Report of work performed for

DEP GG EMARR (10/1/03 to 6/30/04)

Prepared by

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Executive Summary

The goals of the Eastern Middle Anthracite Recovery Region (EMARR) Project are: (1) eliminate the water quality problems in the region's groundwater and streams; (2) create an economic advantage from the region's abundant, but currently polluted, water resources; and (3) reclaim mine-damaged property.

Penn State University (Brian Dempsey as PSU project coordinator) is an EMARR cooperator, and was asked to assist with the study in the areas of water chemistry, analytical chemistry, impacts on streams, development of baseline conditions for streams, and discussion of *in-situ* as well as point treatment options.

The following tasks were included in the work plan for the Penn State cooperator.

- Develop baseline information about current surface water quality, including estimations of pollutant loadings from point and non-point sources. The focus during the first year was on Black Creek, the Little Nescopeck, and the Nescopeck starting at the confluence with the Little Nescopeck.
- Use the new information to identify or confirm trends over time in the concentrations and loads of pollutants that are discharged from tunnels into the Little Nescopeck and Black Creek watersheds.
- Identify possible impacts associated with reclamation of mine-damaged property and diversion of surface water from mine shafts or permeable areas by monitoring flows and concentrations in streams and in tunnel discharges in some of the areas in which development will decrease of flow into shafts porous materials and increase flow into streams.
- Make initial suggestions about possible treatment options.

Eventually these data and recommendations should be used to assist in accomplishing the following tasks.

- Develope sampling protocols for deep mines, especially with regard to mapping water quality in the mine and tunnel system as a function of depth and X-Y coordinates. This task will be a focus of the second year EMARR activities.
- Further study and recommend alternatives for treatment and remediation of mine-contaminated waters in the ground and surface water resources of the Hazleton area.
- Identify and establish beneficial uses for the reclaimed ground and surface water resources of the Hazleton area.

The following results and conclusions were derived from the work performed at Penn State.

- Twenty-eight sample sites were investigated in collaboration with the PA DEP Bureau of Watershed Management. The sites included the discharge of the Jeddo Tunnel, discharge of Gowen Mine tunnel, and the Derringer discharge. Flow and concentrations permitted calculation of loadings into the Little Nescopeck, Black, and Nescopeck of acidity, sulfate, iron, aluminum, manganese, and total suspended solids.
- The dominant sources of contaminants in the studied basins were (from largest to smallest) the Jeddo tunnel, Gowen mine, Stoney Creek and Cranberry Creek discharges, upstream Black Run discharges, and Derringer discharge.
- There was net improvement in water quality related to mine drainage parameters due to discharges from the Hazleton area POTW and from other waste treatment facilities for sanitary sewage. In particular, the Hazleton area POTW added sufficient alkalinity to the stream to overcome upstream pollution and to make Black Creek compliant with PA DEP water quality standards for mine drainage for several downstream miles.
- Several remediation, remining, and redevelopment efforts are underway within these watersheds. This study has provided a baseline that may be used in the future to identify the effects of these works on water quality and on the loading of pollutants to surface waters.
- The data from the tunnel discharges indicated continuing improvements in water quality and decreases in the total load of pollutants discharged from these locations. The data set that was accumulated during this study was important because there had been a recent gap of several years during which no flow measurements had been made on some of these discharges.
- The Jeddo tunnel contributes most of the load of mine drainage pollutants into the Nescopeck. There was a positive correlation between flow and total pollutant load, and therefore a decrease in infiltration or direct entrance of storm water into the mine pool will result in decreased loading of pollutants to the Nescopeck.
- The discharge drains from a massive but unstudied mine pool. A spatial characterization of the concentration and load of contaminants within the mine pool is needed.
- A wide range of treatment and remediation options should be considered for the tunnels or tunnel discharges. Treatment options should include in-situ treatment, such as by discontinuous titration of the acidity in the mine pool using slag, fly ash, or other alkaline material. The discharges could also be treated using conventional active or passive processes or using novel treatment processes that have been developed at Penn State and result in more

concentrated and pure sludges. Any of the mouth-of-the-tunnel treatment techniques would be expensive and would require substantial further study.

- Water quality at the Gowen tunnel and the Derringer discharge seem to be improving, following remediation activities. Monitoring at these sites should be continued. The mine pool at Gowen should be investigated in a manner analogous to the recommendations for the Jeddo tunnel, to determine whether in-situ treatment should be considered. The effects of remediation, remining, and redevelopment activities at the other sources of mine drainage should also be monitored.
- POTWs are examples of existing infrastructure that could be used to assist in treating the mine drainage (for soon-to-be abandoned treatment facilities such at Drums) or for counter-acting the effects of mine drainage through addition of excess alkalinity.

Background

The Eastern Middle Anthracite Region (EMAR) of Pennsylvania surrounds the city of Hazleton, and is the smallest of the state's four major anthracite fields. Much of the surface in the region is scarred by the remnants of a history of coal mining such as abandoned pits, spoil piles, and refuse banks. The subsurface of the region is a maze of collapsed gangways, tunnels and chambers that interconnect the main coal beds (Ballaron, et. al., 1999). Large tunnel complexes that were constructed to dewater the deep mine workings were subsequently abandoned and flooded. These tunnels currently discharge significant loads of acidity, iron, aluminum, manganese, and sulfate to receiving streams.

All streams within the Hazleton area have been impacted by AMD. The focus of this study was the Little Nescopeck Creek and Black Creek, both of which drain North, through the Nescopeck Creek, into the Susquehanna River. The Little Nescopeck Creek receives a large AMD discharge from the Jeddo tunnel, which receives the combined flow from a series of five tunnel sections that drain an area of 32.24 square miles, including 12.6 square miles of coal basins (Ballaron, 1999). The polluted Little Nescopeck Creek then joins the Nescopeck Creek. Nescopeck Creek is a High Quality Cold Water Fishery above the confluence (Commonwealth of Pennsylvania, 2002), but is degraded in all sections downstream from the confluence with the Little Nescopeck. Black Creek flows through the city of Hazleton. Black Creek receives discharges from active and abandoned mines (upstream and downstream from Hazleton), from the city's wastewater treatment plant, and further downstream by AMD discharges from the Derringer Tunnel and Gowen Mine. Black Creek joins Nescopeck Creek several miles downstream from the confluence of the Nescopeck and the Little Nescopeck. Nescopeck Creek enters the Susquehanna River near Berwick, PA, and eventually discharges to Chesapeake Bay.

Objectives and Scope of Study

The long-term goal is to reduce the load of contaminants to these streams in order to restore the pre-mining quality of the streams, such that the streams can support fishing and other beneficial uses and become compliant with Pennsylvania water quality standards for streams affected by AMD. The specific goal of this part of the EMARR study was to measure AMD contamination in the identified streams in terms of concentration and loading., and to quantitatively identify the current polluted "baseline" condition of the regional streams. There are no existing measures of loadings within the streams themselves. Previous investigators measured the concentration and loadings of contaminants from the Jeddo Tunnel, but there have been no recent measures of flow from Jeddo Tunnel and therefore no recent measures of contaminant loading. In addition to measuring concentration and loads, another goal of this study was to identify long-term trends in the concentration and load of contaminants coming from the major sources.

Specifically, a baseline study of water quality was conducted for some perennial streams within the Hazleton area in order to identify sources of mass loadings of acidity, aluminum, iron, manganese, and sulfate to the streams. These data were also used to determine the reduction of acidity and metals loads that will be necessary to comply with the water quality standards, in the context of the Total Maximum Daily Load (TMDL) program of the PADEP.

Methods

Eighteen sample locations were identified along Black Creek including main-stem samples, tributaries, and the discharges from the Derringer Tunnel and Gowen Mine. Little Nescopeck sample locations were selected as main-stem sites both upstream and downstream of the Jeddo Tunnel discharge, which was also sampled. Nescopeck Creek samples were collected upstream and downstream of the confluence with the Little Nescopeck and Black Creek.

Water samples from each location were collected in acid-washed polyethylene bottles after three rinses. Stream velocity was measured at 60% of depth at 20 to 30 locations across the stream channel to calculate flow and, subsequently, pollutant loading. Each sample was analyzed for pH, acidity (hot peroxide method), alkalinity, total aluminum, total iron, total manganese, sulfate, and suspended solids. Acidity and alkalinity measurements were performed by electrometric titration using a VWR Scientific 2000 pH meter. Samples for total metals were digested and extracted using hot HCl/HNO_3, and metals were analyzed using an Inductively Coupled Argon Plasma (ICAP) spectrophotometer at the Penn State University Materials Characterization Laboratory. Sulfate concentration was determined using a Dionex DX-100 Ion Chromatograph after filtration through 0.20 μm membrane filters. Suspended solids concentrations were determined by gravimetric analysis after filtration through 47 mm glass fiber filters.

The TMDL of total Al, Fe, and Mn as well as acidity was determined through the use of Monte Carlo simulation assuming that the observed data are log-normally distributed as suggested by USEPA (PADEP, 2001). Each stream section was evaluated using @Risk software and 5000 iterations of the Monte Carlo simulation to determine the required percent reduction of each contaminant so that water quality criteria will be met in-stream at least 99 percent of the time. The PA water quality criteria that were used to evaluate stream sections (Commonwealth of Pennsylvania, 2001, 2002) are shown in Table 1. In this study, the criteria value for acidity was taken as zero hot acidity, i.e. all streams sections must possess net alkaline water.

Table 1. PA water quality standards and criteria for streams affected by AMD

Parameter	**Standard or Criterion Value**
Aluminum	0.75 (mg/L as total)
Iron	1.50 (mg/L as total)
Manganese	1.00 (mg/L as total)
pH	6.0 – 9.0

Water Quality & Mass Loadings

Most of the stream locations that were monitored in this study were sampled six times between September 2003 and May 2004 with this study serving as the first systematic survey of water quality in many of the stream locations. The samples were collected during varying stream flow conditions to determine the impact of stream flow on pollutant concentration.

<u>Black Creek</u>

Eighteen sample locations were monitored along the length of Black Creek. The sites were chosen so as to obtain water quality data in all segments of Black Creek, with stations located between the most upstream monitoring point (Site #25) located just east of State Highway 309 in Hazleton and the confluence of Black Creek with Nescopeck Creek near Tank, PA. Ten monitoring points were located on the main-stem of Black Creek; six monitoring points were located on tributaries to Black Creek and discharge from the Gowen Mine was monitored. Additional samples were taken from the discharge of the Derringer Tunnel, which enters Black Creek just upstream from the Gowen Mine discharge. These samples were taken to qualitatively measure the impact of the discharge from the Gowen Mine and Derringer Tunnel on Black Creek. The relative locations and numbering for sites on Black Creek are identified in Figure 1.

Black Creek has been severely affected by mining activities, in terms of flow and in terms of the concentration of contaminants. As an example, there is a well-developed channel upstream of Hazleton, but there was no flow in the channel even during large storm events. Perrennial flow begins just to the West of Route 309, and the most upstream site on Black Creek was located just East of Route 309. The average pH, acidity, and alkalinity values in the main stem sites are reported in Figure 2 and the average metal concentrations for the main stem Black Creek sites are reported in Figure 3.

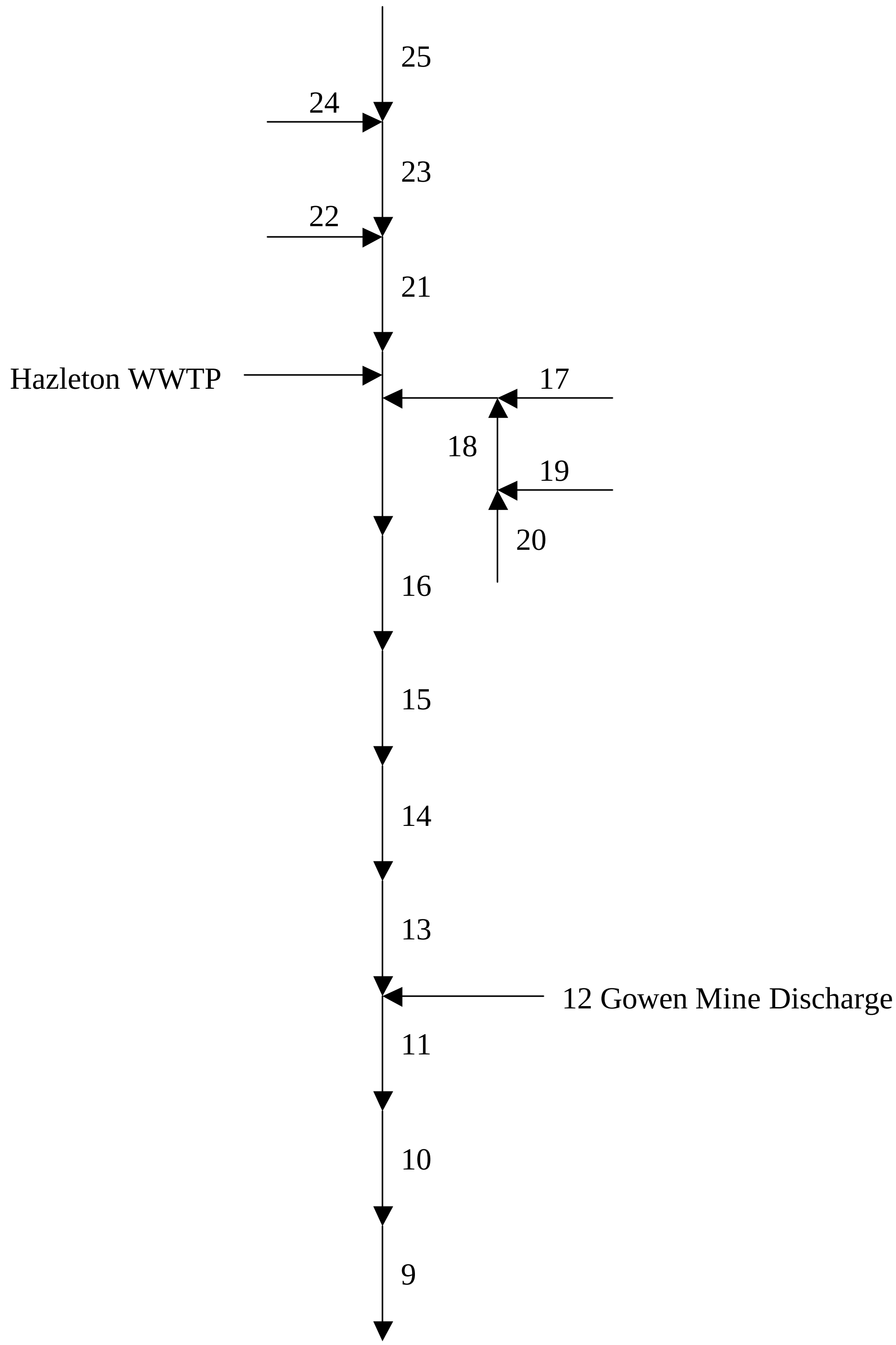


Figure 1: Schematic flow diagram of Black Creek

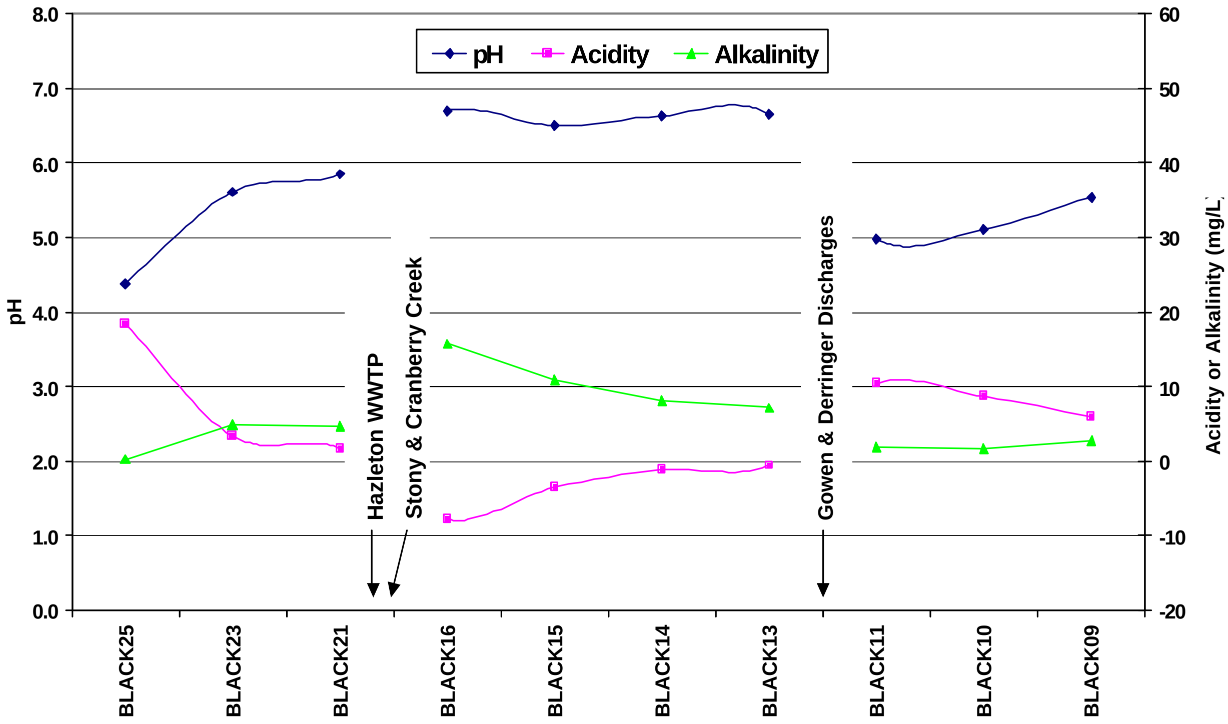


Figure 2: Average pH, acidity, and alkalinity in main-stem Black Creek

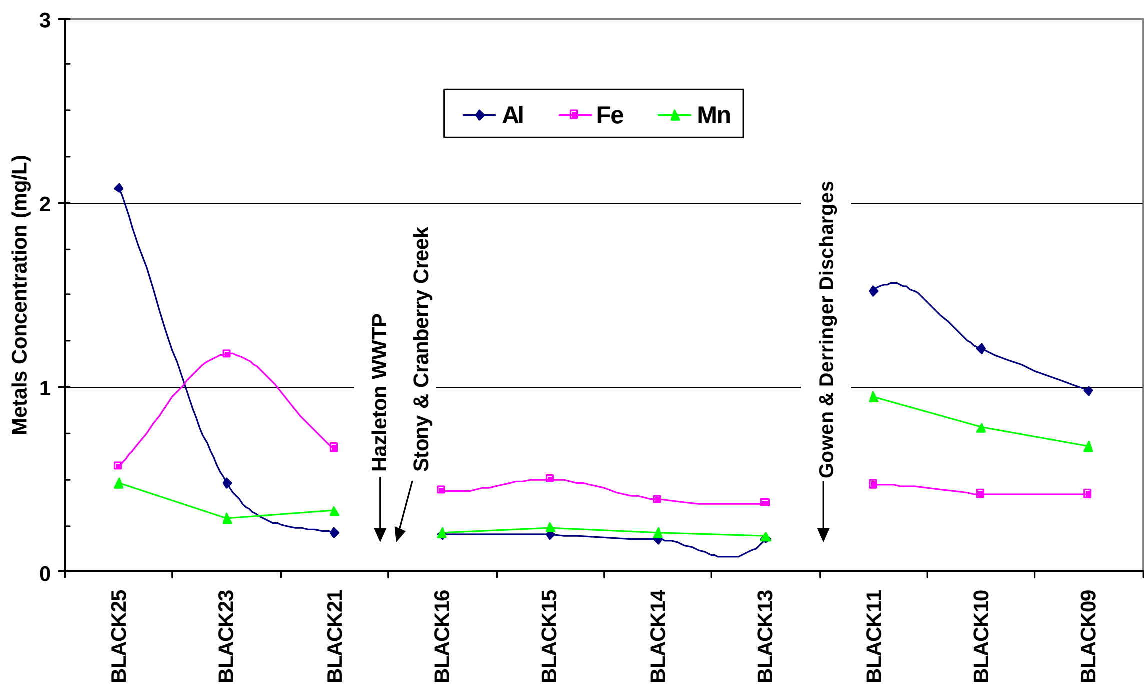
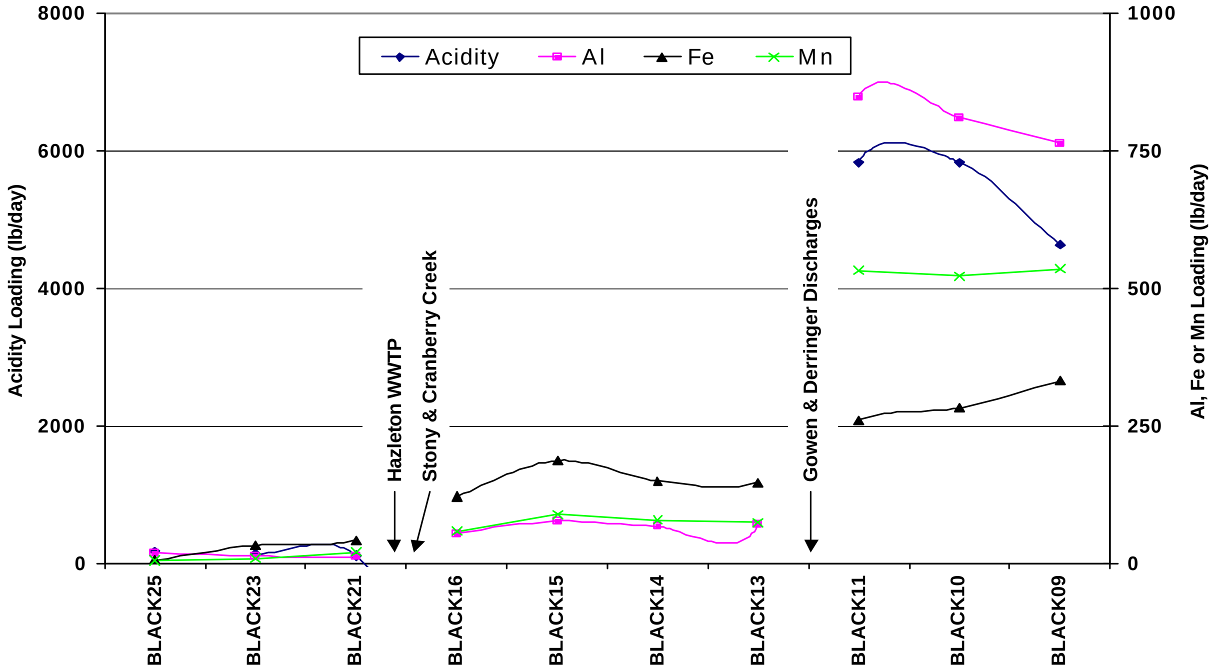


Figure 3: Average metals concentrations in main-stem Black Creek

Figure 4. Mass loadings of AMD pollutants in main-stem Black Creek



The loading of contaminants (lb/day) in the main-stem sites are reported in Figure 4. Three distinct sections were identified in Black Creek. The most upstream section extended from site #25 (just East of Route 309) to above the discharge from the Hazleton wastewater treatment plant (Site #21). The most upstream site was contaminated but water quality improved through this section. The average hot peroxide acidity concentrations were all greater than zero and pH was less than 6.0. Site #25 displayed the lowest pH of upstream locations at pH 4.38, highest concentrations of hot acidity with an average concentration of 18.4 mg/L as $CaCO_3$ and total aluminum concentrations greater than 2.00 mg/L, all in violation of the PA water quality criteria.

Water quality in Black Creek downstream from the discharge of the wastewater treatment plant (Sites #13 - #16) improved significantly from upstream locations despite the acidic discharges from Cranberry and Stony Creek (Sites #17 - #20), which enter Black Creek just downstream of the wastewater treatment plant. Discharges from the wastewater treatment plant and Cranberry and Stony Creek led to a significant increase in flow in Black Creek compared to upstream sections. Samples taken downstream from the wastewater treatment plant displayed an increase in pH to above 6.0 and decreases in acidity and aluminum, compared to water quality upstream from the wastewater treatment plant. Average hot acidity concentrations of samples taken from Sites #13 - #16 were less than zero, presumably due to the addition of $Mg(OH)_2$ at the wastewater treatment plant. Average values of total metals concentrations from samples taken from Sites #13 - #16 were less than the criteria values. The loading of metals was higher in this section, due to contributions from Sandy and Cranberry Creeks, but the increased flow resulted in compliance with PA standards. Cranberry and Stony Creek (Sites #17 - #20) samples contained hot acidity concentrations greater than zero and pH well below the criteria value of 6.0. Despite violating the criteria for hot acidity and pH, these samples did not contain total metals concentrations in violation of the water quality criteria with the exception of one sample taken from Cranberry Creek on 10/10/2004. This sample contained elevated concentrations of total Al and Fe compared to the remaining samples collected from this location.

The third, and most contaminated section of Black Creek was downstream from discharges from the Derringer Tunnel and Gowen Mine, located near the town of Fern Glen, PA. Table **2** displays water quality data for samples taken from these discharges. The Derringer Tunnel drains a reclaimed mining area and had flows and concentrations of hot acidity, total metals, and sulfate much less than those observed in the discharge from the Gowen Mine, which is currently undergoing reclamation activities as required under remining regulations. Gowen Mine discharge samples contained average hot acidity concentrations of 60 mg/L as $CaCO_3$, total Al of 8.7 mg/L, and total Mn of 5.5 mg/L. The average pH of samples taken from the Gowen Mine was 4.0. Gowen had the worst water quality of the sample sites in this study, except for a relatively low total Fe of less than 1.0 mg/L. The concentrations of AMD contaminants in Gowen Mine samples were greatest at the beginning of this study and began to decrease during subsequent rounds of sampling, accompanied by a slight increase in pH perhaps caused by seasonal variation or the reclamation activities.

Table 2: Water quality data for Derringer Tunnel and Gowen Mine discharges

Gowen Mine Discharge						
Date	**pH**	**Acidity (mg/L)**	**Total Al (mg/L)**	**Total Fe (mg/L)**	**Total Mn (mg/L)**	**Sulfate (mg/L)**
9/26/2003	3.93	78.86	12.00	1.00	7.50	350
10/10/2003	3.88	77.38	11.00	0.82	6.80	409
10/31/2003	3.98	52.77	7.60	1.10	5.50	283
11/22/2003	4.01	49.29	7.60	0.84	4.80	250
3/21/2004	4.01	54.29	7.59	0.67	4.69	248
5/1/2004	4.17	45.38	6.59	0.94	4.15	223
Average	**4.00**	**59.66**	**8.73**	**0.90**	**5.57**	**294**
Derringer Tunnel Discharge						
Date	**pH**	**Acidity (mg/L)**	**Total Al (mg/L)**	**Total Fe (mg/L)**	**Total Mn (mg/L)**	**Sulfate (mg/L)**
3/24/2004	4.39	15.22	1.63	0.28	0.55	83
5/1/2004	4.53	13.08	1.08	0.31	0.48	54
5/24/2004	4.33	15.74	1.46	0.16	0.53	63
Average	**4.42**	**14.68**	**1.39**	**0.25**	**0.52**	**67**

The Derringer Tunnel and Gowen Mine discharges affected both water quality and flow in Black Creek. Downstream water samples in Black Creek (Sites #9 - 11) violated the PA water quality standards for pH, acidity, and total Al. Precipitates of $Al(OH)_3$ coat much of the stream bottom at site #11 just below the Gowen Mine discharge. The concentrations of AMD pollutants in Black Creek decreased downstream from Site #11 at Sites #10 and #9. The improvement in water quality may be due to dilution with groundwater sources, wastewater discharges or tributary streams. Samples taken from Site #9 near the confluence of Black Creek contained average concentrations of hot acidity and total Al, Fe, and Mn of 6.7 mg/L as $CaCO_3$, 0.98 mg/L, 0.42 mg/L, and 0.71 mg/L respectively. Black Creek, containing these concentrations of AMD contaminants, discharges to Nescopeck Creek near Tank, PA.

Table 3 displays the results of correlation between flow and AMD pollutants for Black Creek. The strongest correlations were between flow and acidity (or alkalinity) in the complying section between the Hazleton wastewater treatment plant and the Derringer/Gowen discharges (sites #16-13). This was probably due to dilution of the alkalinity additions during storm flows, either due to inflow/infiltration that overwhelmed the alkaline addition equipment at the plant, or due to increased surface runoff.

There were negative correlations between flow and contaminant concentrations for Cranberry Creek (site #17). Most other sites in this study showed a positive correlation between flow and acidity, although the relationships were not strong, and in some cases there was also a negative correlation between flow and sulfate concentrations.

Black Creek Correlations						
Site Number	**Flow vs**					
	Acidity	**Alkalinity**	**Al**	**Fe**	**Mn**	**Sulfate**
9	0.16	-0.13	0.33	0.14	0.09	0.04
10	0.28	-0.21	0.16	0.32	0.09	-0.02
11	0.03	-0.17	-0.19	0.18	-0.22	-0.23
12	N/A	N/A	N/A	N/A	N/A	N/A
13	0.36	-0.53	0.71	-0.22	0.24	-0.41
14	0.61	-0.68	0.60	-0.29	0.08	0.24
15	0.91	-0.94	0.61	-0.27	-0.12	-0.43
16	0.93	-0.97	0.58	-0.25	-0.28	-0.45
17	-0.18	-0.73	-0.58	-0.60	-0.82	0.47
18	0.75	-0.19	0.72	0.74	-0.79	-0.69
19	-0.24	0.78	0.46	0.81	0.93	0.05
20	0.70	0.21	0.13	-0.28	-0.13	-0.67
21	0.68	-0.41	0.83	0.28	-0.49	0.72
22	0.38	-0.51	0.63	0.13	0.49	0.61
23	0.50	-0.38	0.70	-0.82	0.09	0.56
24	0.65	-0.57	0.92	0.69	0.32	0.83
25	0.29	-0.03	0.39	-0.01	0.01	0.29

Table 3: R-values for regression results of flow vs. concentration in Black Creek

Mass Loading in Black Creek

There was a significant load of acidity and Al at the most upstream main stem site. Stony and Cranberry Creek contribute mass loads of acidity to Black Creek, but these loads were neutralized by the addition of alkalinity at the wastewater treatment plant.The Gowen Mine and Derringer Tunnel were by far the largest discharges to Black Creek, in terms of concentrations of acidity and the metals. The two AMD sources discharged an average of 6000 lb/day of acidity to Black Creek, and decreased pH in the stream from an average value of 6.65 immediately upstream at Site #13 to below 5.0 at Site #11. Gowen Mine and Derringer Tunnel discharged 775 lb/day of Al and 450 lb/day of Mn.

Acidity oncentrations were lower in Derringer Tunnel than in Gowen Mine. Flow in Gowen was determined using concentrations, the total incremental flow between main stem sites #11 and #13, and flow at Derringer. Flow from the Gowen Mine was nearly twice as great as flow from the Derringer Tunnel based on these calculations. Based on these results, more than 80% of total loading of acidity, total Al and Mn, and sulfate added to Black Creek between Sites #13 and #11 were contributed by the Gowen Mine discharge.

From the TMDL analysis of Black Creek, load reductions of AMD pollutants were required in the sections of Black Creek upstream from the wastewater treatment plant discharge and downstream of the Derringer Tunnel and Gowen Mine, for compliance with PA water quality criteria 99% of the time. No load reductions were necessary in Black Creek between the wastewater discharge and the Derringer Tunnel and Gowen Mine discharges (Sites #13 - #16). Load reduction would be required for acidity at all upstream sample locations (Sites #25 - #21), with the greatest reduction of 170 lb/day necessary at Site #25. Following reduction of this load, no downstream reductions were necessary at Sites #23 and #21. Load reductions of Al were necessary in Sites #25, #24, #23 and #21, with load reductions at #25 and #24 satisfying the necessary reduction throughout the remaining downstream sections, i.e. no additional reductions were necessary. Fe load reduction was only required at Site #23. None of the upstream locations required Mn load reductions to meet PA criteria.

In Stony Creek, the reduction of the acidity load was the only required AMD pollutant reduction. Cranberry Creek required reductions of Al, Fe and acidity mass loading to meet PA criteria. Despite the fact that these tributaries discharge loads of acidic water to Black Creek downstream of the Hazleton wastewater treatment plant, no load reductions were necessary to meet PA criteria at downstream Sites #13 - #16 due to the addition of alkalinity at the treatment plant. These sites did not appear to be affected by AMD from the upstream sources, as they possessed water quality within PA criteria.

Deterioration in water quality was observed in Black Creek downstream from the Derringer and Gowen discharges. All Black Creek sample locations downstream from these discharges (Sites #9 - #11) required load reductions of acidity, Al and Mn. The reduction of Fe was not required in these sites as loads in this study were less than the allowable long-term average. Required load reductions of acidity, Al, and Mn necessary at Site #11 just downstream of the Derringer and Gowen discharges were 5800, 680, and 290 lb/day respectively, with slightly lower load reductions of Al and Mn required at downstream Sites #10 and #9. Complete reduction of the required loads at Site #11 satisfied the required reductions at the downstream sites with the exception of Site #10 which required a minor additional acidity reduction.

Little Nescopeck and Nescopeck Creek

Eight sample locations were monitored along the Little Nescopeck and Nescopeck Creeks, including the discharge from the Jeddo Tunnel. One site on the Little Nescopeck was upstream of the Jeddo Tunnel discharge. One site on Nescopeck Creek was upstream of the confluence with the Little Nescopeck, one site was below the confluence with the Little Nescopeck, and another site was below the confluence with Black Creek. The Jeddo Tunnel discharge was expected to be the primary source of AMD pollution in the Little Nescopeck and Nescopeck Creek. A schematic diagram of sites on the Little Nescopeck and Nescopeck Creeks is shown as Figure **5**.

The Little Nescopeck Creek upstream from the Jeddo tunnel discharge (Site #8) had negative hot acidity values (i.e. was net alkaline), pH values greater than 6.0, and metal concentrations much less than the PA water quality criteria. There was no visual evidence of AMD pollution and fish were observed upstream of the Jeddo discharge.

Figure 5: Schematic flow diagram of Little Nescopeck and Nescopeck Creek

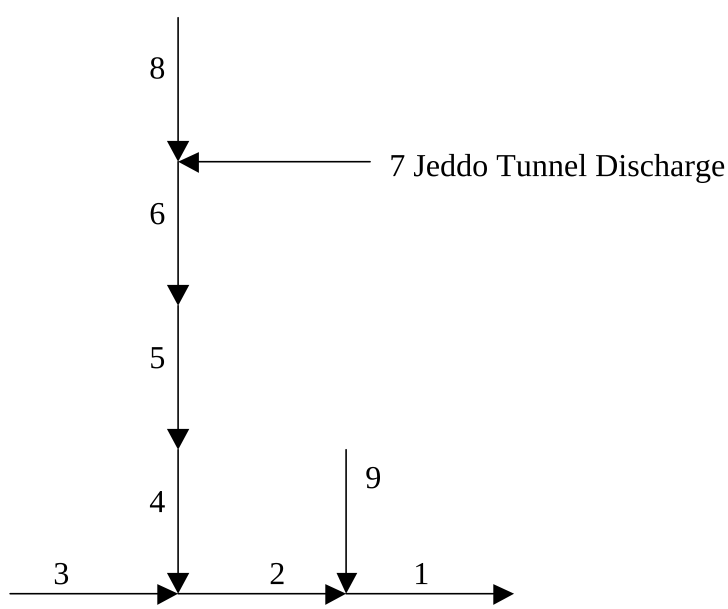


Figure 5: Average pH, acidity, and alkalinity in main-stem Little Nescopeck and Nescopeck

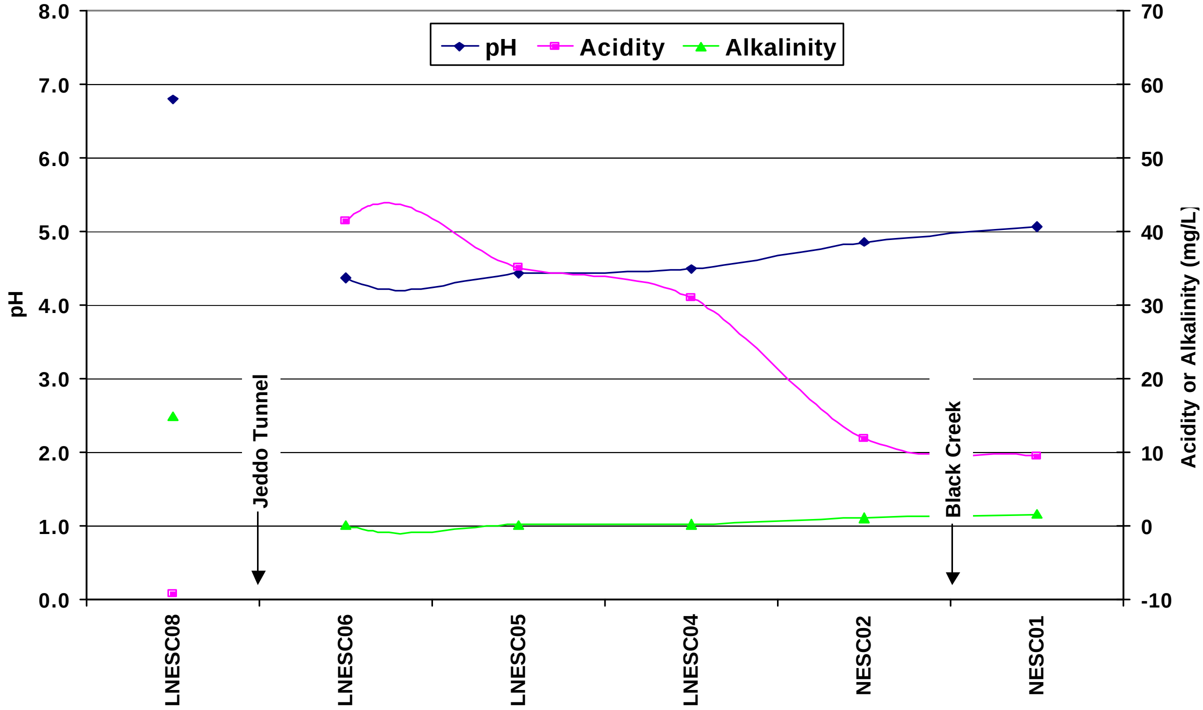
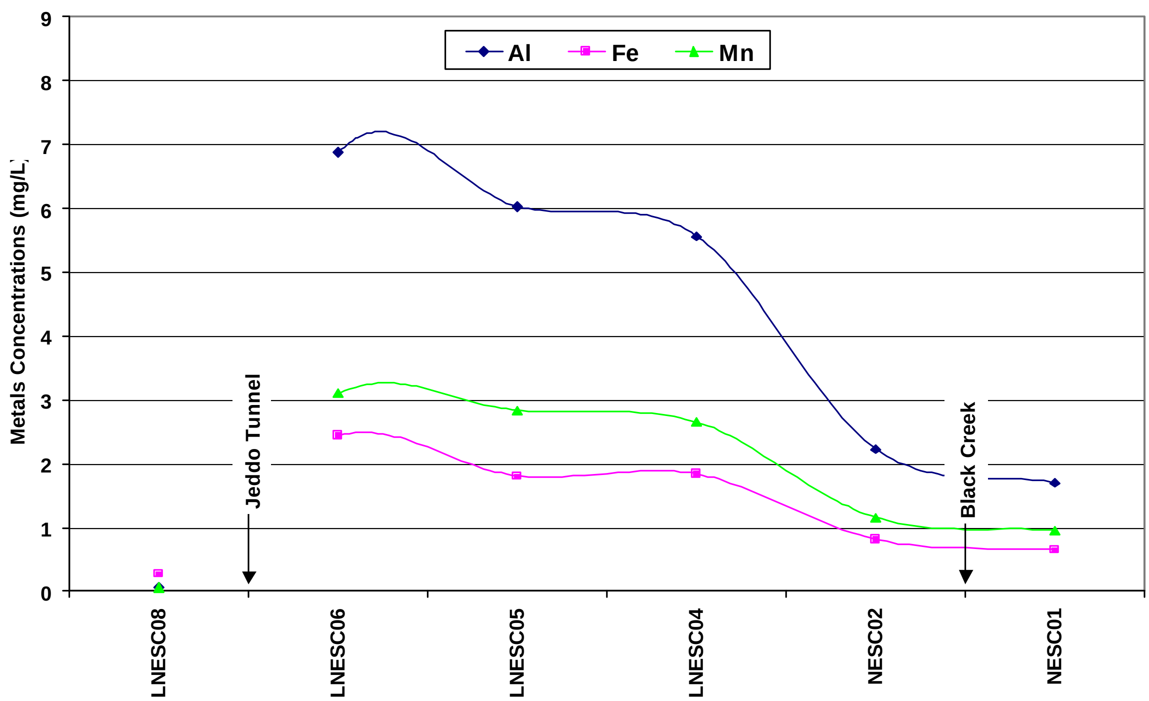


Figure 6: Average metals concentrations in Little Nescopeck and Nescopeck Creek



The Jeddo Tunnel discharge (Site #7) had average hot acidity of 44.7 mg/L as $CaCO_3$ and pH 4.33. Average total Al, Fe, and Mn were 7.4, 2.5, and 3.3 mg/L respectively, all in excess of the PA water quality criteria. Sulfate from the Jeddo Tunnel discharge ranged from 300 to 400 mg/L, with an average value of 350 mg/L. **Table** 4 displays water quality data for Jeddo Tunnel discharge samples.

Table 4: Water quality data from Jeddo Tunnel discharge samples

Jeddo Tunnel Discharge							
Date	**Flow (gpm)**	**pH**	**Acidity (mg/L)**	**Total Al (mg/L)**	**Total Fe (mg/L)**	**Total Mn (mg/L)**	**Sulfate (mg/L)**
10/10/2003	33426	4.27	46.92	8.00	2.30	3.70	406.00
10/24/2003	28796	4.33	44.34	8.00	2.30	3.70	373.00
3/21/2004	29225	4.28	49.32	7.62	2.42	3.26	344.00
5/1/2004	41381	4.42	40.17	6.58	2.85	2.89	299.00
5/12/2004	39799	4.39	42.62	6.52	2.34	3.09	322.00
5/24/2004	27800	4.30	44.97	7.67	2.82	3.63	355.00
Average	**33405**	**4.33**	**44.72**	**7.40**	**2.51**	**3.38**	**350.00**

The Jeddo Tunnel discharge significantly alters water quality and flow patterns in the Little Nescopeck Creek. Samples taken from Little Nescopeck Creek downstream of the Jeddo Tunnel discharge (Sites #4 - #6) displayed water quality parameters similar to Jeddo discharge samples and violated the water quality standards for pH, acidity, and concentrations of total metals. The pH of the samples increased slightly with distance from the Jeddo Tunnel discharge, while hot acidity, total metals, and sulfate concentrations decreased somewhat. Wastewater discharges from the Drums and Conyngham treatment facilities enter the Little Nescopeck downstream of the Jeddo Tunnel and may cause the decrease of AMD pollutants in downstream sections. Average values of samples taken from the Little Nescopeck just upstream of the confluence with Nescopeck Creek (Site #4) possessed an average pH of 4.49 and average concentrations of hot acidity, and total Al, Fe, and Mn of 30.9 mg/L as $CaCO_3$, 5.6 mg/L, 1.8 mg/L and 2.7 mg/L, respectively.

Samples collected from Nescopeck Creek upstream from the confluence with the Little Nescopeck Creek (Site #3) displayed water quality parameters within PA criteria. Samples taken from Site #2 downstream of the confluence with the impaired Little Nescopeck violated PA criteria for pH, acidity, and total Al and

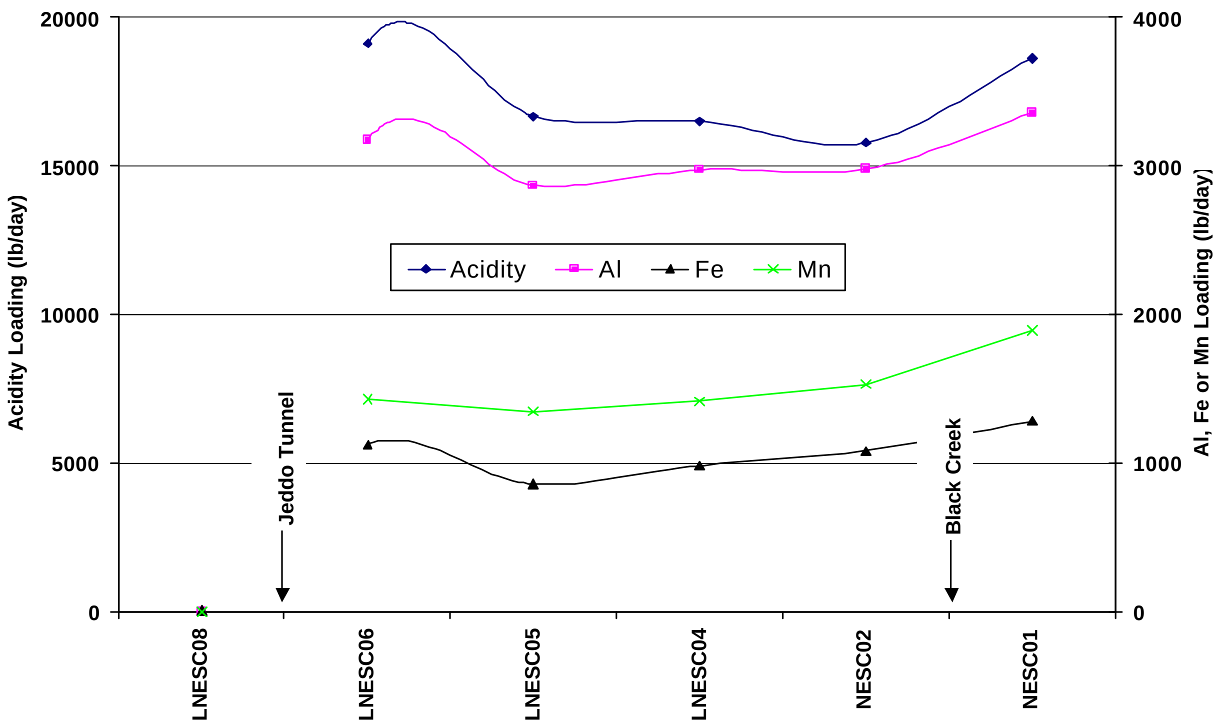
Mn. The concentrations of AMD contaminants in these samples were much less than those observed in Little Nescopeck Creek samples due to dilution from flows in Nescopeck Creek. The Black Creek, containing AMD pollution from the Derringer Tunnel and Gowen Mine discharges, enters Nescopeck Creek just below Site #2. Samples taken from Site #1, located below the confluence of the Nescopeck with Black Creek, violated PA criteria for pH, acidity and total Al. Although Site #9 violates PA water quality criteria as detailed above, Site #1 has better water quality than exists immediately upstream at Site #2. Average concentrations of AMD pollutants in main-stem Little Nescopeck and Nescopeck Creek are shown in Figures 5 and 6.

Nescopeck Creek Correlation						
Site Number	Flow vs					
	Acidity	Alkalinity	Al	Fe	Mn	Sulfate
1	-0.78	0.69	-0.78	0.75	-0.96	-0.90
2	-0.73	0.76	-0.90	0.42	-0.96	-0.93
3	0.87	-0.93	0.22	0.29	0.84	-0.29
4	-0.75	N/A	-0.88	-0.47	-0.89	-0.84
5	-0.77	N/A	-0.88	0.15	-0.90	-0.86
6	-0.81	N/A	-0.81	0.23	-0.87	-0.71
7	-0.72	N/A	-0.87	0.16	-0.79	-0.62
8	0.95	-0.96	-0.14	0.65	-0.16	0.89

- Table 5: R-values for regression of concentrations and flows for Little Nescopeck and Nescopeck.

The results of correlation between stream flow and AMD pollutant concentration for Little Nescopeck and Nescopeck Creek are shown in Table 5. Concentrations of acidity, total Al and Mn, and sulfate displayed a negative correlation for stream segments that receive the discharge from the Jeddo Tunnel, i.e., as flow in these sections increases, concentrations of those contaminants decrease, probably due to dilution of the discharge by precipitation or increased groundwater flows.

Figure 8: Mass loadings of AMD pollutants in main-stem Little Nescopeck and Nescopeck Creek



Mass Loading in Little Nescopeck and Nescopeck Creek

The largest source of AMD mass loading to the Little Nescopeck Creek was the discharge from the Jeddo Tunnel. During this study, average mass loadings of acidity, Al, Fe, and Mn added to the Little Nescopeck from the Jeddo Tunnel were 17,900, 2960, 1000, and 1355 lb/day respectively. The acidic loading from the Jeddo Tunnel completely eliminates the net alkaline conditions that exist in the Little Nescopeck just upstream of the discharge (Site #8). The only significant increases in mass loading in downstream sections of the Little Nescopeck occurred close to the Jeddo Tunnel discharge, and could have been due to unidentified seeps. The results of this study make it clear, however, that the Jeddo Tunnel discharge was the dominant source of AMD pollutants to the Little Nescopeck.

AMD contamination in the Nescopeck Creek was due primarily to the discharges of the Jeddo Tunnel and Black Creek. Upstream from the confluence with the Little Nescopeck, the Nescopeck Creek displays net alkaline water quality and is listed as being in attainment with PA water quality standards, however the addition of mass loads of AMD pollutants from the Little Nescopeck leads to considerable degradation in water quality in the downstream sections. Black Creek discharges considerable mass loads of acidity and total Al, Fe, and Mn to Nescopeck Creek, most of which emanates from the Derringer Tunnel and Gowen Mine discharges. A plot of mass load of AMD pollutants in the Little Nescopeck and Nescopeck Creek is shown as Figure 8.

TMDL analysis of AMD Pollutants in Little Nescopeck and Nescopeck Creek

Load reductions of AMD pollutants were necessary for all sections of the Little Nescopeck and Nescopeck Creek that receive the discharge from the Jeddo Tunnel. Upstream from the Jeddo discharge, Little Nescopeck Creek (Site #8) required no load reduction as samples taken from this location were consistently within the PA criteria. The Jeddo Tunnel discharge required load reductions of acidity, Al, Fe, and Mn in the amount of 17,900, 2700, 530, and 1030 lb/day, respectively, in order to meet PA water quality criteria. An increase in mass loading of AMD pollutants possibly due to unidentified seeps was observed just downstream of the Jeddo Tunnel discharge at Site #6 resulting in greater load reductions necessary at this site than required at the mouth of the Jeddo Tunnel. The required load reductions decreased at downstream Sites #5 and #4, most likely caused by alkaline wastewater discharges from the Drums and Conyngham treatment facilities to the Little Nescopeck. The analysis showed that the reduction of load at the Mouth of the Jeddo Tunnel and downstream Site #6 satisfied the required reductions of AMD pollutants throughout the remaining sections of the Little Nescopeck.

Nescopeck Creek required load reductions of AMD pollutants in Sites #1 and #2 to meet PA criteria. No load reductions were required upstream of the confluence with the Little Nescopeck (Site #3). Results of the TMDL analysis of Nescopeck Creek showed that load reductions of acidity, Al and Mn of 15,780, 2400, and 840 lb/day, respectively were necessary at Site #2 to meet the criteria. The reduction of the required loads at the Jeddo Tunnel and Site #6 would eliminate the need for additional reduction at Site #2, thus treatment of the Jeddo discharge and any unidentified seeps would produce acceptable water quality in sections of Nescopeck Creek downstream of the confluence with the Little Nescopeck. Site #1, located downstream of the confluence of Nescopeck Creek with Black Creek, required load reductions of acidity, Al and Mn. These reductions would be satisfied by the required load reduction in Black Creek at site #11 and the reduction of AMD pollutants at the upstream sources on the Little Nescopeck. Load reductions of Fe were not required in Nescopeck Creek as average loads in this study were less than the allowable long-term average load of Fe at these sites.

Historical Trends in Water Quality

One of the objectives identified for this study was to compare the water quality of the Jeddo Tunnel and Gowen Mine discharges obtained in this study to historical water quality data from these sources obtained from PADEP. The historic water quality data, as well as data from this study for the Jeddo Tunnel discharge showed that the severity of AMD contamination has decreased with time. The pH of the discharge has increased while the concentrations of hot acidity and total Al, Fe, and Mn, and sulfate have decreased. Samples taken from the Jeddo Tunnel discharge during this study displayed an increase in pH, and decreases in hot acidity, total Al, Fe, and Mn, and sulfate compared with the historic data. These long-term improvements are consistent with previously reported trends, which have indicated a decrease over time in the severity of AMD contamination. Figures 4.9–4.14 display the concentrations of AMD pollutants in the Jeddo Tunnel discharge with time including data obtained in this study. Values obtained during this study are displayed in pink while the historical data obtained from PADEP are displayed in blue.

Water quality data obtained from this study for the Gowen Mine discharge when compared to historical data from PADEP from 1996 – 2003 did not show definite trends toward a decrease in AMD contamination. The pH values of the discharge samples obtained in this study were lower than previous pH values reported by PADEP. Sulfate concentrations obtained in this study were higher than those previously reported while concentrations of total Al and Mn have remained fairly constant with time. The concentrations of total Fe obtained in this study were lower than past concentrations. Changes in water quality of the discharge may have been caused by the gradual decline in mining activity and implementation of reclamation activities at the Gowen Mine. Plots of AMD pollutant concentrations with time for the Gowen Mine Discharge are shown in Figures 15-20. Data from this study are displayed in pink while historical data from PADEP is displayed in blue.

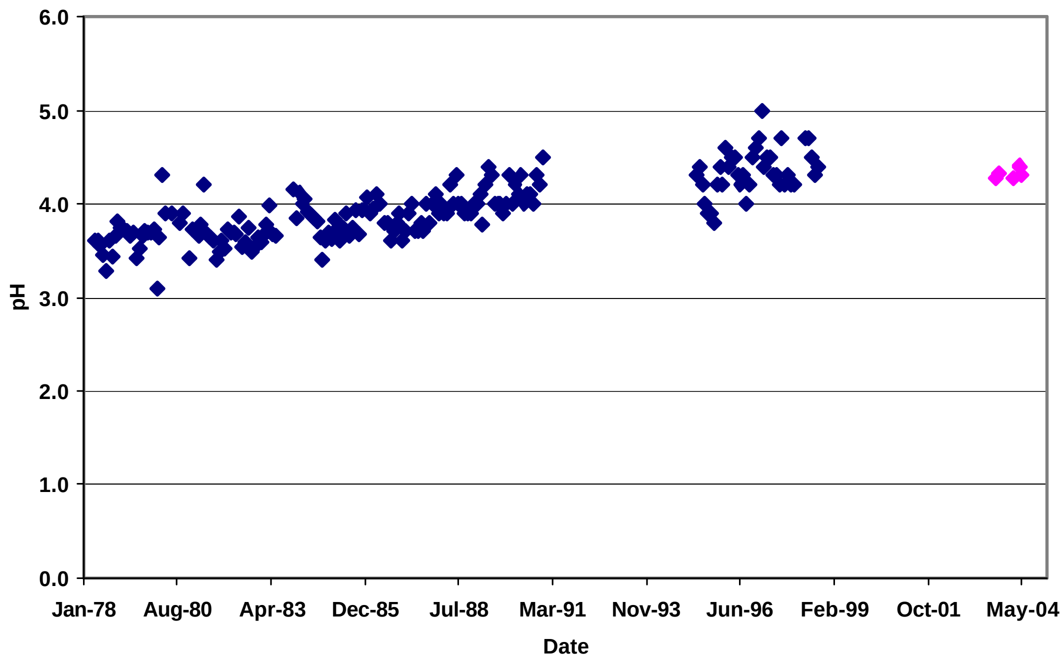


Figure **9:** pH vs. time for Jeddo Tunnel discharge

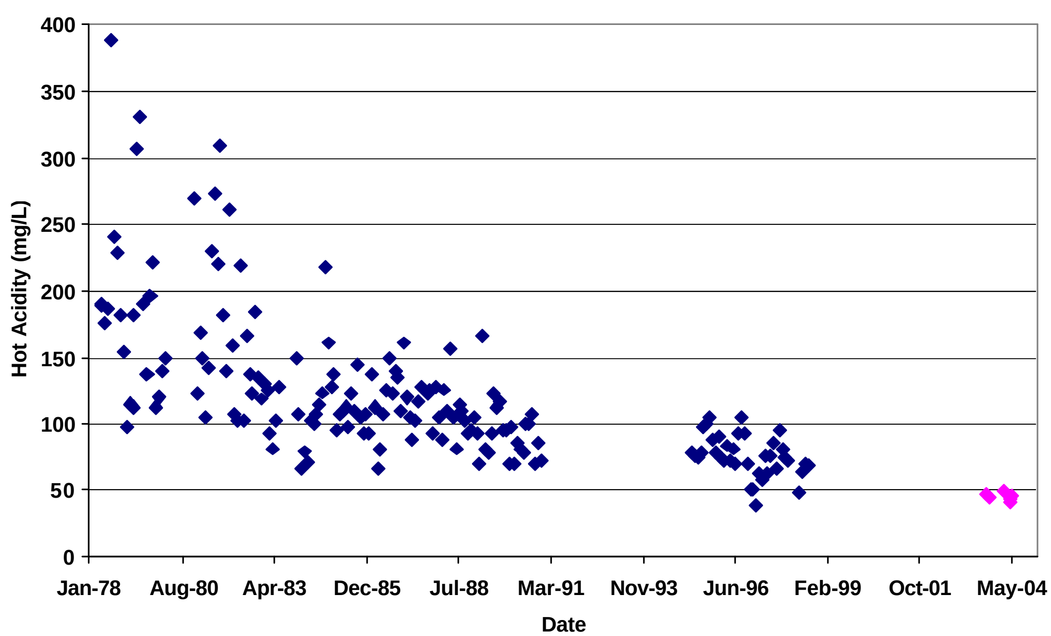


Figure 10: Hot acidity vs. time for Jeddo Tunnel discharge

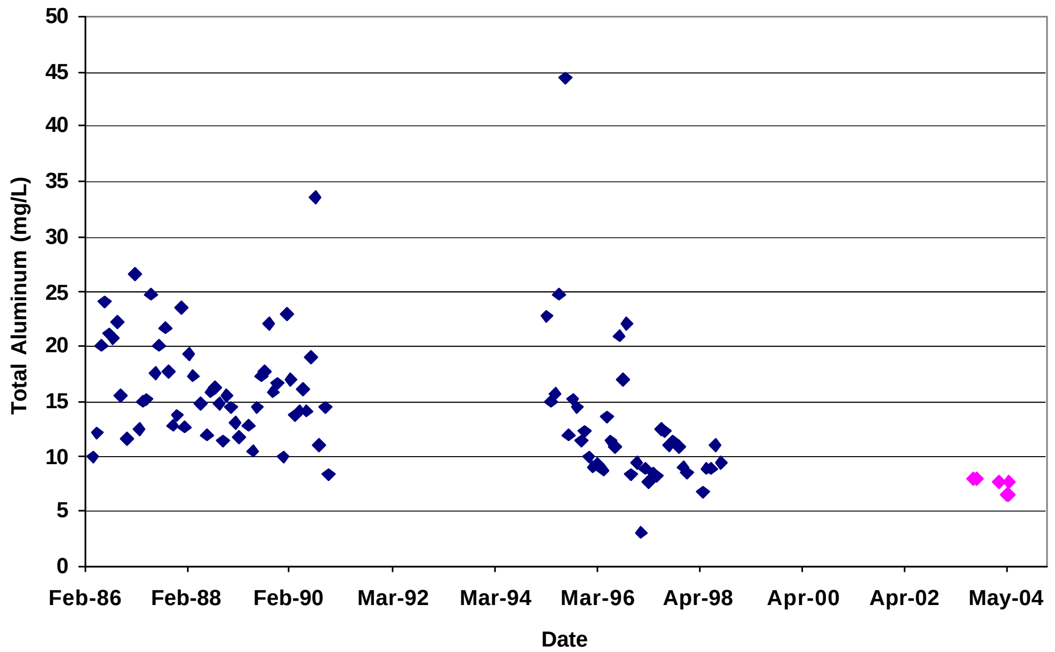


Figure 11: Total aluminum vs. time for Jeddo Tunnel discharge

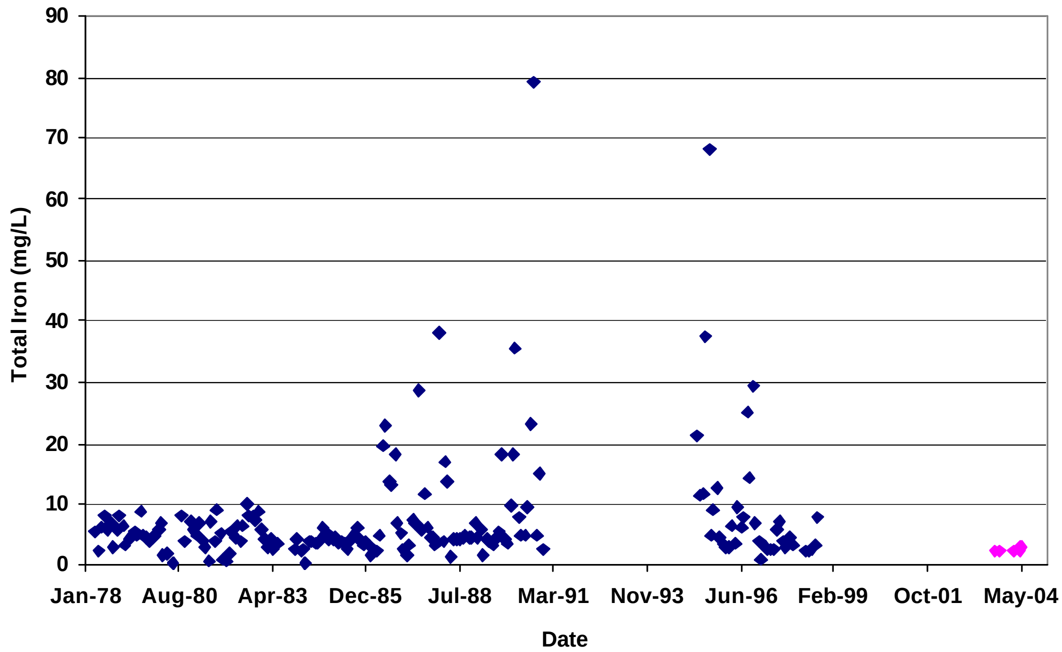


Figure 12: Total iron vs. time for Jeddo Tunnel discharge

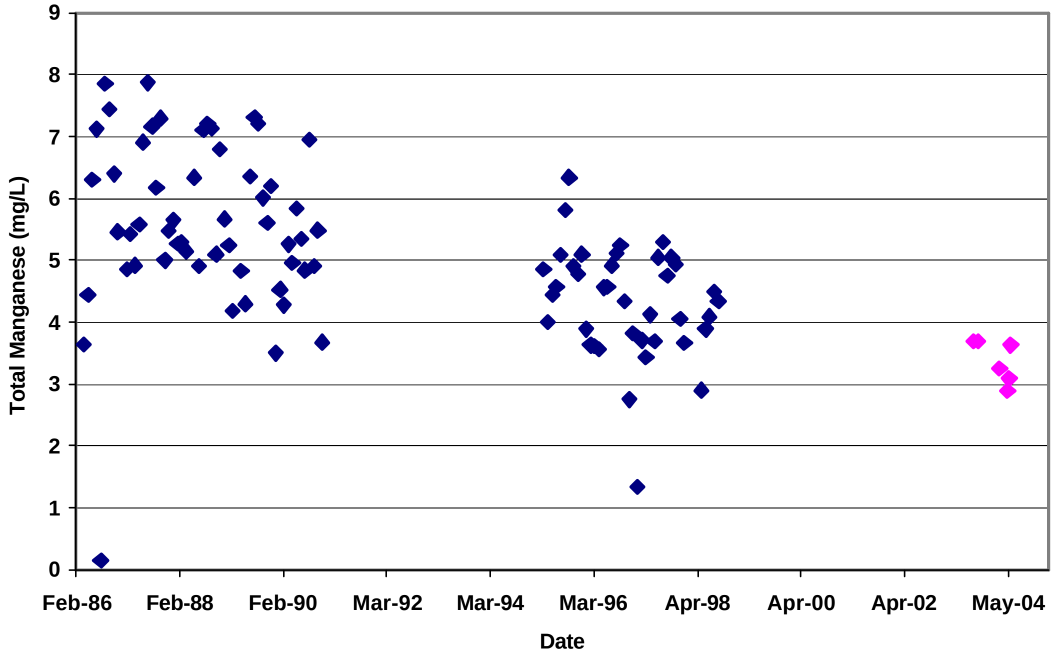


Figure 13: Total manganese vs. time for Jeddo Tunnel discharge

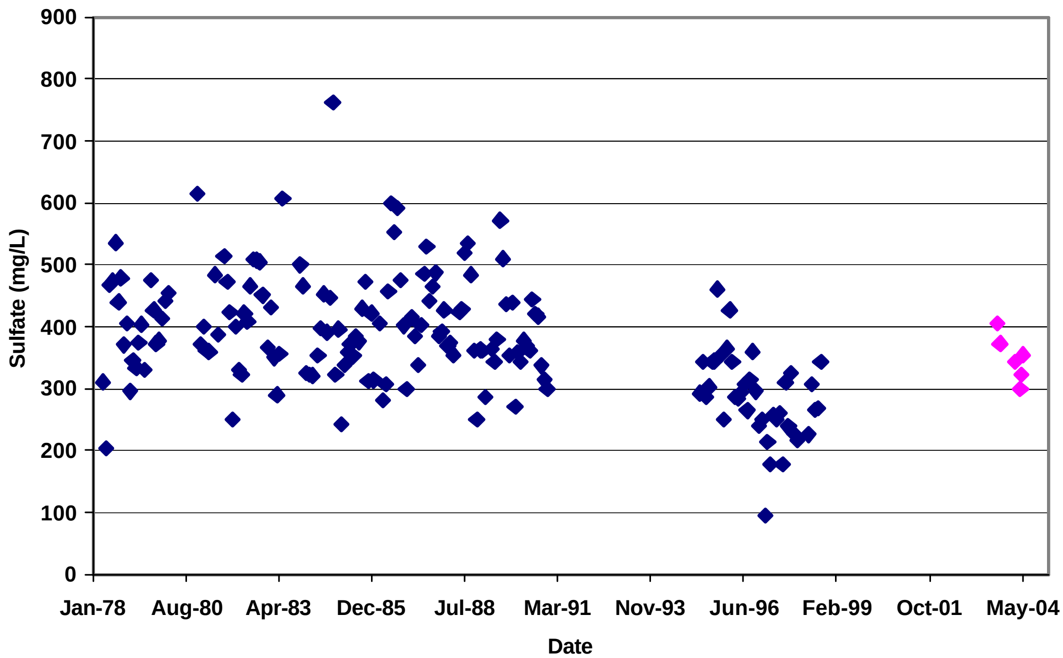


Figure 14: Sulfate vs. time for Jeddo Tunnel discharge

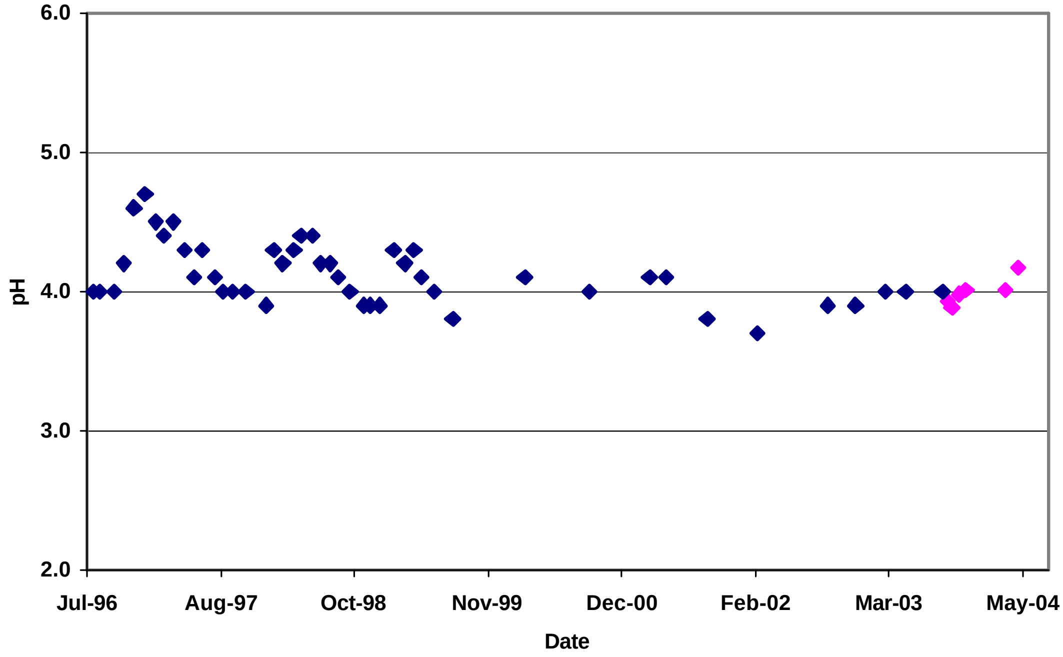


Figure 15: pH vs. time for Gowen Mine discharge

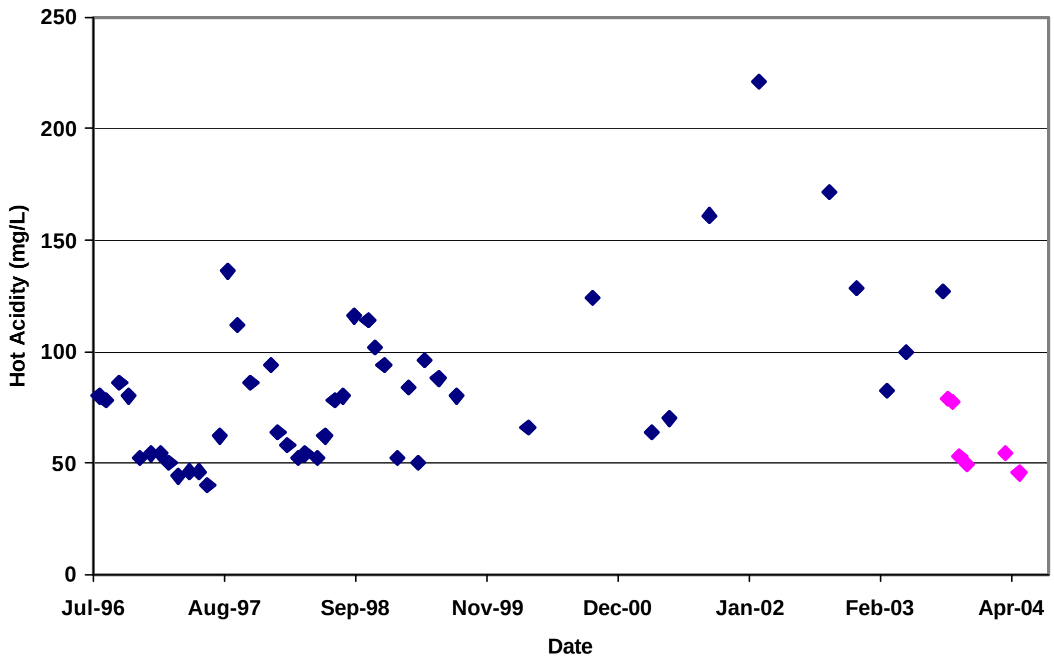


Figure 16: Hot acidity vs. time for Gowen Mine discharge

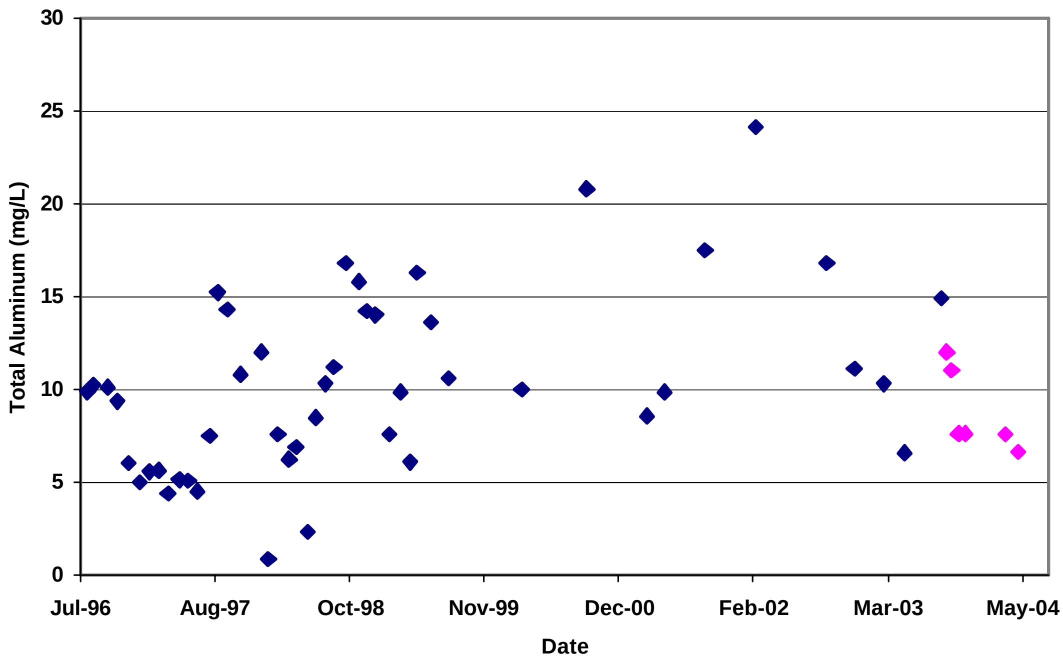


Figure 17: Total aluminum vs. time for Gowen Mine discharge

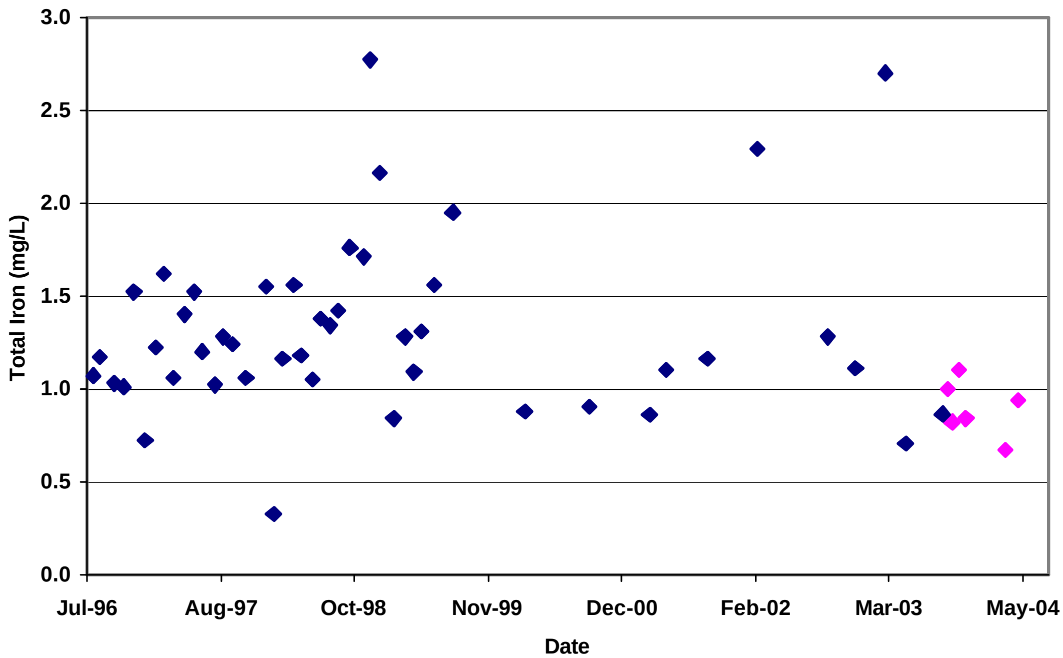


Figure 18: Total iron vs. time for Gowen Mine discharge

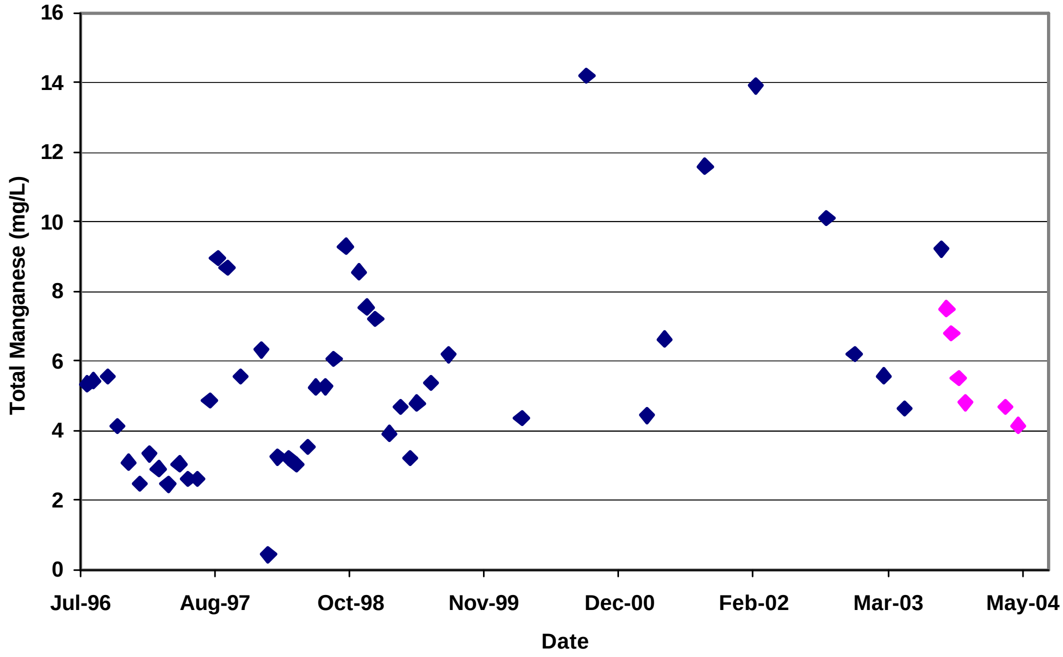


Figure 19: Total manganese vs. time for Gowen Mine discharge

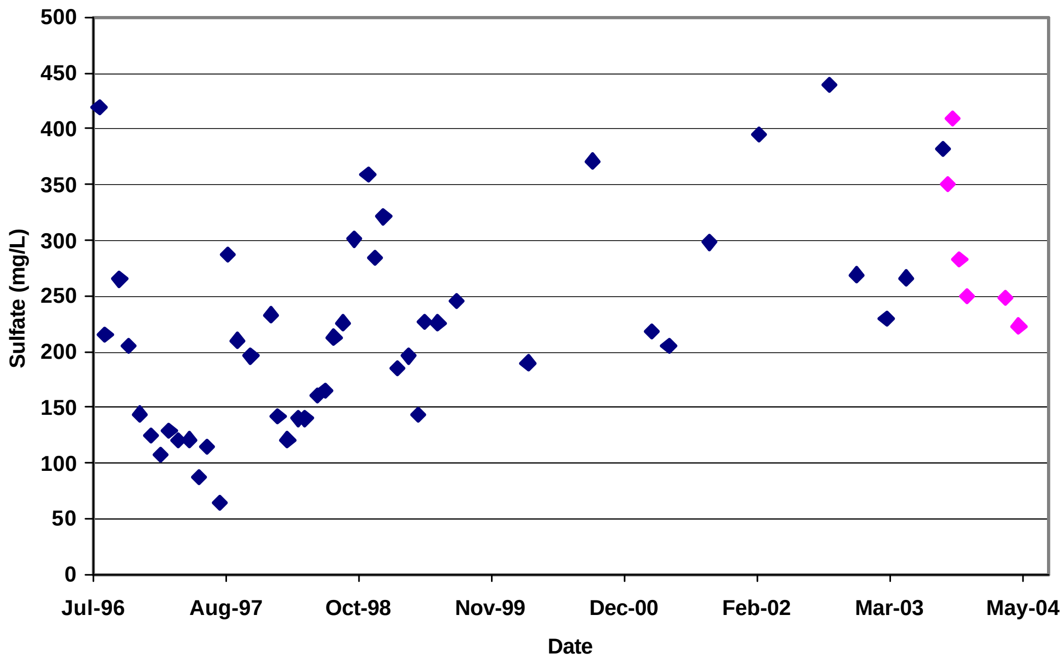


Figure 20: Sulfate vs. time for Gowen Mine discharge

Summary of Water Quality Analyses

The water quality analyses conducted in this study showed that the major sources of AMD pollution in Black Creek and the Little Nescopeck and Nescopeck Creek were large discharges from mine drainage tunnels, which emit toxic loads of acidity and metals to the receiving streams. All of the sites in this study that were located downstream of these discharges violated PA water quality criteria for pH, acidity and concentrations of metals, and required load reductions in order to meet the criteria 99% of the time as required by PADEP. Lesser sources of AMD contamination such as unidentified seeps exist in these streams, which also led to degradation of water quality within the streams.

The dominant effect of the tunnel discharges on water quality in the Nescopeck watershed is illustrated in Figures 21 and 22. Figure 21 shows the average loadings of hot peroxide acidity in pounds per day during the study period, for the following sites: Nescopeck upstream from the Little Nescopeck, Jeddo Tunnel, all of the tributaries in the Black Creek watershed upstream from the Hazleton publicly owned treatment works (POTW), the combination of the Hazleton POTW and immediate downstream remediated sites, the combination of Gowen and Derringer discharges,and finally the Nescopeck downstream from both the Little Nescopeck and Black Creek. Figure 21 shows the average metals loadings for the same sites.

These figures are used to emphasize that in order for all sections of Black Creek and the Little Nescopeck and Nescopeck Creek to become compliant with the governing water quality standards, treatment or neutralization of the large tunnel discharges must be undertaken. Although historical data for the Jeddo Tunnel discharge shows that the water quality of the discharge has improved with time, this AMD source must be treated to produce acceptable water quality in downstream sections of the Little Nescopeck and Nescopeck Creek. Water quality of the Gowen Mine discharge may have decreased with time, thus the need to address this source to improve water quality in the Black Creek. The results of TMDL analyses performed in this study indicated that the reduction of AMD pollutant loads from the tunnel discharges will satisfy most of the reductions required at downstream locations, with only minor additional load reductions necessary at a few locations. However, complete treatment of the tunnel discharges may prove costly or impractical, and alternative treatment methods should be considered. Alternative strategies that may be implemented to reduce AMD pollution to and improve water quality in Black Creek, Little Nescopeck Creek, and Nescopeck Creek are identified later in this report.

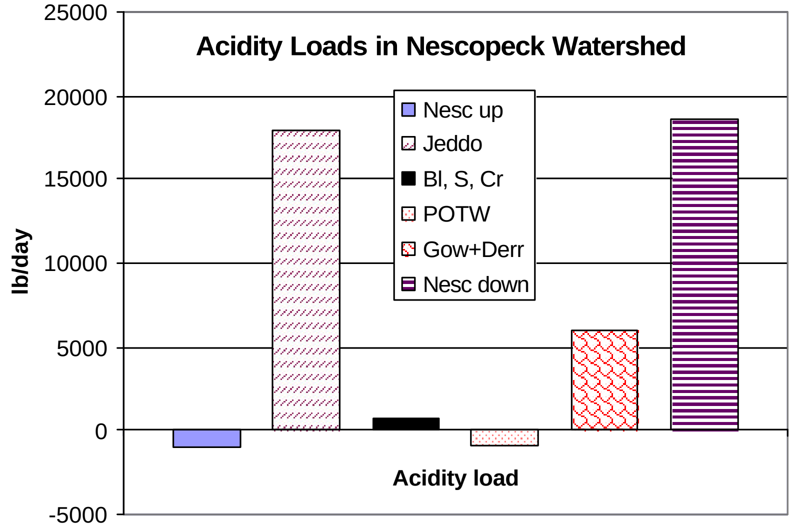


Figure 20. Hot peroxide acidity loading (lb/day) for the following: Nescopeck upstream; Jeddo Tunnel; sum of loads from Sandy, Cranberry, and Black upstream from the POTW; Hazlton POTW plus downstream remediated sites; Gowen and Derringer; and the Nescopeck downstream from the Little Nescopeck and Black Creek discharges.

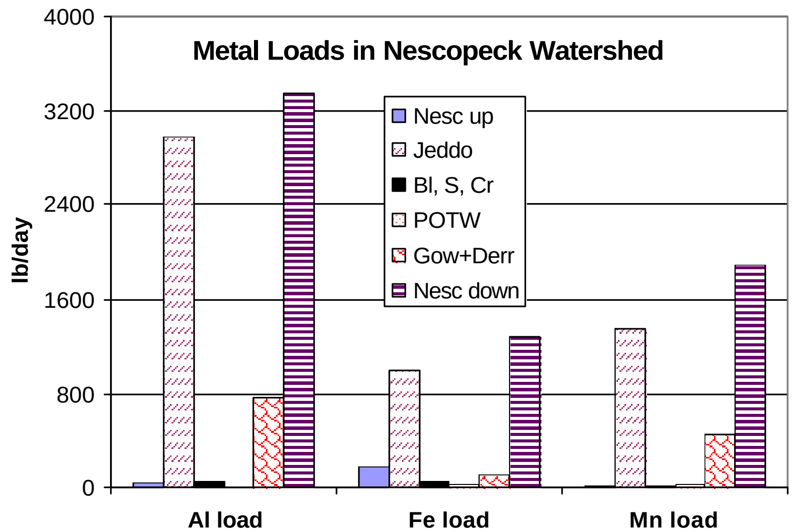


Figure 21. Loadings (lb/day) of Al, Fe, and Mn for the sites described in Figure 20.

AMD Abatement Strategies for Black Creek and Nescopeck Creek

The results of the water quality study of Black Creek, the Little Nescopeck, and Nescopeck Creek indicated that segments of these streams contained significant AMD pollution and violated the PA water quality criteria. Several strategies could be used to decrease the loading of pollutants entering the Little Nescopeck and Black Creek. Some of the strategies are currently used within the study area (e.g., mine reclamation, re-mining, and land development), but the impacts of these remediation efforts on surface water quality has not been quantitatively determined. Other strategies could also be considered, especially regional management of alkalinity and acidity by using existing wastewater treatment plants or direct treatment of the mine pools. It is recommended that several of the proposed strategies should be the focus of additional study to determine the cost, optimal design, and potential effect of remediation activity on surface water quality in the study area.

Conventional treatment and remediation schemes include active and passive treatment technologies and the reduction of AMD formation through abandoned mine reclamation and remining activities. Passive treatment strategies could be implemented on upstream sections of Black Creek and its tributaries, and this would reduce generation and transport of AMD contaminants into the stream in these segments. However, passive techniques are not appropriate for treatment of the tunnel discharges due to high flows and limited space. Active AMD treatment of the tunnel discharges could be implemented, but operation of active treatment systems is both costly and complicated.

<u>Alkaline Injection to Mine Pools</u>

The major sources of AMD pollution to streams in the study area were mine drainage tunnels that drain the coal basins of the Eastern Middle Field. A significant improvement in water quality in the impacted streams is expected if the pollutant loads from the tunnel discharges were removed from the streams. The injection of alkaline materials into the mine pools that discharge through the drainage tunnels may reduce the loads of AMD pollutants added to the Little Nescopeck and Nescopeck Creek.

Underground mine pools in the Hazleton area are fed by groundwater, stream seepage, and precipitation that infiltrates through cave-ins and open pits in the mining areas. Much of the water held in surface pools in the mined areas also infiltrates to underground mine pools. Nine major mine pools in the Hazleton basin that contain great quantities of water overflow to the Jeddo Tunnel (Ballaron, et al., 1999). Treatment of the individual mine pools that form the Jeddo Tunnel discharge by alkaline injection involves injecting an alkaline material, preferably solid materials such as coal combustion by-products (fly ash), steel slags, or slurries of lime, through boreholes or mineshafts from the surface into portions of the mine void. Studies have suggested that the addition of alkalinity to underground mine pools may have the potential to neutralize stored acidity, precipitate metals from solution, and reduce further pyrite oxidation by inhibiting bacterial activity (Aljoe & Hawkins, 1993). Metal precipitates would be expected to settle to the bottom of the mine pools as alkaline water is discharged. An advantage of this procedure is that the effect of alkaline reagent addition on water quality can be monitored prior to addition of the next aliquot of the material. The injection of alkaline materials into the mine pools may prove less expensive than construction and maintenance of AMD treatment facilities. Fixation of atmospheric CO_2 could be a secondary benefit of this strategy, since the recommended neutralizing agents all contain hydroxide alkalinity and could react with CO_2 to produce bicarbonate alkalinity.

One location where alkaline materials may be injected into a mine pool that overflows to the Jeddo Tunnel is the Hazleton Shaft, which passes through the coal beds of the Hazleton basin. Tunnel X of the Jeddo complex intersects the Hazleton Shaft. Since the flow in Tunnel X constitutes a large portion of the total flow at the mouth of the Jeddo Tunnel, neutralizing AMD waters that discharge through this tunnel section may serve to reduce pollutant concentration at the mouth of the Jeddo complex. Injections of alkaline materials to the remaining mine pools draining to the Jeddo Tunnel may also reduce loads of AMD pollutants in the Little Nescopeck and Nescopeck Creek. Additional research and field studies are necessary prior to the implementation of alkaline injections as a method of reducing AMD pollution in the impacted streams.

<u>Reclamation of Mined Lands Near Hazleton</u>

Reclaiming abandoned and active mine sites surrounding Hazleton may significantly improve water quality in the AMD impacted streams. Restoring the mine lands in the Hazleton area would have impacts on water quality and stream flow in all of the stream monitoring locations that were included in this study. The backfilling of open pits and reestablishment of surface drainage and vegetation would decrease the flow of water into the tunnel complexes and reduce the loads of AMD pollutants added to the receiving streams. Reclamation of the mine lands may reduce the flow of water into the mine pools and tunnels, but may also lead to an increase in flow in the surface streams exiting the coal basins resulting in a decrease of AMD pollutant concentrations in these streams from dilution with the surface water. AMD pollutant loads emanating from the Jeddo Tunnel may be reduced as a result of reclaiming mine lands in the tunnel's drainage basin. Ballaron et al. (1999) identified 29 areas where surface water directly enters the Jeddo system. The reader is referred to this source for a description of the problem areas and suggested remediation measures to eliminate their impact on the Jeddo system. Eliminating these sources of water would reduce the amount of flow in the tunnel complex and result in a reduction of AMD pollutant load in the Little Nescopeck and Nescopeck Creek.

Reclaiming the mined lands in the Jeddo basin would also influence Black Creek and its tributaries. Originally, much of the Black Creek Basin was drained by Black Creek. Mining activities in the basin have resulted in the destruction of much of the stream east of Hazleton, allowing water in the stream to infiltrate to the Jeddo Tunnel. The restoration of mined lands in this area should include reestablishing the Black Creek channel to convey surface water away from the Jeddo' drainage basin. This action would increase stream flow in Black Creek, perhaps diluting the concentration of AMD pollutants in Black Creek at Site #25 and further downstream. Restoration of mined lands in the Hazleton Basin should include reestablishing sections of Cranberry Creek where water infiltrates to the mine workings and subsequently to the Jeddo Tunnel. This would increase stream flow in Cranberry Creek and may lead to a dilution of AMD pollutant concentrations in Cranberry Creek and Black Creek.

PADEP recently began the Cranberry Ridge Abandoned Mine Reclamation Project, which will reclaim 186 acres of abandoned mine lands in the Hazleton Basin (PADEP, 2004). The project will include backfilling of abandoned strip pits, elimination of 3800 linear feet of highwall, reestablishment of vegetation, and installation of drainage ditches and pipes to convey storm water runoff.

The Hazleton Community Area New Development Organization (CAN DO) has also worked to rehabilitate the abandoned mine lands surrounding Hazleton by developing the lands for industrial and recreational uses. Their projects have included efforts to reclaim the abandoned mine lands by backfilling strip pits, removing refuse piles, and reducing infiltration of water to the mine pools by closing boreholes and mine shafts and channeling surface discharges to existing streams (John Ackerman - CAN DO Director of Operations, personal communication, June 2004). CAN DO is currently working with PADEP on their Cranberry Ridge project and will create a recreational area and business park in the Cranberry Basin which will further reduce surface water flow into the Jeddo complex.

Coal Contractors, Inc. is currently reclaiming the Gowen Mine as part of remining requirements (personal meeting, 3/24/04), which will help to restore water quality in Black Creek. The reclamation of the Gowen Mine will include the restoration of Roberts Run, a stream that originally flowed through the center of what is now the Gowen Mine. The stream was destroyed by mining activities and is presently a source of water to the Gowen Mine pool. Restoring the stream channel will reduce infiltration to the mine pool and subsequently reduce the flow and pollutant loading from the mine's tunnel discharge. Other reclamation activities which will be performed at the site include eliminating highwalls, construction of drainage channels to maintain surface water flow, removal and reclamation of silt and refuse storage areas, and the construction of surface water erosion and sedimentation controls and wetland areas to maintain and enhance water quality. The discharge from the Gowen Mine is of poorer water quality than the discharge of the Derringer Tunnel, which drains a reclaimed mining area. Reclaiming the Gowen Mine should reduce flow into the mine pool and improve water quality of the discharge and subsequently reduce AMD pollution in Black Creek.

Addition of Excess Alkalinity at Existing Wastewater Treatment Plants

It was shown that the water quality in Black Creek is significantly improved dueto the addition of excess alkalinity at the Hazleton POTW. This demonstrates the possibility of executing a regional strategy and using existing locations and facilities to counteract acidity in the stream or that might enter downstream. This strategy is analogous to pumping alkaline groundwater into acid streams (from acid precipitation) during storm events. Adding these reagents to the wastewater discharge also can lead to oxidation of Fe(II) and perhaps of Mn(II) in the stream. Al, Fe, and Mn would be converted to precipitated forms and thus the toxic effects of these metals to the streams would be diminished or removed completely. The use of existing wastewater discharges to neutralize AMD in the study area may prove to be an economical regional abatement strategy, since the incremental cost for improvement of water quality is likely to be less than the cost of constructing new facilities dedicated to treating AMD discharges. Alkalinity dosing rates may be properly controlled at the facilities to maintain the desired downstream water quality.

There are four municipal wastewater treatment facilities near Hazleton that presently discharge treated effluent to the Black, Little Nescopeck and Nescopeck Creek. Wastewater from the city of Hazleton is treated by the Greater Hazleton Joint Sewer Authority. At this facility, a daily wastewater flow of 10 MGD is treated and discharged to Black Creek just downstream of Site #21. Black Creek showed a significant improvement in water quality in sections downstream of the wastewater discharge and upstream of the Derringer and Gowen AMD sources. As a result, a TMDL calculation showed that load reductions of AMD pollutants were not required in this stretch of Black Creek.

The Drums and St. Johns treatment plants are operated by the Butler Township Authority and the Conyngham Borough treatment plant and currently discharge to the Little Nescopeck. The Drums wastewater treatment plant is located on the Little Nescopeck Creek between Sites #5 and #6. The water quality study showed that a reduction of all AMD pollutant loads is experienced at Site #5 from upstream Site #6, suggesting that the present alkaline wastewater discharge from the Drums treatment plant neutralizes a small portion of the acidic load from the Jeddo Tunnel and may result in in-stream oxidation and precipitation of metals. Further neutralization of mine water flowing from the Jeddo Tunnel may be possible by adding incremental amounts of alkalinity to the wastewater discharge at the Drums facility or further down the Little Nescopeck at the Conyngham facility. The St. Johns treatment facility discharges to Nescopeck Creek upstream of the confluence with the Little Nescopeck. Incremental alkalinity addition at this treatment facility could result in water quality improvements in Nescopeck Creek sections impaired by the Jeddo Tunnel discharge. Treatment at these locations would only be useful in the great majority of acidity from the Jeddo Tunnel were already removed by another remediation technique, such as treatment of the mine pool or end-of-tunnel treatment.

Summary and Conclusions

The following results and conclusions were derived from the work performed at Penn State.

- Twenty-eight sample sites were investigated in collaboration with the PA DEP Bureau of Watershed Management. The sites included the discharge of the Jeddo Tunnel, discharge of Gowen Mine tunnel, and the Derringer discharge. Flow and concentrations permitted calculation of loadings into the Little Nescopeck, Black, and Nescopeck of acidity, sulfate, iron, aluminum, manganese, and total suspended solids.
- The dominant sources of contaminants in the studied basins were (from largest to smallest) the Jeddo tunnel, Gowen mine, Stoney Creek and Cranberry Creek discharges, upstream Black Run discharges, and Derringer discharge.
- There was net improvement in water quality related to mine drainage parameters due to discharges from the Hazleton area POTW and from other waste treatment facilities for sanitary sewage. In particular, the Hazleton area POTW added sufficient alkalinity to the stream to overcome upstream pollution and to make Black Creek compliant with PA DEP water quality standards for mine drainage for several downstream miles.
- Several remediation, remining, and redevelopment efforts are underway within these watersheds. This study has provided a baseline that may be used in the future to identify the effects of these works on water quality and on the loading of pollutants to surface waters.
- The data from the tunnel discharges indicated continuing improvements in water quality and decreases in the total load of pollutants discharged from these locations. The data set that was accumulated during this study was important because there had been a recent gap of several years during which no flow measurements had been made on some of these discharges.
- The Jeddo tunnel contributes most of the load of mine drainage pollutants into the Nescopeck. There was a positive correlation between flow and total pollutant load, and therefore a decrease in infiltration or direct entrance of storm water into the mine pool will result in decreased loading of pollutants to the Nescopeck.
- The discharge drains from a massive but unstudied mine pool. A spatial characterization of the concentration and load of contaminants within the mine pool is needed.

- A wide range of treatment and remediation options should be considered for the tunnels or tunnel discharges. Treatment options should include in-situ treatment, such as by discontinuous titration of the acidity in the mine pool using slag, fly ash, or other alkaline material. The discharges could also be treated using conventional active or passive processes or using novel treatment processes that have been developed at Penn State and result in more concentrated and pure sludges. Any of the mouth-of-the-tunnel treatment techniques would be expensive and would require substantial further study.
- Water quality at the Gowen tunnel and the Derringer discharge seem to be improving, following remediation activities. Monitoring at these sites should be continued. The mine pool at Gowen should be investigated in a manner analogous to the recommendations for the Jeddo tunnel, to determine whether in-situ treatment should be considered. The effects of remediation, remining, and redevelopment activities at the other sources of mine drainage should also be monitored.
- POTWs are examples of existing infrastructure that could be used to assist in treating the mine drainage (for soon-to-be abandoned treatment facilities such at Drums) or for counter-acting the effects of mine drainage through addition of excess alkalinity.

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