FLOW MEASURMENT, SITE RECONOSANCE,
AND
PROPOSED REMIDIAL ACTION
FOR
MINE DISCHARGES
IN THE
LOWER DUNKARD CREEK WATERSHED

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Executive Summary

Mining of the Pittsburgh and Sewickley coal seams in the lower Dunkard Creek valley has resulted in discharges of acid mine drainage to Dunkard Creek. Periodically, under low flow conditions, these discharges result in fish kills in Dunkard Creek, and have led to a serious degradation of the water quality in the last six miles of Dunkard Creek. The purpose of this study is to gather mine maps in the study area, perform a site reconnaissance to determine site hydrology, measure the discharge volume from the mines, use water quality data collected by the Greene County Conservation District to calculate acid loads from the discharges, and based on the extant hydrology and the acid loads recommend remedial action to minimize or eliminate the pollution load to Dunkard Creek.

Mines in the Dunkard Creek Valley include Maiden #1, Maiden #3, Maple Sterling, Moffet Sterling, Walnut Hill, Shannopin, Valley Bend, Poland Mines, and portions of Rosedale mine. Mine maps of these Pittsburgh seam mines were obtained from various sources, geo-referenced and combined into a single map shown in Plate 1.

Site reconnaissance has revealed: a large sink hole which allows direct flow of surface water into the mine; numerous open mine entries; an open slope; and a previously undocumented mine discharge. These mine openings pose a significant safety hazard and support the continued production of acid mine drainage. The Office of Surface Mining, Reclamation and Enforcement (OSMRE) is charged with the elimination of safety hazards posed by mining, and may be a source of funds for some of the proposed remedial action. In addition many reclaimed surface mines were observed at the Sewickley horizon; however, these mine were not observed to have any water discharges.

Interpretation of the mine maps, the discharge locations, and the available mine water level data has led to the identification of probable mine recharge areas. These recharge areas have been utilized in the proposed reclamation plan where *in situ* methods are indicated.

Hydrologic monitoring consisted of the purchase of four, and the installation of five H-flumes at sites 2A, 2B, 4, 7, and the sink hole. Site 2B and the sink hole were equipped with recording pressure transducers that recorded the water level every 20 minutes. All of the other sites were measured during site visits. These water level data were converted into flows. The flow data was combined with the water chemistry data to provide acid loads for each discharge. These acid loads form the basis for the proposed remedial action.

Conventional solutions have been proposed for sites 4 and 7 because there is sufficient flat land available at these sites to accommodate conventional treatment. *In situ* solutions are proposed for sites 2A, 2B and 6 because there is little land available at these sites for a conventional system. The *in situ* treatment proposal has been combined with the sealing of the mine openings so as to reduce the overall cost of the project and to reduce future acid mine drainage formation.

Introduction

The Dunkard Creek watershed encompasses 234.65 square miles in Greene County, Pennsylvania, and Monongalia County, West Virginia (Greene County Conservation District, 2000). Only the last 6.2 miles of the main stem of Dunkard Creek are impacted by acid mine drainage. The Rivers Conservation Plan for the Dunkard Creek Watershed (Greene County Conservation District, 2000) has identified eight mine discharges as the primary cause of degradation in the stream from Taylortown to the mouth of Dunkard creek at the Monongahela River.

Mining in the Dunkard Creek watershed has been very extensive on both the Pittsburgh seam and the Sewickley seam. The Pittsburgh seam outcrops in the Dunkard Creek valley and dips to the west. Just upstream of Taylortown, Pennsylvania the Pittsburgh seam descends below the elevation of Dunkard creek itself. All of the mine discharges that impact Dunkard creek are down stream of this point. Although the Sewickley seam, which lies 90 to 120 feet above the Pittsburgh seam, is extensively mined, all of the mine discharges are from underground mines in the Pittsburgh seam.

The purpose of this study is to identify the extent of mining that is contributing water to Dunkard creek, determine the seasonal variation in flow from the significant discharges, determine the metals and acid load from these discharges, and to make recommendations for future remedial action in the watershed.

Mine Maps

Mine maps for Pittsburgh seam mines in the area were obtained from the Pennsylvania DEP mine map repository as well as from coal mine operators in the area. These mine maps were scanned and geo-referenced to the United States Geological Survey (USGS) topographic maps of the Morgantown North, and Masontown quadrangles. Geo-referencing is the process of aligning the scanned image to the topographic base map or to some known geographic coordinate. This allows the scanned image to be represented on the same map as the topographic data. Additional scanned and geo-referenced maps were added to form a composite image of the Pittsburgh seam mining in the Dunkard creek area. Plate 1 is a plot of this underground mining in relation to the surface topography. Mines shown in this plate include the Maiden #1, Maiden #3, Maple Sterling, Moffet Sterling, Walnut Hill, Shannopin, Valley Bend, Poland Mines, and portions of Rosedale mine. Several unnamed mines are also included in this coverage.

Mine Discharges

Eight Mine discharges were identified in the Rivers Conservation Plan for the Dunkard Creek Watershed (Greene County Conservation District, 2000). These discharges range in flow from seeps to high volume discharges in excess of 347 gallons per minute (Greene County Conservation District, 2000). The water quality at these sites ranges from low pH, acidic discharges, particularly from the Maiden #1 mine complex to a neutral pH, net alkaline discharge from Maiden #3 mine. For the purposes of this study, these discharges were ranked according to their impact on Dunkard Creek. Based on this ranking project resources were focused on the most serious impact(s) to the watershed. Table 1 contains these rankings.

Table 1
Adapted from Greene County Conservation District, 2000

Discharge	Iron Load	Aluminum Load	Acid Load	Ranking
2A – 2B	36.54	31.97	220.75	1
4	17.77	8.17	128.64	2
7	21.14	0.13	20.24	3
6	8.38	14.83	121.25	4
8	10	.11	39.37	5
5	N/A	N/A	N/A	6
3	N/A	N/A	N/A	7
1	N/A	N/A	N/A	8

Additional weight was given to site 7 due to its high iron loading, potential for treatment, and the resulting significant stream discoloration from this discharge.

Site Reconnaissance

The surface area overlying the study area was observed both by vehicle and by foot in an effort to identify locations where water was infiltrating into the mines and sites where a surface facility(s) could be constructed that would support the addition of alkalinity to the ground water flow system. Surface land owners were contacted and were helpful in locating a large sink hole, stream loss from Crooked Run into Maiden # 1, an abandoned entrance to the Shannopin mine upstream of Taylortown, a previously unidentified discharge to Dunkard Creek, and an abandoned slope into Maiden #1 mine.

A large sink hole was located at in the valley of an unnamed tributary to Dunkard Creek. The sink hole is located east southeast of the old Taylortown School at coordinates are presented in Appendix A. The sink hole is about 40 feet by 63 feet and about 20 feet deep. It is estimated to have a volume of 900 cubic yards. Water, in the unnamed tributary, drains into the sink hole on a continuous basis. This sink hole presents an opportunity for *in situ* treatment of the Site 2 discharges consequently it was decided to monitor the flow going into the mine at this location.

Crooked Run overlies the Shannopin and Maiden #1 mines. The stream and ponds built into the stream are reported to drain water into the Maiden #1 mine. While no sink hole exists at this location, significant water loss is believed to occur from this stream reach. A site visit during a spring recharge event in 2002 revealed large volumes of water flowing into one of these ponds with no discharge occurring. This may only indicate that the pond is refilling following a dry period, but it also indicates that the pond leaks, and with the Maiden #1 mine only 100 feet below the pond leakage to the mine is anticipated. An abandoned entrance to the Shannopin mine was identified about ten feet above stream elevation upstream of Taylortown. The entrance is sealed and no water is flowing from it. The elevation of this entrance was determined to be about 840 msl. This elevation is higher than the elevation of the Shannopin mine pit mouth at elevation 821ft. msl. Consequently, no discharge from Shannopin mine is expected at this location. Although no discharge is expected, it may be possible to utilize this mine access point if a unified treatment plan is adopted. This potential option will be discussed in the water treatment section.

While investigating this mine opening, a previously unidentified mine discharge was observed on the opposite bank of Dunkard Creek. This discharge appears to be associated with the abandoned Pittsburgh seam surface mining operation, and lies at the down dip extreme of the mining operation. This discharge is located upstream of the site

1 discharge which was visited and found to be dry. Lisa Bennett was made aware of this site for future monitoring. The approximate location is 39°44.527 N by 79°59.019 W.

An abandoned open slope was identified in the same unnamed tributary that contains the sink hole. Coal was apparently extracted from this site after the main mining of Maiden #1 was completed. It is believed that this operation may have removed the remaining coal pillars in this portion of the mine. This pillar removal could have lead to the collapse of the sink hole. The stream segment between the slope and the sink hole was walked to see if any other features could be identified. While no large features were observed it was evident that this unnamed tributary is leaking water into the mine based on reduce to no flow conditions in the creek. Overburden thickness is this stream reach is between 10 and 50 feet. The slope dimensions are about 12 feet wide by 8 feet high.

Unsealed mine openings were observed at five locations. These sites pose serious health and safety issues. The previously mentioned sink hole and mine slope sites have the potential for injury or death from falling, collapse, or asphyxiation. The Greene County Conservation District has installed protective fencing around the sink hole however this is only a temporary measure. In addition to these sites the drift entries at site 2, site 4, and the Shannopin supply yard pose a similar danger of falling, collapse, or asphyxiation. These sites and the mine slope are currently unprotected. The Office of Surface Mining is charged with the elimination of these health and safety issues, and they have the funding necessary to eliminate the risks. OSM also has a role in watershed improvement and can provide funding of up to $100,000.00 for water quality remediation. It is possible that these two responsibilities can be applied at these sites. The potential role of OSM will be discussed in the remediation section.

The mine entrances to Moffitt Sterling, Maple Sterling, and Poland Mines were found to be sealed. The mine entrances to Maiden #1 in Monongalia County, West Virginia were found to be sealed and a discharge from Maiden #1 was also found along Rt. 100 in West Virginia. This discharge will be discussed in the section on mine hydrology. A sealed Maiden #1 ventilation shaft was found near Taylortown, and an open abandoned borehole into Maiden #1 was identified on the Lilly property south of the state line in West Virginia.

Discharge Flow

Four H-flumes were purchased by the Greene County Conservation District on behalf of this project. These flumes were installed at site 2A, 4, 7, and up stream of the sinkhole. A 2 foot H-flume supplied by the contractor was installed at site 2B. Continuous water level recorders were purchased at contractor's expense and installed on the H-flumes at site 2B and the sink hole. Water level measurements were made at all these sites on a periodic basis. These data were combined with flow measurements made at the same sites by a master's degree student at West Virginia University that pre-date the current study.

Chart 1 shows the hydrograph of Site 2B. Maximum flow was 1,248 gpm on April 12, 2001, and the minimum flow of 130 gpm was observed between December 27 and 30 2001. This discharge exhibits rapid response to precipitation on top of a significant seasonal variation. Part of the rapid response is due to the co-mingling of surface water with the deep mine effluent. This co-mingling occurs from three sources. The first is water that flows into the mine at the sink hole, the second is surface water inflow at the slope, and the third is water that flows into the mine at the road culvert at Taylortown. Efforts to exclude the road culvert water from the mine discharge were only partially successful. Channel improvements that were made to direct the culvert flow away from the mine were washed out and the surface flow returned to the mine just upstream of the discharge. Consequently peak flows are influenced by this source. Options for dealing with this water will be discussed in the remediation section.

Site 2A is located about 250 feet south of site 2B. This discharge is much smaller than 2B and is believed to originate in the same mine. Chart 2 shows the discharge volumes that were observed at this site. A minimum flow of 11.5 gpm was observed on May 9, 2001, a maximum flow of 141 gpm was observed on April 23, 2002, and the average observed flow from this site was 44.8 gpm. Site 2A is 8.8 percent of site 2B's low flow and 11.3 percent of site 2B's high flow. For the purpose of *in situ* treatment calculations these two flows must be combined.

The stream flowing into the sink hole was monitored to determine the inflow rate to the mine from this source. Chart 1 shows the hydrograph from this site. Flows into the sink hole ranged from zero to 97.8 gpm. The average flow in the dry season as measured between September 7 and October 31 2001 was 3.07 gallons per minute. The average high flow value between April 29 and May 28 was 20.5 gpm. The average flow value between May 28 and June 21, 2002 was 6.18 gpm. These flows represent 1.28%, 3.38%, and 0.976% respectively of the discharge at site 2B during these time periods. Based on these data, sealing of the sink hole, for the sole purpose of preventing water infiltration, will not be effective at reducing the mine discharge at site 2.

Site 4 discharges from the Maiden #1 mine downstream from Taylortown. The discharge emanates from a partially collapsed drift entry into the mine. Some water is impounded behind the rubble. The water flows across the mine bench and cascades over the bank into a volunteer wetland that has formed in and abandoned oxbow of Dunkard Creek. A 1.5 foot H-flume was installed at this location and the discharge volume is presented on chart 3. Flows measured at this site ranged from a low of 41.8 gpm on December 27, 2001 to a high of 570 gpm on March 18, 2002. Since this site was not monitored on a continuous basis these maximums and minimums may not represent the full range of variability at this site. Despite this limitation, a high flow of 522 gpm was observed at site 4 on the same day that site 2B was reaching its spring 2002 peak flow that was not dependent on an ongoing precipitation event.

The discharge at site 7 originates in the Maiden #3 mine. Access to the site is quite difficult. The discharge occurs on a steep embankment directly above Dunkard Creek. Flume installation at this site was hampered by the lack of any horizontal flow channel. Installation was finally achieved right at the point of discharge. Discharge from this site has been measured at 233 gpm on December 9, 2000; 538 gpm on April 30, 2001; with and average flow of 342 gpm. Flows prior to April 2002 were measured via the bucket and stop watch technique. Chart 4 shows the flow measured at site 7.

The discharge volume from site 6 was not measured during this study. Field recognizance revealed that there are numerous discharges occurring from the coal outcrop in this area and upstream of this area. The large number of discharge points made it unpractical to measure the flow in this area of the mine.

Chart 1

Site 2B with Sink Hole

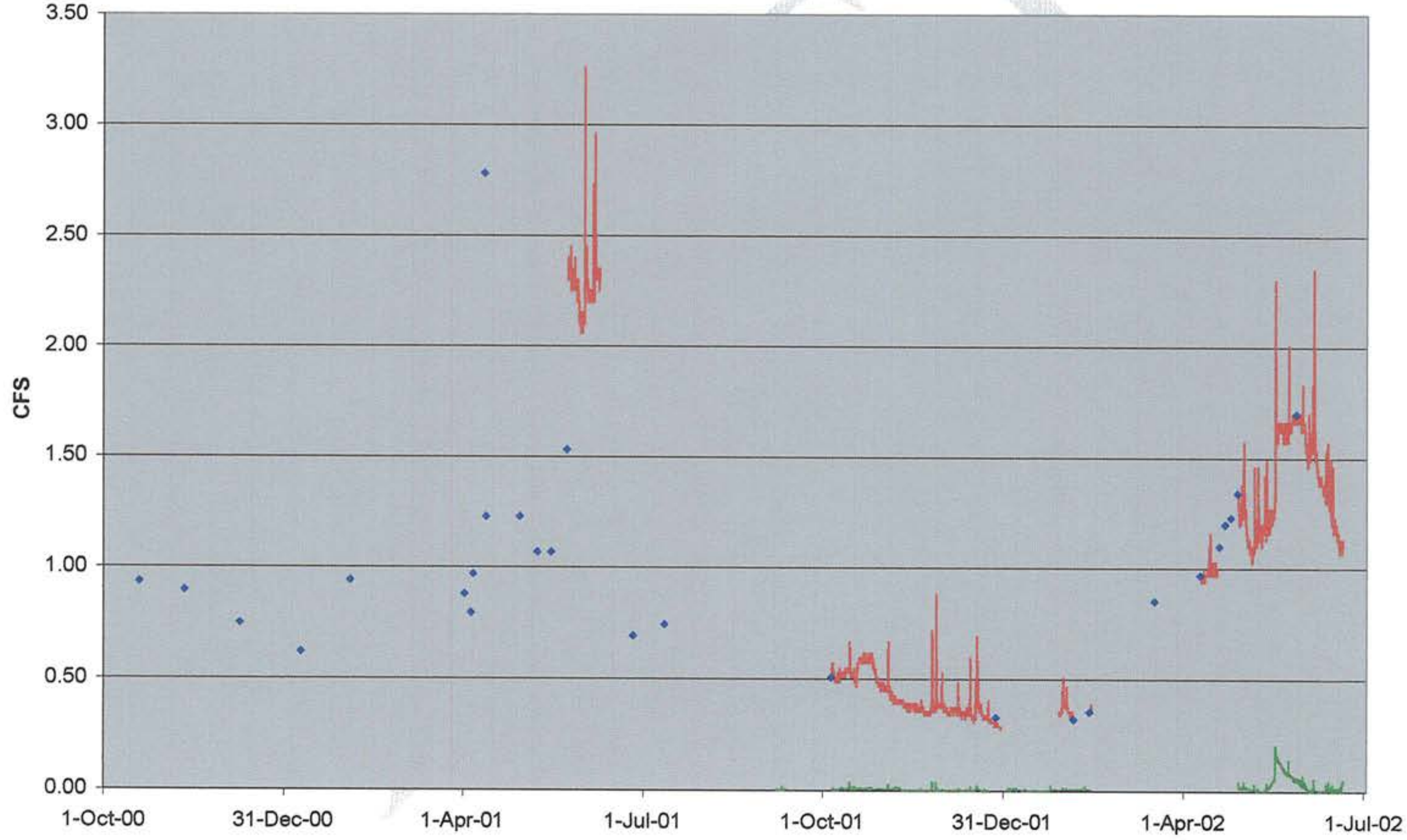


Chart 2

Site 2A

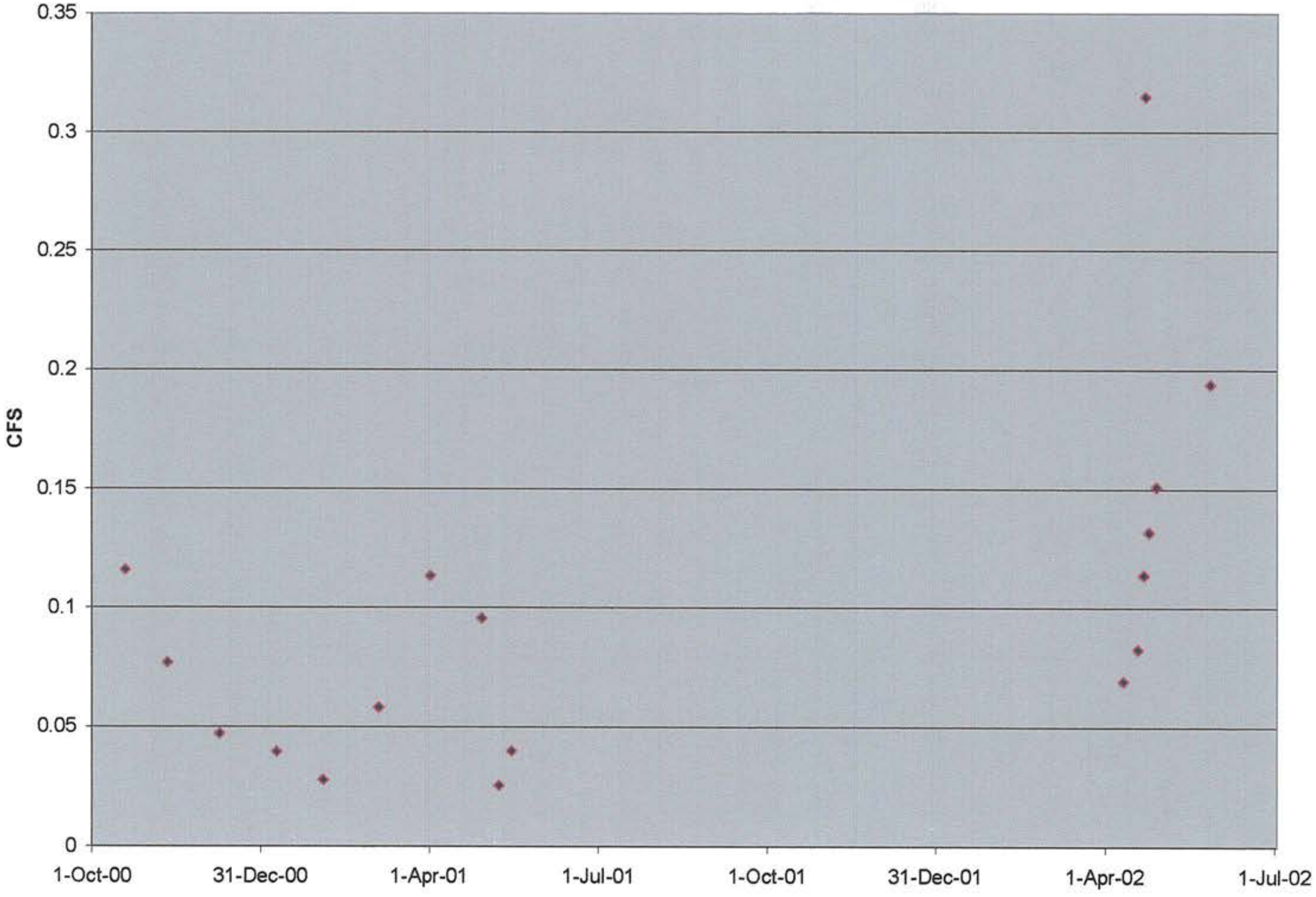


Chart 3

Site 4

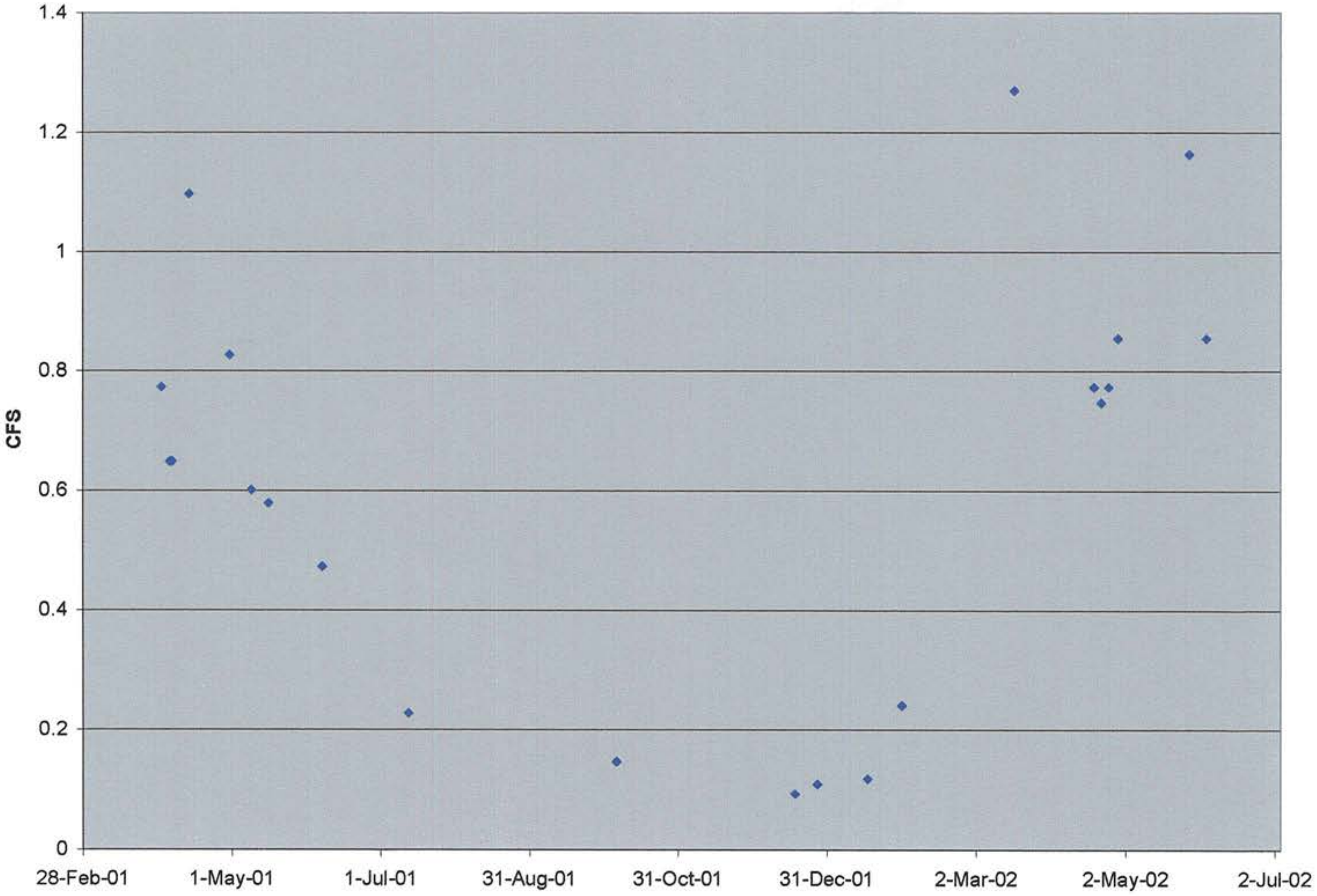
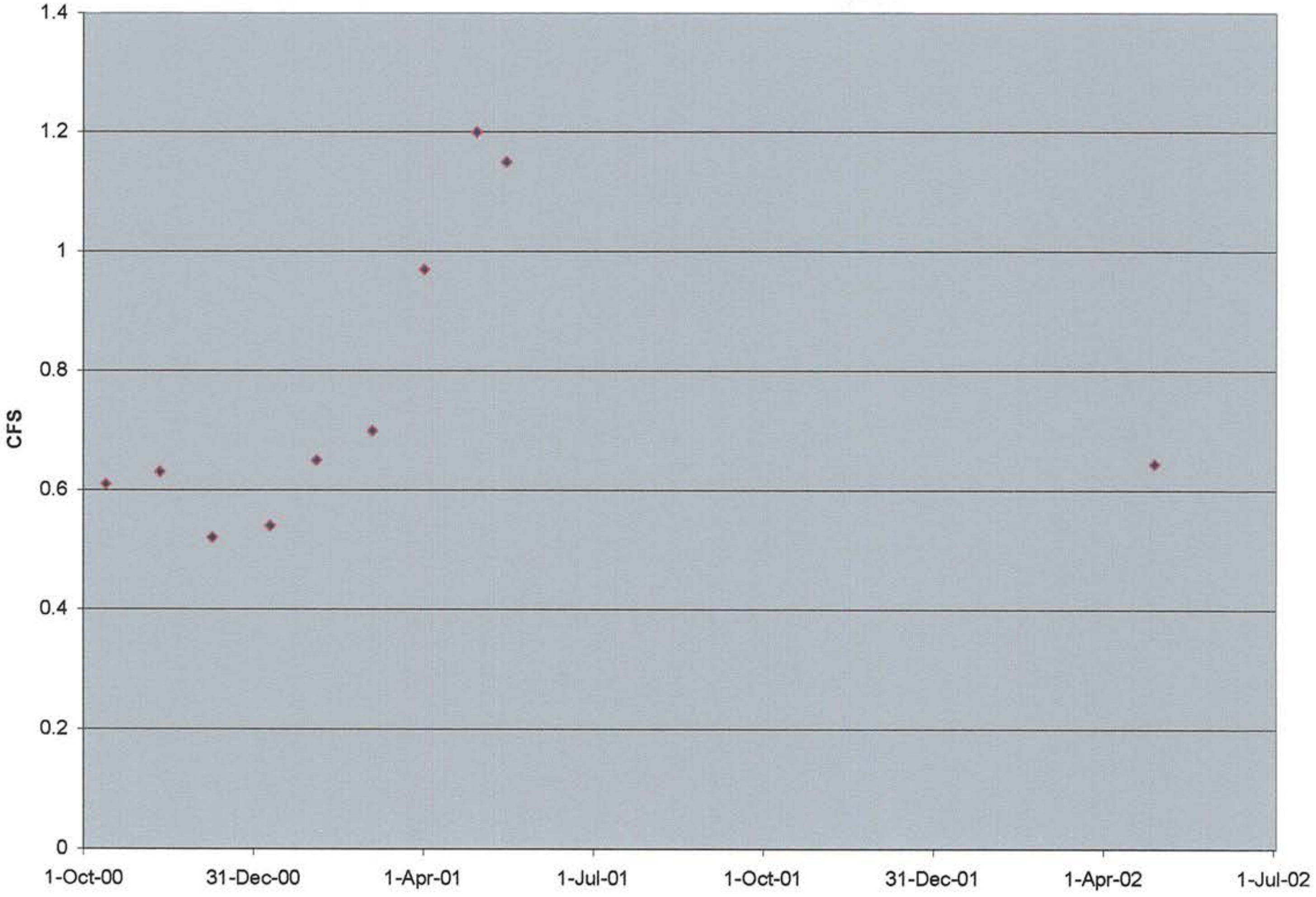


Chart 4

Site 7



Discharge Chemistry

The Greene County Conservation District has been taking samples from these sites on a periodic basis. The samples have been analyzed by the Pennsylvania State laboratory. Sampling was not conducted in conjunction with flow data collection. Tables 2 thru 7 contain the results of this analysis. These data are also shown graphically for site 2B, site 4, and site 7 in Charts 5 through 7 respectively

Table 2

SITE 2A

Sample ID	Date	pH	Al Acidity mg/l	Metal Acidity mg/l	Acid mg/l	Alk mg/l	Net Acid mg/l	Fe mg/l	Al mg/l	Mn mg/l	SO4 mg/l	Na mg/l	TSS mg/l
4135-006	6/26/2000	3.2	174.02	225.10	302.0	0	302.0	24.4	31.3	4.06	1525.0	41.9	<3
4135-015	7/25/2000	3.1	170.68	234.59	340.0	0	340.0	31.5	30.7	4.12	1562.8	41.6	<3
4135-023	9/5/2000	4.6	80.62	104.17	88.0	12	76.0	11.1	14.5	2.02	948.8	34.7	<3
4135-031	1/24/2001	3.1	210.16	310.83	492.0	0	492.0	50.8	37.8	5.33	1578.0	43.2	12
4135-041	3/1/2001	3.7	105.63	151.04	128.0	0	128.0	23.3	19.0	2.02	1140.0	40.2	42
4135-051	4/4/2001	4.5	66.72	93.34	60.0	8.6	51.4	13.1	12.0	1.74	981.3		58
4135-059	6/14/2001	3.8	100.63	147.63	126.0	0	126.0	23.5	18.1	2.70	1111.6		48
4135-064	7/11/2001	3.5	128.43	171.41	209.2	0	209.2	20.9	23.1	3.05	773.0		60
	2/12/2002	3.5	121.76	175.04	230.2	0	230.2	26.9	21.9	2.81	1041.7		108
	Average		128.74	179.24	219.5		217.2	25.1	23.2	3.09			
	Percent Al Acidity		71.82%										

Table 3

Site 2B

Sample ID	Date	pH	Al Acidity mg/l	Metal Acidity mg/l	Acid mg/l	Alk mg/l	Net Acid mg/l	Fe mg/l	Al mg/l	Mn mg/l	SO4 mg/l	Na mg/l	TSS mg/l
4135-016	7/25/2000	3.1	166.23	215.41	300.0	0	300.0	23.7	29.9	3.70	1328.2	41.0	6
4135-024	9/25/2000	3.0	200.15	281.13	436.0	0	436.0	40.2	36.0	4.94	1505.2	46.8	<3
4135-032	1/24/2001	3.2	190.70	299.52	406.0	0	406.0	55.3	34.3	5.38	1521.0	49.1	16
4135-042	3/1/2001	3.2	177.91	275.70	268.0	0	268.0	51.2	32.0	3.35	1390.0	46.7	34
4135-045	4/4/2001	3.0	157.34	234.66	368.0	0	368.0	38.5	28.3	4.60	1789.0		16.0
4135-060	6/14/2001	2.9	165.68	229.62	372.0	0	372.0	30.9	29.8	4.73	1628.4		10
4135-065	7/11/2001	3.1	195.14	261.98	397.4	0	397.4	32.4	35.1	4.84	1274.9		14
4135-090	2/12/2002	3.2	204.6	308.95	474.8	0	474.8	53.1	36.8	5.09	1687.7		8.0
	Average		182.2	263.4	377.8	0.0	377.8	40.7	32.8	4.6	1515.6		
	Percent Al Acidity			69.19%									

Table 4

Site 4

Sample ID	Date	pH	Al Acidity mg/l	Metal Acidity mg/l	Acid mg/l	Alk mg/l	Net Acid mg/l	Fe mg/l	Al mg/l	Mn mg/l	SO4 mg/l	Na mg/l	TSS mg/l
4135-005	6/26/2000	3.0	136.77	256.42	424.0	0	424.0	61.5	24.6	5.23	1871.0	28.9	<3
4135-009	7/17/2000	2.9	147.89	280.90	528.0	0	528.0	68.5	26.6	5.68	1485.2	26.3	6
4135-017	7/25/2000	2.9	133.43	246.54	420.0	0	420.0	58.3	24.0	4.78	1477.6	24.4	<3
4135-025	9/5/2000	2.9	133.99	239.43	428.0	0	428.0	54.0	24.1	4.80	1723.7	25.1	<3
4135-033	1/24/2001	3.1	122.31	226.78	388.0	0	388.0	53.0	22.0	5.25	1677.0	37.1	12
4135-039	3/1/2001	2.9	159.56	304.87	416.0	0	416.0	76.3	28.7	4.76	1560.0	34.0	16
4135-049	4/4/2001	2.8	144.00	314.92	492.0	0	492.0	89.7	25.9	5.65	1632.9		10
4135-057	6/14/2001	2.8	118.42	231.92	480.0	0	480.0	58.4	21.3	4.90	1626.6		6
4135-067	7/11/2001	3.0	96.18	233.10	439.6	0	439.6	68.0	17.3	8.32	1474.1		12
4135-95	2/12/2002	3.0	146.22	260.29	458.2	0	458.2	58.3	26.3	5.31	1659.1		<3
	Average		133.9	259.5	447.4		447.4	64.6	24.1	5.5			
	Percent Al Acidity			51.59%									

Table 5

Site 6

Sample ID	Date	pH	Al Acidity mg/l	Metal Acidity mg/l	Acid mg/l	Alk mg/l	Net Acid mg/l	Fe mg/l	Al mg/l	Mn mg/l	SO4 mg/l	Na mg/l	TSS mg/l
4135-003	6/26/2000	3.0	227.95	286.28	418.0	0.0	418.0	26.1	41.0	6.37	1795.0	26.7	<3
4135-014	7/25/2000	3.0	222.94	280.57	406.0	0.0	406.0	26.2	40.1	5.88	1936.2	25.1	4
4135-022	9/5/2000	3.0	223.50	296.78	436.0	0.0	436.0	34.7	40.2	6.12	1443.7	25.4	<3
4135-030	1/24/2001	3.2	179.02	273.89	400.0	0.0	400.0	46.6	32.2	6.27	1442.0	24.6	<3
4135-036	3/1/2001	3.0	192.92	275.97	354.0	0.0	354.0	39.9	34.7	6.37	13.9	25.8	8
4135-046	4/4/2001	2.9	202.37	271.97	414.0	0.0	414.0	32.3	36.4	6.46	1662.0		8
4135-056	6/14/2001	2.9	197.37	245.77	376.0	0.0	376.0	20.9	35.5	6.03	1994.8		8
4135-071	7/19/2001	3.0	236.84	301.98	436.4	0.0		29.4	42.6	6.86	1313.2		8
4135-094	3/14/2002	3.1	186.25	277.53	432.0	0.0		44.6	33.5	6.27	1132.5		8
	Average		207.68	279.0	408.0	0.0		33.4	37.4	6.3	1414.8		
	Percent Al Acidity			74.45%									

Table 6

Site 7

Sample ID	Date	pH	Al Acidity mg/l	Metal Acidity mg/l	Acid mg/l	Alk mg/l	Net Acid mg/l	Fe mg/l	Al mg/l	Mn mg/l	SO4 mg/l	Na mg/l	TSS mg/l
4135-001	6/26/2000	6.1	2.78	240.43	106.0	168	-62.0	130	0.5	4.19	2106	279	24
4135-012	7/25/2000	6.1	2.78	262.00	142.0	170	-28.0	142	0.5	4.23	2104	276	10
4135-020	9/5/2000	6.1	2.78	294.63	182.0	180	2.0	160	0.5	4.45	3092	285	22
4135-028	1/24/2001	6.1	2.78	378.81	256.0	182	74.0	208	0.5	3.47	1914	>300	28
4135-037	3/1/2001	6.1	2.78	391.26	194.0	188	6.0	213	0.5	5.39	1650	324	72
4135-047	4/4/2001	6.1	2.78	305.41	144.0	184	-40.0	166	0.5	4.47	1933		36
4135-054	6/14/2001	6.2	2.78	313.93	132.0	198	-66.0	171	0.5	4.23	2894		32
4135-070	7/19/2001	6.1	2.78	340.15	180.8	200	-19.2	185	0.5	4.86	2890		26
4135-092	3/14/2002	6.1	2.78	453.06	322.0	196	126.0	247	0.5	5.89	2114		30
	Average		2.78	331.08	184.3	185.1	-0.8	180.2	0.5	4.6			
	Percent Al Acidity		0.84%										

Table 7

Site 8

Sample ID	Date	pH	Al Acidity mg/l	Metal Acidity mg/l	Acid mg/l	Alk mg/l	Net Acid mg/l	Fe mg/l	Al mg/l	Mn mg/l	SO4 mg/l	Na mg/l	TSS mg/l
4135-002	6/26/2000	3.2	32.58	183.89	292.0	0	292	76.4	5.86	7.96	2013.2	249	<3
4135-013	7/25/2000	3.4	26.58	260.24	326.0	0	326	123.0	4.78	7.36	3137.1	273	10
4135-021	9/5/2000	3.4	16.85	292.78	354.0	0	354	147.0	3.03	6.97	3271.3	275	8
4135-029	1/24/2001	3.7	4.94	330.68	380.0	0	380	174.0	0.89	7.77	1930.0	281	14
4135-038	3/1/2001	3.7	4.70	399.36	374.0	0	374	213.0	0.85	7.26	1870.0	325	20
4135-048	4/4/2001	3.5	8.45	326.94	408.0	0	408	169.0	1.52	8.70	2490.8		22
4135-055	6/14/2001	3.0	13.90	222.58	*82.0*	0	*82*	108.0	2.50	8.39	2866.4		12
4135-068	7/11/2001	3.0	*140.10*	*251.90*	335.6	0	335.6	*57.0*	*25.20*	5.34	2888.8		32
4135-095	2/12/2002	3.3	2.78	350.51	479.4	0	479.4	186.0	0.50	8.04	2356		24
	Average		27.87	290.99	336.78	0.0		139.27	5.0	7.53	2535.96		
	Percent Al Acidity			9.58%									

Table 2 for site 2A has two unusual data points. September 5, 2000 and April 4, 2001 both had unusually good water for this site. The pH values were up and metals and sulfate values were down. In comparison, Site 2B did not experience any change in water quality on these dates. Since both of these waters come from the same source the difference in chemistry is unexplained.

Table 7 contains some data on June 14 and July 11, 2001 that are questionable; these data have been highlighted in italic. Iron and acidity values on June 14, 2001 are unusually low, and the aluminum value is unusually high. These questionable data also cause the calculated values of aluminum acidity and metal acidity to be unreliable as well.

Aside from these anomalies, the chemistry data are quite consistent seasonally within each data set. There are no pronounced variations indicative of high or low flow events.

These chemical data fall into two distinct groups, those discharges that have a low pH and a high percentage of aluminum acidity, and the single discharge that has a near neutral pH and a low percentage of aluminum acidity. Sites 2A, 2B, 4, and 6, fall into the former category, site 7 into the later. Site 8 is in between these two extremes in that it has a low pH and a low percentage of aluminum acidity. The fundamental difference between these discharges is that the low pH high aluminum sites are free draining with air circulation through the mine, while the near neutral pH and low aluminum found at site 7 is from a mine that is mostly flooded with little to no air circulation. This difference can be used to improve the water quality from the low pH discharges. The method of doing this is discussed in the remediation section.

Chart 5

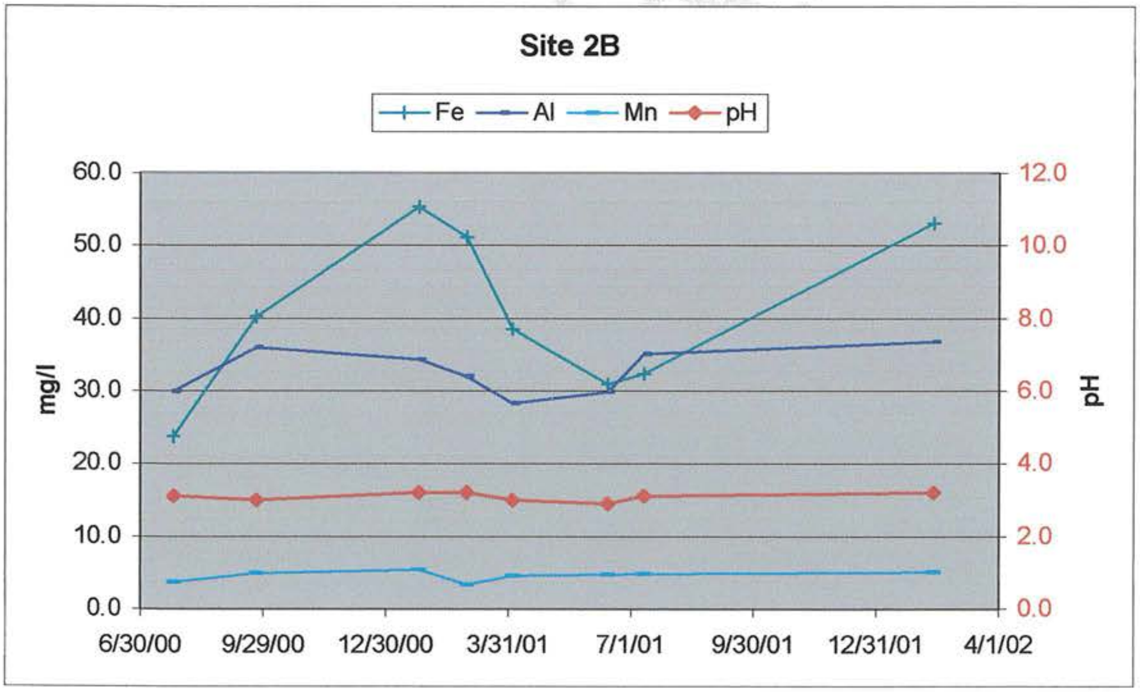


Chart 6

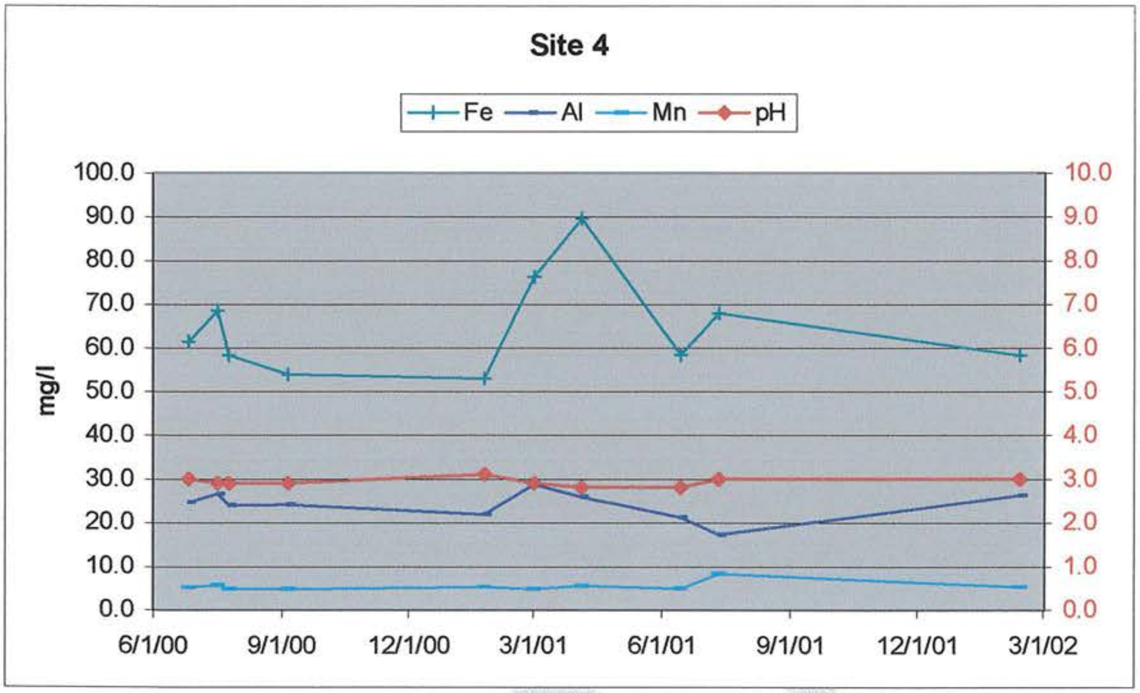
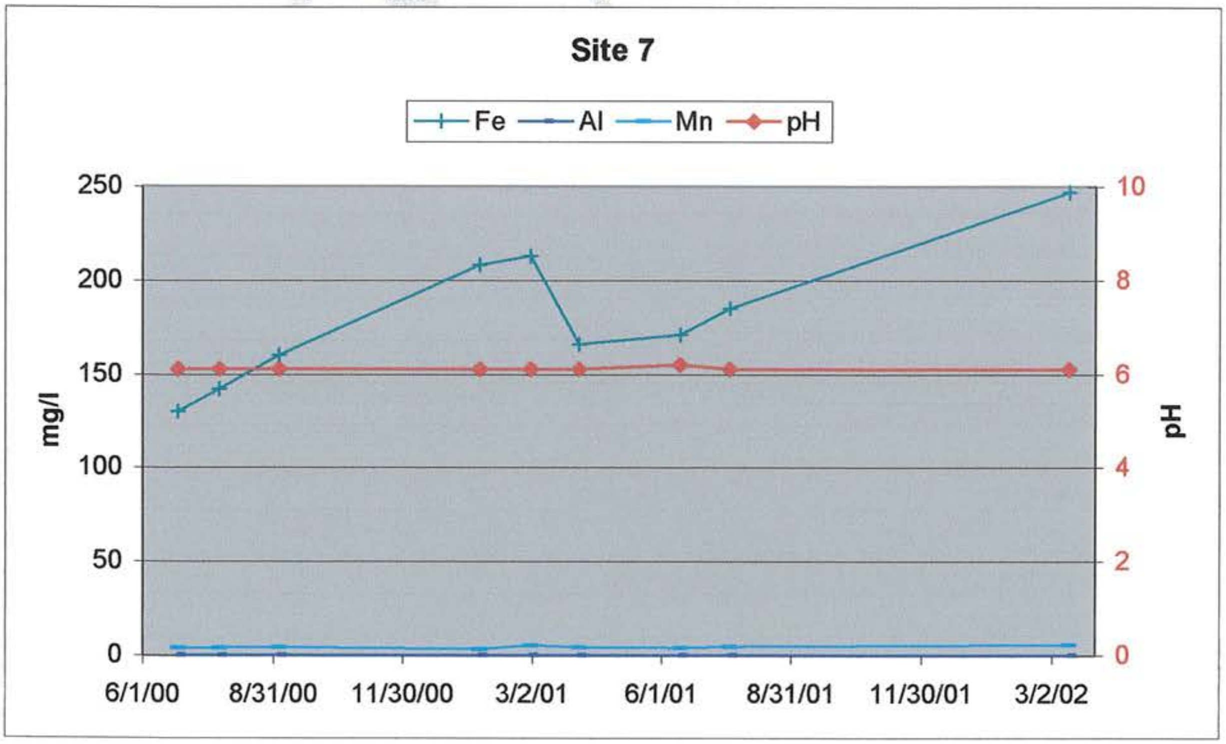


Chart 7



Metal and Acidity Load

Metal and acidity loads are calculated by multiplying the metal or acidity concentration by the discharge rate after conversion to consistent units. Table 8 contains the result of these calculations for the studied discharges. Although sites 2A and 2B are measured separately, they originate in the same mine and should be added together. These data are listed in Table 8 under Site A + Site B.

The key parameter in this table is the net acidity load in grams per minute. The net acidity load is indicative of the level of pollution and consequently it can be used to rank the severity of the individual discharge and its potential for impact on Dunkard Creek. Based on these data it is evident that the Site 2 discharges have the single greatest impact on Dunkard Creek. Site 2 is followed in order by site 4 and site 7.

Site 2, at high flow, can add 2.9 kilograms of acidity per minute to Dunkard Creek while at average flow it contributes 0.62 kilograms per minute. Site 4, at high flow, adds 1.1 kilograms per minute and at average flow it adds 0.47 kilograms per minute. Site 7 is fundamentally different than the proceeding two discharges. The water from this site has significantly less acidity and aluminum, and considerably more iron. Negative net acidity values indicate that under some conditions the water is actually net alkaline. The site 7 water chemistry is consistent with a mine that is flooded as opposed to a mine that is freely draining as is the case for sites 2, 4, and 6. At high flow, site 7 only adds 0.26 kilograms per minute of acidity and at average flow conditions site 7 is slightly net alkaline. This difference in water chemistry will lead to a different recommended approach to remediation.

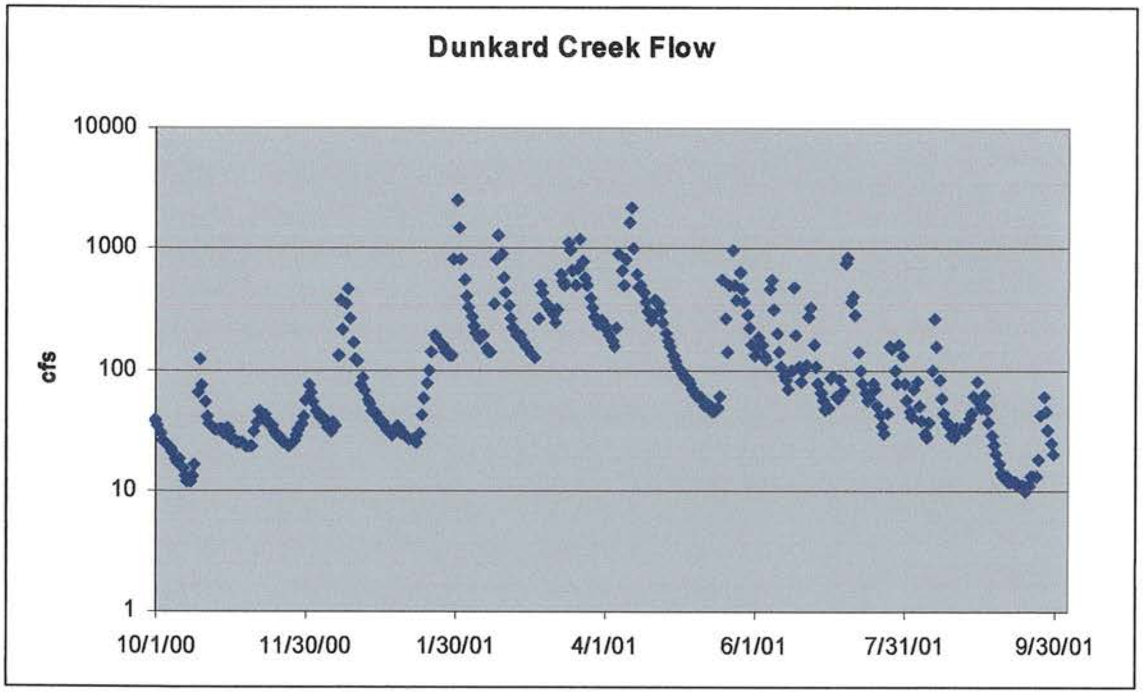
Table 8
Metal and Acidity Loads

		Flow cfs	Fe mg/l	Al mg/l	Mn m/l	Net Acidity mg/l	Fe g/sec	Al g/sec	Mn g/sec	Net Acidity g/sec
Site 2A										
	min	0.03	11.1	12.0	1.7	51.4	0.008	0.009	0.001	0.037
	max	0.32	50.8	37.8	5.3	492.0	0.453	0.337	0.048	4.388
	average	0.10	25.1	23.2	3.1	217.2	0.071	0.065	0.009	0.614
Site 2B										
	min	0.28	23.7	28.3	3.4	268.0	0.185	0.221	0.026	2.094
	max	3.26	55.3	36.8	5.4	474.8	5.104	3.397	0.497	43.822
	average	0.92	40.7	32.8	4.6	377.8	1.053	0.849	0.119	9.787
Site 2A + Site 2B	min	0.30				249.6	0.129	0.158	0.018	2.131
	max	3.58				476.3	3.621	2.486	0.343	48.204
	average	1.01				364.2	0.740	0.616	0.081	10.464
Site 4										
	min	0.09	53.0	17.3	4.8	388.0	0.140	0.046	0.013	1.023
	max	1.27	89.7	28.7	8.3	528.0	3.225	1.032	0.299	18.985
	average	0.62	64.6	24.1	5.5	447.4	1.134	0.423	0.096	7.852
Site 7										
	min	0.52	130.0	0.5	3.5	-66.0	1.914	0.007	0.051	-0.972
	max	1.20	247.0	0.5	5.9	126.0	8.392	0.017	0.200	4.281
	average	0.76	180.2	0.5	4.6	-0.8	3.885	0.011	0.099	-0.017

The United States Geological Survey (USGS) maintains a stream gauging station on Dunkard Creek adjacent to the public park. Flow data from Dunkard Creek are available for download from the USGS web site at www.usgs.gov. Data for 2001 are posted through the end of the water year on September 30, 2001. More recent data has not yet been posted. Chart 8 shows the hydrograph for Dunkard Creek. The vertical axis of this graph shows the flow of Dunkard Creek in cubic feet per second (cfs). This axis is displayed on a logarithmic scale so that both the high and low extremes can be observed. The peak discharge of 2500 cfs occurred on January 31, 2001 and the minimum flow of 9.9 cfs occurred on September 19, 2001. The average discharge of Dunkard Creek at the USGS gauging station for water year 2000-2001 is 190 cfs.

The Dunkard Creek flow measured by the USGS gauge includes the site 2 and site 4 discharges. While flows were not measured at these sites on September 19 they were measured on October 5, 2001. The flows at these sites were 0.51 cfs and 0.30 cfs respectively. Based on the observed data it is possible that the discharge from the mines on September 19, 2001 was slightly higher than on October 5, 2001. However, this is not expected to significantly alter the result. The total mine discharge upstream of the USGS gauge is 0.81 cfs. This means that the Dunkard Creek stream flow above the mine discharges is 9.09 cfs. Consequently, under the observed low flow condition, the discharge from these two points represents 10% of the Dunkard Creek flow upstream of Site 2.

Chart 8



Under low flow conditions theses two discharges can have a significant effect on the water quality in Dunkard Creek. Although Dunkard Creek is under low flow conditions, monitoring of the mine discharges has indicated that the mines have not yet achieved low flow. The calculated acidity loads for the October 5, 2001 mine discharge conditions are 5.5 grams per second from the site 2 discharges and 3.8 grams per second from the site 4 discharge for a total of 9.3 grams per second. The available alkalinity in Dunkard Creek, assuming 40 mg/l as $CaCO_3$, under the observed low flow conditions on September 19, 2001 is estimated to be 10.3 grams per second. This results in only one gram per second of stream alkalinity. Any reduction in stream flow below 9.09 cfs, any reduction in the available alkalinity of the stream, or any additions of acidity from the other discharges would result in Dunkard Creek becoming net acidic. This mechanism may be the cause of the fish kills that have been observed in this reach of Dunkard Creek.

Mine Hydrology

Coal from the Pittsburgh seam was mined in the watershed using room and pillar, and room and pillar full extraction techniques. The Sewickley seam was mined using surface mining methods as well as room and pillar underground mining methods. Precipitation falling on these mined areas infiltrates into the ground and becomes part of the ground water system. The reclaimed surface mining sites are capable of holding more water than unmined sites. The water in these mines is available to leak into the underlying mined out Pittsburgh seam. The surface mine spoils act at reservoirs that supply water to the Pittsburgh mines on a continuous basis. This is the reason that the mine discharge rates recede more slowly than the discharge rates in Dunkard Creek.

Maiden #1 Mine

Maiden #1 mine is located between Dunkard Creek in Pennsylvania and Robinson Run in West Virginia. Maiden #1 mine is the source of discharges 2A, 2B, 4, 5, and 6. In addition, Maiden # 1 mine also has a discharge located along Robinson Run in West Virginia.

Water infiltrating into Maiden #1 mine will flow down dip to the West unless it encounters an obstruction in the mine. These obstructions can include Perimeter barrier pillars, interior barrier pillars, areas of unmined coal, and collapsed mine entries. Mine maps of Maiden #1 mine were used in conjunction with elevations of bottom of the Pittsburgh seam as well as the mine discharge locations to identify those portions of the mine that are contributing water to each of the discharges. Information gathered from a mine operator indicated that there were potentially multiple water levels within this mine. This complication made a simple analysis of the mine difficult. If the statement were correct, then water could be flowing from portions of the mine that were not obvious sources of contribution. Plate #1 shows the inferred location of these zones of contribution.

A monitoring well was drilled into the Maiden #1 mine at a point that would be a natural overflow from the southern portion of the mine to the northern portion of the mine. The georeferenced mine map and the global positioning system were used to locate the hole. The site was located on a reclaimed Sewickley seam surface mine site. Drilling proceeded through the reclaimed spoil material without intercepting any water. The rock between the Sewickley horizon and the Pittsburgh coal horizon was also dry. The hole was completed in an uncollapsed Pittsburgh seam mine entry. No water was found at this location which indicates that there is no communication between the northern and southern portions of

Maiden #1 mine. This finding is significant because it limits the locations at which in situ treatment can be attempted.

Maiden # 3

Maiden # 3 mine is located north of Dunkard Creek, discharges 7 and 8 emanate from this mine. Analysis of the mine map and the discharge elevations indicates the majority of Maiden # 3 is flooded. Water level is maintained in this mine pool by the elevation of the discharge at approximately 830 msl. This flooded condition is responsible for the circum neutral pH and the elevated iron content of this water.

Discharge Remediation

The mine discharges of the Dunkard Creek watershed present significant obstacles to their remediation. Most notable are the low pH values at sites 2A, 2B, 4 and 6; and the lack of suitable flat acreage for a treatment facility at discharges 2A, 2B, 6 and 7. In this section the low pH issue is addressed with a combination of approaches, the most novel of which is *in situ* neutralization. In situ neutralization consist of the addition of alkalinity directly to the underground mine. It is hoped that this alkalinity will raise the pH of the mine water from the low threes to 5.5 or greater. At this higher pH aluminum will begin to precipitate in and be retained in the mine. Aluminum precipitation does not require the presence of oxygen and hence it will continue even if the mine atmosphere becomes anoxic. This technique is combined with the use of mine sealing, wetlands, open limestone channels to create a holistic approach to discharge remediation.

Site 2

The Taylortown AMD discharges exit the Maiden # 1 Mine via the entries which daylight under cliffs at the head of a small drainage within 200 feet of Dunkard Creek. The Maiden # 1 Mine extends southward from the discharge toward the Pennsylvania/West Virginia state line. The mine entries underlie a stream channel up gradient from the portals. The Site 2 Discharges are located about 20 feet above stream elevation and are located on a site with very little useable area. A long abandoned wagon road exists from the vicinity of site 2A down to Dunkard Creek. This road is about ten feet wide and 200 feet long.

Several remedial actions have been evaluated for this discharge and a combination of actions has been selected for recommendation. Possibly the simplest action would be to pipe the combined discharge via gravity flow into the Shannopin mine for treatment at a remote location. Although this action is simple it ignores several significant issues, most notably the health and safety issues posed by the open drift entries, the open slope and the sink hole. In addition, this action is not a treatment of the problem but rather a transfer of the problem. Consequently, unless treatment for Shannopin is implemented the option of water transfer should not be considered further.

Table 9 contains the dimension of the drift entries where sealing is required at site 2A – 2B.

Table 9

Entry	Width	Height	Status	Seal type	Discharge
1	16	3.5	Open	Dry	
2	14	1.5	Open	Dry	
3	8	1.0	Open	Dry	2B
4	12	1.0	Open	Dry	
5	33	2.5	Open	Dry	
6	20	4.0	Open	Wet	
7	25	3.0	Open	Dry	
8	20	3.5	Open	Dry	
9			Blocked	Dry	
10	16	5.0	Open	Dry	
11	16	5.0	Open	Dry	
12	20	5.0	Open	Wet	2A

The first recommended action is to seal the twelve drift entries utilizing ten dry seals and two wet seals. Sealing of these entries will prevent access to the mine by children and it will significantly reduce the breathing of the mine that is currently taking place. The continued addition of oxygen to the underground mine supports the continued oxidation of Pyrite and the continued generation of AMD. Over time sealing of these entries as well as sealing of the slope, the sinkhole and the two wells should reduce the acid load from the mine by reducing the rate of pyrite oxidation. As part of this process the stream flow that is currently entering the mine at entry 7 is to be diverted so that this water does not become commingled with and contaminated by the mine water. The wet seals must be designed for peak flow conditions and they should be provided with blowout protection in the event that iron deposits block the pipes.

The wet seals should be installed in entries 6 and 12 thus diverting the flow from entry number 3 to entry 6. This diversion will allow ready access to the proposed open limestone channel for the flow that reports to the 2B discharge.

The sink hole should be filled with alkaline producing steel slag. It is estimated that 900 cubic yards of this material will be required. Large rip rap sized material should be placed in the bottom of the sink hole with finer material placed on top. The stream flow that is currently being captured by the mine should be allowed to flow through the steel slag and into the mine. Under low flow conditions in Dunkard Creek it is estimated that 0.1 g / minute or 4.7 percent of the acid load would be neutralized. The alkalinity from this source is expected to last for 10 years under average flow conditions.

The Maiden #1 slope should also be backfilled with steel slag. This slag should be placed as far down the slope as possible. This can be accomplished pneumatically with out the need for people entering the mine. It is estimated that 56 cubic yards of slag are needed for this purpose. Surface water should be encouraged to flow through the steel slag to pick up additional alkalinity. The volume of surface water can be regulated to achieve sufficient in situ neutralization. An additional surface water source may be required for this purpose. Water can be obtained from the adjacent watershed possibly with out the need for pumping, or it can be pumped from Dunkard Creek. At 10 gpm, 0.62 g / minute or 29 percent of the acid load can be neutralized. This alkalinity should last for 10 years under 10 gpm flow conditions.

It is the goal of the in situ alkaline addition program to raise the pH of the water in the mine to 5.5 standard units or greater. At this pH the aluminum in the mine water will precipitate in the mine without the addition of oxygen. With the two passive approaches described 34 percent of the acidity is expected to be neutralized. This is expected to raise the pH slightly, reduce the acidity by 34 percent, and reduce the aluminum content of the discharge by almost 50 percent.

It is clear that these slag beds alone will not fully treat the site 2 discharges. An abandoned wagon road near site 2A could be utilized as an open limestone channel. This channel would be ten feet wide three feet deep and 200 feet long. It would be filled with about 380 tons of limestone with a high calcium carbonate content. This would provide additional neutralization capacity and a safety net of protection for Dunkard Creek. Under low flow conditions 1.87 grams per minute of alkalinity could be realized. This is equal to 88 percent of the required alkalinity which is sufficient to treat the water under low flow conditions. However, metals precipitation it still expected to occur in Dunkard creek. Under average flow conditions this open limestone channel is expected to last for four years before additional limestone is required. It hoped that by the time limestone replacement is required the water quality improvement resulting from the sealing of the mines will reduce or eliminate the need for the limestone addition.

Utilizing this combined system, 100 percent of the acidity should be neutralized under low flow conditions. Under high flow conditions it is expected that 36 % of the acidity would be neutralized with the contribution from the sink hole being the primary source of increased alkalinity. Although all of the acidity is not neutralized under high flow conditions this shortfall occurs at a time when Dunkard creek is able to significantly dilute any contribution from the mines.

Site 4

The following recommendations are proposed for the discharge at site 4.

A wet seal should be installed in the drift entry to prevent air infiltration into the mine. The discharge pipe should be sized to convey the peak discharge with out excessive head buildup in the mine. The seal should be equipped with blowout protection in the event that the discharge pipe is blocked by mineral deposits or other adverse conditions.

A 200 foot long open limestone channel should be constructed to convey the mine discharge down the slope to the wetland. Such an OLC would be ten feet wide and three feet deep and would contain 380 tons of limestone with a high calcium carbonate content. Under low flow conditions in Dunkard Creek it is expected to reduce the acidity of the discharge by 1.12 g/day which is 109 percent of the low flow acidity present at that time. However, it will only neutralize about 15 percent of the acidity under high flow conditions. This OLC is expected to operate for 3.8 years before the limestone must be replaced.

The volunteer wetland that is located below the mine discharge should be upgraded to maximize the retention time of the mine water in the wetland. This wetland is currently about 10 acres in size, but flow through it is not optimized. This is more than enough area for treatment of this discharge provided that sufficient neutralization can be put into the system. No acidity reduction has been ascribed to the wetland.

Site 6

Discharge 6 emanates from a cliff above Dunkard Creek below the town of Newtown. There is no space available at the discharge site to implement a passive treatment system. Due to this limitation, the do nothing alternative should be considered. If passive systems are built at the other sites, it may not be necessary to address the site 6 discharge. However, if treatment at site 6 is deemed necessary, then the following approach, and its risks, should be considered.

The flow of this discharge was not measured during this study, but the load was determined in prior work. Evaluation of the mine maps indicates that the water that is being discharged from this site infiltrates into the mine east of the discharge location. See Plate 1. A valley bottom located over this recharge area has been identified. This site is located about ¼ mile east northeast of the final discharge from the site 4 wetland. An active steel slag system is proposed for this site; however, there are potential risks with this system. This non-standard approach would utilize water pumped from site 4 to actively dissolve alkaline steel slag. The resulting alkaline solution would then be allowed to flow into the mine so that the acid water could be neutralized in situ. The flow of water to the active bed could be varied in order to provide neutralization of the mine water that is proportional to the mine inflow rate. It is estimated that 135 tons of slag per year would be required to achieve neutralization of this mine water depending on slag utilization efficiency. Aluminum precipitation is anticipated to occur within the mine thus reducing metals loading to Dunkard creek. This system would require electrical power to operate the pump as well as regular additions of slag to the mixing chamber.

There is a potential adverse impact to this proposed alternative. If the metals precipitate at the discharge point and cause the discharge to become plugged, then mine water could buildup in the mine until the water pressure causes a catastrophic failure of the barrier pillar. If this approach is adopted then regular inspections of the discharge will be necessary to ensure that blockage does not occur. It is also possible to under treat this site at a rate of 60 percent of the acid load. This should result in aluminum precipitation in the mine while allowing the iron to remain dissolved in the discharge. Aluminum is known to flow freely through such restrictions while iron is known to form deposits under these circumstances.

The proposed system would consist of a sump at the site 4 discharge, electrical power at the sump, one or more pumps in the sump, a pipeline(s) from site 4 to the injection point, a water powered slag dissolution chamber, a slag feeder, and an injection borehole. Annual electrical costs are estimated to be under $500.00 per year.

Site 7

As previously noted, the water quality at site 7 is substantially different than from the other sites. As a result the need to add alkalinity to the system is significantly diminished. The primary requirement for treating this water is aeration and settlement. In fact the water is so ready to drop its iron load that iron deposits are precipitating within a couple of feet of the discharge. This tendency will cause future maintenance requirements at this site as the deposits will have to be removed from any water conveyance that is employed.

Like site 6, this discharge occurs in a very difficult position on the bank of Dunkard creek. It is located across the creek from the supply yard of the Shannopin mine. This large flat area is suitable for the development of settlement ponds and wetlands. The major obstacle to utilizing this site is the need to convey the water across Dunkard Creek. Because of the tendency of this water to precipitate and coat surfaces, the use of a pipe is not recommended. These waters are more easily handled in an open channel flume where cleaning can be accomplished. This necessitates the construction of a bridge across Dunkard Creek. There is an existing road bridge 465 feet downstream of the discharge and an abandoned mine bridge 1,423 feet upstream of the discharge. However, the use of these bridges is believed to be impractical due to the long flume sections that would be required on the steep banks of the creek and the added maintenance that these longer flumes would require. In addition, the upstream bridge would require an additional bridge to cross a small tributary of Dunkard Creek. The proposed flume should be designed to carry 200 percent of the peak flow so that cross section loss due to metals precipitation does not result in overflow of the flume between flume cleanings.

If a bridge with a flume is deemed to be impractical and a pipeline is chosen as the means of conveyance then all efforts must be made to prevent contact of the mine water with the air. This isolation should be maintained from the mine to the pipe outlet, and it will reduce the rate of precipitation. Further, all piping sections must be designed to be removable for cleaning.

Once the water is across Dunkard creek the water should be aerated utilizing a cascade or stair step aerator. The cascading water should fall at least two feet into a one foot deep pool of water lined with limestone to provide any needed alkalinity. This aeration should be distributed across the entire width of the settling pond. Aeration should be followed by a settling pond of at least 8 hours retention with 50 % excess capacity for sludge storage. Based on a peak flow rate of 1.2 cfs the pond, and an additional sludge storage volume the pond should have a capacity of at least 2,000 cubic yards. This pond will allow the bulk of the iron to precipitate and settle where it can be cleaned as required. If needed, a flow control curtain can be installed to enhance settlement. The outflow from the pond should be designed to cascade into a pool lined with limestone providing additional aeration, alkalinity, and turbulence for coagulation. This step can be followed by an aerobic wetland of four to nine acres in size for the removal of the final metal content. A wetland of four acres is capable of removing the normal iron concentrations during average flow periods without the use of a settling pond. A wetland of nine acres is capable of removing the iron load from the peak discharge on a continuous basis without a settling pond. (Skousen & Ziemkiewicz 1996)

References

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APPENDIX A

LOCATION COORDINATES

Site	Northing	Westing
Abandoned Borehole	39° 43.101'	79° 58.829'
Ball Park Discharge	39° 45.569'	79° 58.198'
Maiden #1 Shaft	39° 44.346'	79° 58.189'
Maiden #1 Slope	39° 44.344'	79° 58.559'
Maiden #1 WV discharge	39° 41.958'	79° 59.591'
Maple Sterling Drift	39° 45.695'	79° 56.267'
Unknown Mine Discharge	39° 45.630'	79° 58.198'
Moffet Sterling Drift	39° 45.500'	79° 56.113'
Monitoring Well	39° 43.538'	79° 58.401'
Shannopin Supply	39° 45.833'	79° 58.575'
Sink Hole	39° 44.248'	79° 58.323'
Site 2B Discharge	39° 44.468'	79° 58.673'
Site 4 Discharge	39° 44.935'	79° 57.840'
Site 7 Discharge	39° 45.946'	79° 58.380'