) = 2 x (2) (MG)	1,460	2,920	4,380

PIPELINE LEAKAGE.

Data review indicates that existing water supply, sewerage and waste disposal systems are closely related to the quantitative and qualitative assessment of the study area streams and to the mine pool recharges. A comprehensive review of the existing public water systems was not within the scope of this study. However, reconnaissance surveys conducted during the study period revealed that stream flow is diverted and stored in reservoirs outside of the coal basin to provide public water supply to communities within and outside of the Mill Creek watershed. Conversely, during periods of low flow when the yield of Mill Creek watershed is insufficient to supply the required demand, water is imported into the study area to augment the water supply needs. The imported water from adjacent watersheds is stored in reservoirs. The locations of storage reservoirs, intakes, and the approximate locations of water transmission pipelines are shown on Figure 1, page 5. An average of 8.4 MGD is withdrawn from the Gardner Creek sub-watershed*. The storage capacity of the Gardner Creek reservoir is 74 million gallons and its reported safe yield is 0.1 MGD. A 30" diameter pipeline imports water from Waters and Nesbitt Reservoirs in Lackawanna County. The imported water is discharged into the Gardner Creek Reservoir. Therefore, although the yield of Gardner Creek watershed in an average year is significantly higher than the safe yield of 0.1 MGD, the bulk of the 8.4 MGD withdrawal from this watershed is attributed to the imported source of water.

In addition to the water withdrawn from Gardner Creek, approximately 4.4 MGD is withdrawn from the Main Stem of Mill Creek and Laurel Run. Therefore, the amount of water that is being taken from the study area watersheds, outside of the coal measures (including importation), is 12.8 MGD. The diverted water is used to supply communities in the lower portion of Mill Creek watershed, Solomon Creek watershed and other adjacent areas.

Review of the Luzerne County Master Plan for Water Supply and Waste Water Management indicates that 34 to 50 percent of the water produced in Pennsylvania Gas and Water Company (PGW) is unaccounted for and may be attributed to leakage from pipelines. The following discussion of pipeline leakage is from the 1973 Luzerne County Report.

-* Courtesy of Pennsylvania Gas and Water Company

Master Plan for Water Supply and Waste Water Management; Gilbert Associates, Inc., Reading Pennsylvania (Water Planning Vol. 2, p. 4.1-5) "Water Requirements

Total annual water production in the year 1968 for the entire system was estimated at 32,487,433,000 gallons or 89.1 MGD. The amount produced in 1960 was 32,274,251,000 gallons (88.4 MGD). This slight increase, 0.7 MGD in Little Less than a decade, however, may not be a true reflection of the system requirements. One disturbing factor is that water losses, i.e., water Lost due to Leakage, flushing of mains and hydrants, fighting fires, etc.. (commonly referred to as 'unaccounted-for-water'), have been estimated to range between 34 to 50 percent o f the total water produced. In either case, this is a very high percentage of Loss for a water system. (Normal Losses in a water system can be expected to range between 10 to 20 percent of the total water produced). Therefore, total water produced is difficult to ascertain, and consumption even more so, due to the great disparity between estimates of Lost water. The high water Loss rate is mainly attributed to mine subsidence throughout the service area - the subsidence serving to create open or Leaky joints in water mains or even complete ruptures. The Utility has had some success recently in an effort to minimize Leakage, in placing steel mains with welded joints. This type of construction is Less susceptible to damage from settling. However, this solution is Limited in that it is not economical to utilize steel in smaller diameter mains. A substantial and continuing effort by the Utility should be made to minimize water Losses (1).

The relative absence of water metering in the Spring Brook Division (only 10 percent of the consumers are currently metered) further contributes to the uncertainty of determining how much water is actually "Lost" and how much is "consumed" by users. Extensive metering by the Utility should be effected as soon as possible. This will appreciably reduce water Losses in the system, in that: 1) individual water consumers will become more water conscious when they are billed

(1) It is acknowledged that the high water rate Loss will be difficult to reduce to acceptable standards. Such water Losses, even if major, are difficult or impossible to detect by observation, since the Lost water does not usually surface. However, means are available - leak surveys - for detecting these Losses.

for actual water consumed and thus will effect individual repairs within the unit; and 2) losses will become more readily apparent when total water production is compared to the total metered amount of water consumed.

Per capita production requirements in the Spring Brook Division have been estimated conservatively due to the high rate of water losses and the high percentage of unmetered connections. These requirements have been estimated in 1970 to be 225 gcd* in the urban-industrialized area, and 185 gcd in the suburban and rural areas.(1) TABLE 4.1-VII, located at the conclusion of this Section, contains the estimated per capita production requirements for the PGW system for the entire study period. It is to be noted that these estimated requirements are the highest per capita production rates in Luzerne County. Elsewhere in the County, and outside the PGW area, the rates have been estimated to range from 45 gcd to 135 gcd for 1970. It is estimated also that the Spring Brook Division requires a total average water production of 58.3 MGD to meet daily requirements, within this system alone. (2) (1) This requirement is the average daily rate of all water production in a com munity expressed in terms of the resident population, in gallons per capita per day (gcd). The rate developed throughout the Plan includes estimates' of water usage for domestic, commercial, industrial, institutional and public purposes, and for water losses. (2) It is to be noted that some flow from this system does "cross over" to the Scranton Division. The amount of this flow in 1970 has been estimated to be approximately 5 MGD. "

The city of Wilkes-Barre and some outlying communities have had sewage collection systems for many years. Most of these old systems are combined storm and sanitary sewers. In 1969, construction of a re gional sewage treatment plant was completed and all sewered and some unsewered communities joined the Wyoming Valley Sanitary Authority (WVSA) system. "Each participating municipality has agreed to instiute programs to prevent storm water from entering collection systems, either directly through storm water inlets, or indirectly through infiltration. The municipalities enacted ordinances requiring all housing units to connect to collection systems served by the Authority."

". . . Since many of the older collection systems were combined sanitary and storm lines, it was necessary to limit the volume of flow to the treatment plant during periods of heavy storm water run

** gallons per capita per day*

off in order to avoid excess hydraulic Loading of the plant. This was done by constructing diversion chambers Located at strategic points which best Limit the combined flow in any Line to 200% of the average daily flow. The overflow at such time is discharged, as before, into the various Commonwealth watercourses, but the dilution Limits the pollution effect. While such an arrangement is far from ideal, it is acceptable as an interim measure until more effective solutions to the combined flow problem can be economically placed in service."

Based on data collected in 1970, a large difference is apparent between reported water supply and sewage flow in the watersheds that overlie the South-East Mine Pool Complex as shown in the following:

WATER-SHED	SERVICE AREA	POPULATION SERVED 1970	MEAN DAILY FLOW			
			WATER SUPPLY (PGW CO.)		SEWAGE FLOW TO WVSA PLANT	
			MGD	gpcpd	MGD	gpcpd
SOLOMON CREEK AND MILL CREEK	ASHLEY BOROUGH	3,595	0.8	222.5	0.37	103.0
	HANOVER TOWNSHIP	12,660	2.8	221.2	1.27	100.0
	PLAINS TOWNSHIP	11,180	2.5	223.6	1.07	96.0
	WILKES-BARRE TWP.	4,300	1.0	232.6	0.43	100.0
	WILKES-BARRE CITY	62,520	14.1	225.6	6.25	100.0
	SUB-TOTAL	94,255	21.2	(225.0)	9.39	(100.0)
	Est. Indust. Waste	——			5.91	
WARRIOR & NANTICOKE	SUGAR NOTCH BORO	1,505	0.3	199.0	0.15	100.0
	NANTICOKE CITY	15,690†	3.5	223.0	1.31	83.5
	TOTAL	114,450	25.0	(224.0)	16.76	(150.0)

† *Not served in 1970. Probably connected at this writing.*

The tabulated data indicates that the estimated Mean Daily Sewage Flow is probably based on the population served in each community rather than on actual measurements. Assuming that 10% of the reported water supply in the tabulated service areas is used consumptively,

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the unaccounted difference between water supply and sewage flow is, 0.9 x 25 MGD - 16.76 MGD = 5.74 MGD. Consequently, it is possible that as much as 5.74 MGD (3,986 GPM) of water supply leakage losses can be contributing to the recharge of the South-East Mine Pool Complex, based on data obtained in 1970.

It should also be noted that if water losses are occuring in the water supply pipelines, considerable flow losses can also be expected to occur in separate and combined sanitary and storm sewers overlying the South-East Complex. In addition to steady losses of raw sewage, additional losses can be anticipated when storm runoff is discharged into leaking drainage systems. If the storm sewers in the area were designed to convey runoff from storms having a frequency of 5 to 10-years, the extent of leakage from the storm sewers can be very significant. Therefore, water losses from both sanitary and storm sewers are expected to be a considerable source of recharge to the South-East Mine Pool Complex.

Since there is no deep mining under the City of Wilkes-Barre, the groundwater table is within the alluvial deposits and is higher than the level of the Susquehanna River. The water level in the Lower Mine Pools that surround the City limits is generally above this groundwater table. Therefore, losses from leaky sanitary and storm sewers in the City cannot contribute to the recharge of the mine pools. Moreover, the absence of mining activities underneath the City precludes leakage from sewers due to subsidence activities. Similarly, losses from water supply lines in the City cannot be attributed to subsidence and these losses cannot contribute to recharge of the adjacent higher mine pools.

Although no direct recharge of mine pools can be attributed to in-city pipeline losses, significant, steady losses in sanitary sewers are expected to occur in all sewers above the deep mine pools outside of center-city Wilkes-Barre. Assuming that all of the industrial waste flow discharges into the WVSA Treatment Plant originates within the City limits, the maximum possible sewage losses into the South-East Mine Pool Complex is

16.76 MGD - (6.25 MGD + 5.91 MGD) = 4.6 MGD.

This maximum rate of losses is equivalent to "exfiltration" from the lines amounting to 100 x 4.6 : 16.76 = 27.4%. However, it should be noted that some of these exfiltration losses are offset by groundwater or mine pool infiltration into the main sewer line interceptors along streams and low-lying areas where groundwater and mine pools are at or near stream levels or ground surface. If the flow of sewage into the treatment plant is not diminished by the expected loss, this may be attributed to possible infiltration into gravity storm or sanitary sewer lines that are below the water table or mine pool levels. Consequently, the magnitude of infiltration could also be 27.4%.

During field reconnaissance investigations conducted in 1973 - 1974 in the Warrior Creek watershed, it was observed that the entire sewage flow from the Borough of Sugar Notch was discharged into a strip pit. Other point discharges of raw sewage of lesser magnitude were also observed in the Nanticoke Creek and Solomon Creek watersheds. Similar point discharges of raw sewage and industrial waste into the streams of Mill Creek watershed are shown on Figure 3, page 11. Many of these discharges are from sewered areas that were reported to be connected to the WVSA sanitary sewer system.

Based on the foregoing, the dry weather recharge of the SouthEast Mine Pool Complex from sewer and water line losses from the overlying urban and suburban areas may amount to 5.7 + 4.6 = 10.3 MGD, or about 3,760 million gallons per year. This is equivalent to 80% of the annual surface water losses in the Mill Creek watershed, and is larger than the total losses derived from Solomon Creek watershed. Moreover, the dry weather pipeline losses in Nanticoke, Warrior, Solomon and Mill Creek watersheds are equivalent to 30% of the estimated total annual water losses from these watersheds into the South-East Complex.

On the basis of the above assumptions, verification and isolation of pipeline losses in the urban areas that overlie the South-East Complex is highly desirable to the AMD abatement effort. Abatement of these pipeline losses should be considered as a joint-venture project that will provide multi-purpose benefits to the Department and the various municipalities, Authorities and utility companies responsible for pipeline losses.

Except for recent laws controlling mining operations, present regulations related to discharges into the Commonwealth waters do not prohibit or preclude discharges of clean, unpolluted water. Therefore, the discharge or loss of clean water into the abandoned deep mines, where it subsequently becomes polluted, is a unique situation related to AMD. New regulatory statutes should be considered to prevent discharges and subsequent pollution of clean water in deep mines.

Although leakage from combined sanitary and storm sewers into the deep mines also contributes to AMD, such leakage constitutes discharge of pollutants into the Commonwealth waters and is prohibited by existing regulations. Therefore, both regulatory enforcement and funding vehicles are presently available to assess the magnitude of losses from the combined and separate sanitary sewers and to abate the resulting AMD pollution.

The Pennsylvania Gas and Water Company can play an important role in the AMD abatement effort within the study area, as well as in the entire Northern Anthracite Basin (Wyoming and Lackawanna Coal Basins). The major AMD abatement measures in the Wyoming Valley that could involve the Water Company are projects related to the prevention of mine pool recharges by unpolluted surface water and groundwater sources, Therefore, the utilization of unpolluted surface and groundwater sources from outside the coal measures for water supply could reduce the cost of AMD abatement projects within the coal measures.

It has been reported* that, by the year 2000, the total projected water needs in the Spring Brook Division of the Water Company would increase from the present 59.9 MGD serving a population of 276,035 to 155.5 MGD for a projected Wyoming Valley population of 455,265. The per capita use derived from the projections is 215 gpcpd for the reported year (1970) and 342 gpcpd for the projected year (2020). The unusually large projected per capita requirements indicates that the large water losses that occur in the present system are expected to continue and even to increase in the projected "target" year 2020.

Approximately 140 MGD of additional water sources would have to be developed to meet the projected water demand. The additional water needed to augment the present supply sources is expected to be

* *Ibid, Volume 2*

developed from the following reported* sources:

PROPOSED WATER SUPPLY SOURCE	SAFE YIELD
Susquehanna River at West Pittston	110 MGD
Dam "X" (Spring Brook watershed addition)	25 MGD
Rice Dam (Harveys Creek watershed)	5 MGD
TOTAL	140 MGD

The Susquehanna River Basin Study** indicates that the present per capita need in the Wilkes-Barre area is 211 gpcpd for municipal use. However, the projected per capita municipal water need for the year 2040 is estimated to be 240 gpcpd. Comparison between the two reports cited indicates that the present leakage from pipelines was accounted for in both studies and that the projected leakage in the year 2020 may amount to (342 gpcpd - 240 gpcpd) x 455,265 pop. = 46 MGD±. Therefore, if the above estimates are verified, the actual need of additional water would be 140 MGD - 46 MGD = 94 MGD.

The projected water needs within the watersheds overlying the South-East Complex are tabulated as follows:

WATER-SHED	SERVICE AREA	PROJECTED WATER NEEDS (2020)		
		POPULATION SERVED	AVERAGE DEMAND	
			MGD	gpcpd
	ASHLEY BOROUGH	4,255	1.6	376
	HANOVER TOWNSHIP	18,285	6.8	372
	PLAINS TOWNSHIP	17,380	6.4	368
	WILKES-BARRE TWP.	78,720	29.1	370
	WILKES-BARRE CITY	8,000	2.9	363
	SUB-TOTAL	126,640	46.8	(370)
	SUGAR NOTCH BORO	2,005	0.6	300
	NANTICOKE CITY	20,755	7.7	371
	TOTAL	149,400	55.1	(369)

* *Ibid, Volume 2, Table 4-1-III*
** *Appendix F - Water Supply and Water Quality; Sub-Basin III, Table II-7, June 1970*
† *Master Plan for Water Supply and Waste Water Management; Vol. 2, Table 4-1-VII*

The expected additional water losses related to pipeline leakage into the South-East Mine Pool Complex are (369 - 240) gpcpd x 149,000 population = 19.3 MGD.

Therefore, the additional water needs in the area, if the water leakage is prevented would be:

55.1 MGD - 25.0 MGD - 19.3 MGD = 10.8 MGD
Projected Present Leakage

The total water resources required to supply the projected population in the aforementioned service areas is 25 MGD + 10.8 MGD = 35.8 MGD. Approximately 36 square miles of the drainage areas in the Nanticoke, Solomon and Mill Creek watersheds is located above the coal measures, 50% of which can be controlled by existing or new reservoirs. It is therefore anticipated that the entire projected water need in the foregoing service areas can be supplied from surface and groundwater resources in the Nanticoke, Solomon and Mill Creek watersheds. If similar conditions of pipeline losses to mine pools exists in other watersheds that are within the PGW Company franchise area, the development of future water resources in these other areas can provide a significant contribution to AMD abatement in the entire Northern Anthracite Coal Basin. Consequently, multi-purpose projects that can augment water supply needs and provide AMD abatement can be beneficial to both area and state interests. Serious consideration should be given to initiating discussions between DER and the Water Company to determine the mutual benefits of such multi-purpose projects.

It should be noted that some of the benefits derived by preventing leakage from pipelines can be evaluated at the present writing. If it is assumed for illustration purposes that the rate of leakage from a water supply system is 30% of the available water supply, the following benefits may be derived by preventing such leakage:

a. Benefits to the Water Company:- Since water companies are regulated by the Public Utilities Commission, the rate structure is probably based on the amount of water delivered to the customer. Therefore, excessive water losses by leakage from pipelines should not be charged to the customers. This could amount to a revenue loss of as much as 30%

to the water company. Therefore, if the projected cost of the water company expansion is $97,200,000, the chargeable annual fixed cost alone would amount to 70% of the actual cost incurred.

If subsidence over mined-out areas can be partially attributed to the water level fluctuation in the deep mines, then the recharge of mine pools through leaky pipelines is also contributing to subsidence. Therefore, prevention of leakage from pipelines may absolve the water companies from future liabilities related to subsidence.

b. Benefits to the AMD Abatement Effort: Pipeline leakage into the deep mines is ultimately discharged as AMD with acid concentrations of approximately 200 ppm. Consequently, the prevention of an average daily water loss of 0.3 x 140 MGD = 4-6 MGD into the deep mines under the Wyoming Valley amounts to 76,600 lbs of acid removal per day (200 x 8.33 x 46 = 76,636). If the average cost of AMD abatement in the Wyoming Valley Coal Basin is $250.00 per pound of acid removal, then S250 x 76,600 = $19,150,000 is the expected reasonable cost-benefit that can be allocated to AMD abatement for the multi-purpose projects. This sum can be used to prevent leakage losses and to invest in the development of new water sources such as the proposed* groundwater interceptor wells, Both methods are designed to prevent the loss and subsequent contamination of clean water in the abandoned deep mine pools in the area.

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TOTAL INFLOW AND OUTFLOW OF THE STUDY AREA MINE POOLS.

For the 12 month period 5/l/75-4/30/76, the derived outflows from the Askam Borehole and the South Wilkes-Barre Boreholes are 1,673 MG and 10,680 MG respectively. Comparison between the borehole discharges and the computed water surface losses into the respective mine pools is as follows:

MINE POOLS	ANNUAL FLOW IN MG		
	SURFACE WATER LOSSES	AMD DISCHARGES	
		BOREHOLE	UNACCOUNTED
(1)	(2)	(3)	(4)=(2)-(3)
UPPER	5,071	1,673	3,398
LOWER	7,209*	10,680	(-3,471)
TOTAL	12,280	12,353	(- 73)

** Excluding 438 MG recharge from the Upper Mine Pools that was used in coumputed surface water losses (7,647 MG - 438 MG = 7,209 MG).*

The tabulated values indicate that the total surface water losses into the South-East Mine Pool Complex is in near perfect balance with the total borehole discharges; provided that:

a. The unaccounted for AMD discharges from the Upper Mine Pools recharge the Lower Mine Pools.

b. The three South Wilkes-Barre Boreholes are the only AMD dis charge points from the Lower Mine Pools.

c. The surface water losses into the mine pools (both stream bed losses and off-stream losses from precipitation) are the only source of mine pool recharge.

However, in addition to the surface water losses, pipeline leakage and the inflow of groundwater are also sources of mine pool recharge. Since the surface water losses were conservatively derived*, it is unlikely that all three of the above stipulated provisions are completely valid.

A breakdown of computed and estimated recharge sources in comparison with borehole discharges is presented in Figure 8, page 61 and is summarized overleaf.

* See LIMITATION OF THE TOTAL WATER LOSS METHOD OF ANALYSIS, page 69.

DESCRIPTION	INFLOW (OUTFLOW) MG	
	5/1/75 to 4/30/76	MEAN YEAR
UPPER MINE POOLS	7,441	6,680
ASKAM BOREHOLE	(1,673)	(1,440)
UNACCOUNTED BALANCE	(5,768)	(5,240)
LOWER MINE POOLS	13,417	12,190
SOUTH W-B BOREHOLES	(10,680)	(9,400)
UNACCOUNTED BALANCE	(2,737)	(2,790)

The tabulated values above indicate that for a 12 month period of the study (5/l/75-4/30/76), a total of 20,858 MG recharged the South-East Mine Pool Complex. During the same period, AMD discharge from all boreholes was 12,353 MG. This leaves a total of 8,505 MG (20,858 MG - 12,353 MG = 8,505 MG) of AMD discharges unaccounted for.

The mean annual flow values in the table above were derived through the multiplication of the study period flow by the ratio recorded at the first order climatological station at Avoca (see Hydrologic Conditions, page 25.

$$\frac{\text{Mean Annual Precipitation}}{\text{Study Period Precipitation}} = \frac{35.65''}{40.35''}$$

Off-stream surface water losses are the largest source of mine pool recharge, ranging from 40.9% to 51.5% of the total derived water losses into the lower and upper mine pools, respectively (see Figure 8, page 61).

The relationship between watershed drainage areas that recharge the South-East Mine Pool Complex and the annual losses into the respective mine pools is as follows:

DESCRIPTION	SE MINE POOL COMPLEX		
	UPPER POOLS	LOWER POOLS	TOTAL
TOTAL DRAINAGE AREA (SQ.MI.)	8	50	58
% OF TOTAL	13.8%	86.2%	100.0%
AREA OVERLYING POOLS (SQ.MI.)	6	13.4	19.4
% OF TOTAL	30.9%	69.1%	100.0%
MEAN ANNUAL LOSSES TOTAL OF ALL SOURCES (MG)	6,680	12,190	18,870
% OF TOTAL	35.4%	64.6%	100.0%
SURFACE WATER LOSSES (MG)	4,480	6,760	11,240
% OF TOTAL	39.9%	60.1%	100.0%

The foregoing tabulated values indicate that water losses into the upper mine pools are large in comparison with the contributing watershed area. This is attributed in part to the relatively large areas disturbed by strippings and to slightly larger precipitation over the Nanticoke Creek and Warrior Creek watersheds which overlie the upper mine pools.

If a considerable part of the upper mine pool's overflow is recharging the lower mine pools, the benefits from the abatement projects that were proposed for the Nanticoke and Warrior Creek watersheds could be larger than previously reported*.