IDENTIFICATION AND ANALYSIS OF ACID MINE DRAINAGE SOURCES IN THE BLACK FORK SUB-WATERSHED

by

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Abstract. The Moxahala Creek watershed in southeast Ohio was recognized by the state of Ohio as one of the most acidic watersheds in the state. Four tributaries were determined to be the primary contributors to the negative water quality. The largest by volume of these tributaries is Black Fork, which provides 20 to 25% of the total flow in Moxahala Creek. The current study's objective was to identify the causes of acid mine drainage (AMD) into Black Fork and to evaluate the effects of AMD to the sub-watershed. As a result of the current project, two coal refuse piles and numerous seeps have been acknowledged as the main sources of AMD in Black Fork.

In preliminary sampling, researchers surveyed 50 stream locations to determine the streams which contribute significantly to Black Fork. At present, eighteen locations are sampled every four to six weeks. The flowrate and water quality parameters are measured on site, and samples are being analyzed for common AMD water quality indicators such as pH, acidity, total iron, and sulfate. A wetland was constructed in 1994 to treat the affected water from one of the identified seeps before discharging into Black Fork. This wetland was evaluated before and after vegetation was established to assess the wetland's effectiveness in reducing AMD pollutants. Biological assessments of fish populations, macroinvertebrates, and algal species were also performed throughout the sub-watershed in order to determine number and diversity of species present in the habitat. This report presents water quality data, which gives a basic understanding of the dynamics of the Black Fork sub-watershed. A GIS database was developed for data management and is also demonstrated.

Additional Key Words: Treatment Wetlands, GIS.

Introduction

Acid mine drainage (AMD) is a form of water pollution that stems from mining. The three major components needed to form AMD are pyrite, water, and oxygen. Pyrite, FeS_2, is a mineral that is associated with coal deposits and can be found in spoil from mining operations. As pyrite oxidizes it generates acidity and soluble iron. The iron precipitates and coats the receiving stream as a result of rainwater or groundwater running over or through the spoil or abandoned underground mines and colors the streambed yellow or orange-red.

AMD impacts the environment in many different ways. Iron precipitation inhibits aquatic food supplies, clogs gills, and covers spawning beds. This precipitation flowing throughout the streams also increases the turbidity, obscuring sunlight. High concentrations of precipitate can destroy plant life. The acidity of the water can corrode culverts, pipes, pumps, bridge abutments, locks, and dams.

There are three general chemical reactions that characterize AMD. Equation 1 below represents ferrous iron is being generated and oxidized slowly in acidic water, though iron-oxidizing bacteria catalyze this process. Since pH is the negative log of H^+, as the hydrogen ion concentration increases, the pH decreases. The pH of the affected water is often less than 3.0. When ferrous iron oxidizes, it remains in solution at a low pH as seen in equation 2. Equation 3 occurs when the pH is greater than approximately 3.5, which can be achieved when AMD is diluted by flowing into an unpolluted stream, thereby raising the pH. The higher the pH, the faster the precipitate will form. The reaction represented by equation 3 also creates hydrogen ions, which in turn causes the pH to decrease (Rudisell, et al. 1999).

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$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightarrow 2\,Fe^{2+} + 4\,SO_4^{2-} + 4\,H^+ \qquad (1)$$

$$4\,Fe^{2+} + O_2 + 4\,H^+ \rightarrow 4\,Fe^{3+} + 2\,H_2O \qquad (2)$$

$$Fe^{3+} + 3\,H_2O \rightarrow Fe(OH)_3 + 3\,H^+ \qquad (3)$$

A study performed by the state of Ohio determined that the Moxahala watershed is one of the most acidic in Ohio. There are four main tributaries to Moxahala Creek that are accountable for the decrease in the creek's water quality. Black Fork, supplying approximately 25% of the total flow to the Moxahala, is the largest of these tributaries. It is, however, the least contaminated of these tributaries, contributing only 20% of the total iron load and 15% of the total sulfate load to Moxahala Creek (Eberhart, et al. 1998). Black Fork was chosen for this study because it has the greatest potential for full recovery and its improvement will have the most significant impact on Moxahala Creek because of its high flow contribution.

Objective

The primary objective of this study was to characterize the extent of AMD effects on water quality and biota within the Black Fork sub-watershed by identifying sources of AMD and quantifying the impacts from these sources over a period of time. These results were necessary to propose AMD abatement measures. A secondary objective was to improve the effectiveness of the wetland by analyzing flow patterns, wetland cell residence times, and the role of vegetation in sulfate removal and pH changes (Stoertz 1998). The second objective is addressed in detail in another paper at this conference titled "Evaluation of a Constructed Wetland for Treatment of Acid Mine Drainage in Southeastern Ohio."

Site Description

The Moxahala watershed consists of a 106 square-mile basin in Perry, Muskingum, and Morgan Counties, Ohio (Eberhart, et al. 1998). Moxahala Creek flows north toward Zanesville into Johnathan Creek, which then flows into the Muskingum River, which discharges into the Ohio River. The Black Fork sub-watershed drains approximately 30 square-miles of northeastern Perry County and southwestern Morgan County in southeastern Ohio (Stoertz, et al. 1998). Black Fork flows northward before discharging into Moxahala Creek just south of Crooksville, Ohio. Black Fork's main contributors are Dry Run, Ogg Creek, and Bennett Run (Figure 1).

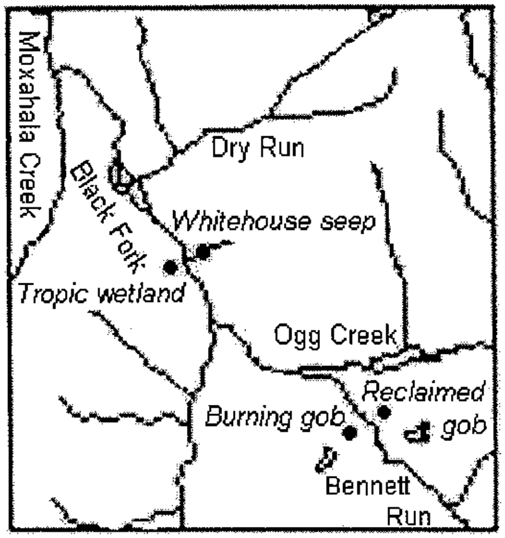

Figure 1. The Black Fork Sub-Watershed

The Muskingum Mining Company mined approximately four square miles of #6 coal from the Misco Mine until 1956. The company left its refuse in two piles in Perry County on both banks of Bennett Run. Since these gob piles were known AMD contributors to the Black Fork sub-watershed, partial reclamation was performed in 1990 by the Ohio Department of Natural Resources – Division of Mines and Reclamation (ODNR-DMR). This reclamation included the excavation and quenching of 22,000 cubic yards of burning coal refuse before the pile was capped. The topsoil placed on the gob is now covered with vegetation. Due to insufficient funds, the other burning 63-foot deep, 12,000 cubic yard pile was left unreclaimed (Stoertz, et al. 1998). An impounded lake perched behind this pile constantly feeds water through the gob before discharging directly into Bennett Run.

Another previously addressed AMD source is that from an underground seep near Tropic Township, Ohio. ODNR-DMR designed and constructed a treatment wetland to treat this seep in 1994. The seep is first routed through an anoxic limestone drain. It then enters a sedimentation pond before flowing through one of twelve wetland cells. The water is then flows into a collection channel before discharging into Black Fork. Extensive discussion on the effectiveness of this wetland is given in another paper at this conference titled "Evaluation of a Constructed Wetland for Treatment of Acid Mine Drainage in Southeastern Ohio."

Methodology

Preliminary Assessment

The first task was to identify the sources of AMD to Black Fork. The investigation began at the confluence of Black Fork and Moxahala and continued upstream. Each tributary to Black Fork was sampled. If the water quality of the tributary was good, the process moved upstream on Black Fork and no further work was performed on the contributing stream. If the water was contaminated by AMD, however, the tributary was traced back with each of its contributing streams being sampled in the same fashion as Black Fork. This procedure was repeated until no evidence of AMD was found in either Black Fork or its contributors, confirming that the AMD sources came from downstream of that geographic point. Handheld probes were used initially to test the pH and conductivity of the water. A peroxide pH of 6.0 or above and a conductivity of 1000 μS/cm or less was considered to be good water quality. Once researchers obtained a general understanding of the sources of AMD in the area, over 50 samples were taken throughout the sub-watershed and analyzed in the laboratory.

Monthly Sampling

From the preliminary assessment, 18 sampling locations were chosen for continuous study. The locations selected represented Black Fork and its tributaries before AMD contamination, various AMD contributing seeps, and each stream before discharging into its receiving waters. Beginning in March 1999, each location was sampled every four to six weeks. Flow measurements were taken using one of several methods: stainless steel cutthroat flumes were used for smaller flows, the bucket and stopwatch method was used for culverts, and a pygmy current meter was used on the larger flows in the area (Stuart, et al. 1998). Flowrates were measured in order to calculate contaminant loads being carried through the rivers (mass per unit time).

The pH, oxidation-reduction potential (ORP), and conductivity were measured at each of the eighteen locations using handheld probes. The pH is an indicator of hydrogen acidity, the ORP indicates the oxidation state of the water, and the conductivity is directly related to the total dissolved solids in the water. Water from each location was then placed in a cup to which a small amount of hydrogen peroxide, H_2O_2, was added. This completed the AMD reaction if the sample had not yet fully oxidized. The pH and ORP were measured once again. By measuring the ORP, it could be seen if the water was fully oxidized. After being oxidized, the pH reading was more representative of the anticipated hydrogen acidity further downstream. This is demonstrated by Figure 2, which shows the seep being treated by the Tropic wetland. Sampling point 1 was taken at the inlet of the sedimentation pond at the point where the underground seep surfaces and first comes in contact with air. Sampling point 2 was taken at the effluent of the sedimentation pond, which enters a wetland cell. Finally, point 3 was sampled at the discharge of the wetland to Black Fork. At the final sampling point, the water has had sufficient contact with oxygen, thereby completing the AMD reaction. As seen in the figure, the initial pH was close to 6.0, whereas the peroxide pH was 3.0. By the discharge of the seep into Black Fork (sampling point 3) the pH and peroxide pH both read approximately 3.0. Therefore, the addition of peroxide to the initial seep successfully predicted the downstream pH.

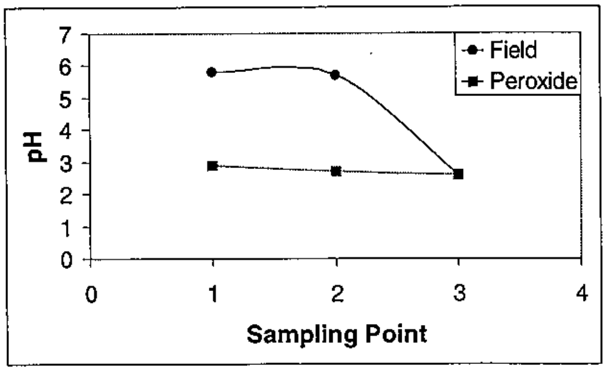

Figure 2. Tropic Wetland Field and Peroxide pH

Laboratory Procedures

Field samples were sent to an analytical laboratory operated by ODNR-DMR. Samples were analyzed for pH, total acidity, carbonate alkalinity, bicarbonate alkalinity, hydroxide alkalinity, phenolphthalein alkalinity, total alkalinity, conductivity, total dissolved solids, total suspended solids, total solids, sulfate, chloride, total calcium, total magnesium, total sodium, total potassium, total iron, ferrous iron, total manganese, total aluminum, and hardness. For the preliminary assessment, and then once during high flow and once during low flow, the water samples were analyzed for total zinc, phosphate, copper, chromium, arsenic, barium, cadmium, lead, mercury, selenium, silver, cobalt, boron, total nickel, total molybdenum, and bromide.

Biological Data

Biological data was collected in order to obtain a more complete evaluation of the area. This was done at locations in the sub-watershed's streams before contamination by AMD and in those same streams after being affected by AMD. Fish communities served as the focus for one biological assessment. There are numerous advantages to performing fish assessments. Extensive life information is available concerning fish species, which can be identified easily. Such assessments survey a wide range of communities representing various trophic levels and stress effects on the fish can be easily classified. All of this data can be related directly to fishable waters (Karr, 1989). The long-line generator unit method of fish shocking, or pulsed direct current electrofishing, was used. Species diversity, number of each species, and quality parameters, such as the presence of abnormalities, were assessed. The surrounding habitat was also evaluated for physical characteristics such as substrate, instream cover, channel morphology, riparian zone, and pool and riffle quality. These attributes have been shown to correlate with stream fish communities in Ohio (Rankin 1989).

The study of macroinvertebrates and algal growth are currently underway. The substrate in both affected and non-affected areas was excavated in order to determine the quality and quantity of insects present. Both the fish and macroinvertebrate studies investigated the effects of AMD on a stream with regard to biological communities, including determination of which species are acid tolerant. Results from the macroinvertebrate and algae studies are not yet available.

Data Management

Each of the 18 sampling locations was recorded using a global positioning system (GPS). This data enabled researchers to determine the precise location of the sampling points on a previously-digitized watershed map. This information was incorporated into a geographic information system (GIS). The GIS is an interactive system allowing users to view the data collected from this study in addition to the previous Moxahala watershed study. One application of the software allows users to select any of the sampling locations. Doing so opens a window with each month's water quality data in tabular and graphical form. Users also see a picture of that location, as well as any biological data or images available. Another feature of the GIS allows users to query the database. For example, users may ask to be shown each location that has a pH below a certain value. The GIS will highlight the sampling points that meet the query. A query may be performed on any parameter (or multiple parameters using logic descriptors) that is included in the GIS's database.

Results and Discussion

Identification

The preliminary assessment determined the sources of AMD to Black. The primary water quality parameters used to evaluate AMD impact included pH, total acidity, total iron, and sulfate. The four main sources of AMD were identified as: the gob piles, a seep being discharged into the Tropic wetland, a seep flowing under a bridge on Whitehouse Road, which will be addressed as the Whitehouse seep, and the entire Dry Run area.

The two gob piles located adjacent to Bennett Run, as seen in Figure 1, were obvious sources of AMD. The water from the burning gob pile, which flows at an average rate of 49 gallons per minute, has a pH of 2.8, an acidity concentration of 1700 mg/L, an iron concentration of 400 mg/L, and a sulfate concentration of 1800 mg/L. The reclaimed pile had no continuous source of recharge; however, rainfall events were observed to cause water of poor quality to drain into Bennett Run. The impacts of the gob piles to Bennett Run were evident in the pH graph shown in Figure 3. Sampling points 9-12 represent upstream data, which indicated good water quality. However, the pH dropped from 7.0 to 3.0 at after sampling point 9 where the discharge from the burning gob enters Bennett Run. Sampling point 5 represented a tributary adjacent to the burning gob that was determined not to be an AMD source. The water quality of Bennett Run is acidic as it flows downstream toward Ogg Creek. Just before Bennett's confluence with Ogg Creek the pH increases, which suggests natural attenuation has occurred along this one-mile stretch of Bennett Run. Note that the pH and peroxide pH values coincide, indicating that the water is fully oxidized along this stream and the AMD reaction has been completed.

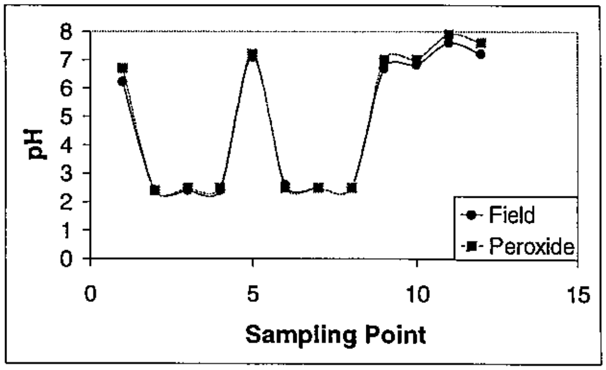

Figure 3. Bennett Run: Preliminary Assessment

The additional AMD sources were identified using the graph in Figure 4. Sampling points 11-16 indicate water quality upstream, which was not AMD-impacted. Sampling point 10 represents the Whitehouse seep. The difference between the pH and peroxide pH indicates that the water was not fully oxidized, which agrees with the observation that the water was discharging from an underground seep. Sampling points 9 and 8 denoted the discharge of the Tropic wetland into Black Fork. Some dilution and natural attenuation assisted with the increase of pH at locations 5-7, until Dry Run entered Black Fork around sampling point 4. Again, dilution and natural attenuation assisted with raising the pH of Black Fork before its confluence with Moxahala Creek at sampling point 1.

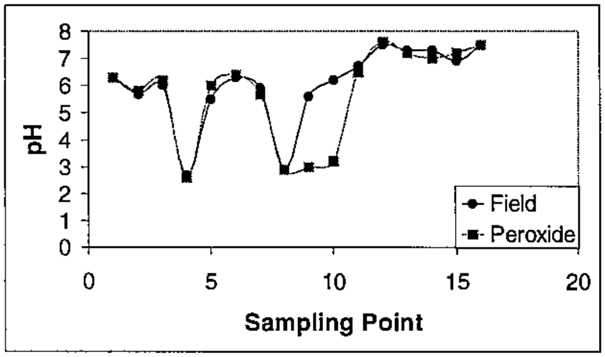

Figure 4. Black Fork: Preliminary Assessment

Another source is that of an underground seep flowing through the constructed wetland near Tropic Township locally known as the Tropic wetland. Some treatment is achieved; however, this seep is still a significant AMD contributor. The seep discharges from the wetland at two effluent points, which combine for a total flow of about 80 gallons per minute. The effluent water has a pH of approximately 3.0, 275 mg/L of acidity, 60 mg/L of iron, and 1800 mg/L of sulfate.

On the bank opposite from the wetland discharge, the Whitehouse seep enters Black Fork at a rate of approximately 480 gallons per minute. This water surfaces from an old mineshaft about 400 feet from the receiving stream. There is currently no treatment in place for this seep, which has a pH of 6.0, an acidity concentration of 130 mg/L, an iron concentration of 110 mg/L, and a sulfate concentration of 650 mg/L. The ORP is only about 144 mV, however, which indicates that the stream is in a reduced state. When peroxide was added to the sample, the pH dropped to about 3.3 and the ORP rose to 486, which indicated that the sample had been successfully oxidized. The reduction in pH after adding hydrogen peroxide revealed that the water quality of this seep would degrade as exposed to oxygen downstream. Since the AMD reaction takes place as the affected water is oxidized, downstream hydrogen acidity would be generated, the pH would decrease, and iron would be precipitated.

Finally, Dry Run, as seen in Figure 1, was also identified as an AMD source. An entire hillside is seeping with AMD-impacted water, which collects in two channels that flow into Dry Run. In addition, AMD-impacted waters essentially provide the headwaters of Dry Run. Dry Run discharges into Black Fork just before Black Fork's confluence with Moxahala Creek. The mouth of Dry Run is approximately 1 to 1.5 miles downstream of the collection channels. At Dry Run's mouth, the water flows at 274 gallons per minute, has a pH of 3.0, an acidity concentration of 300 mg/L, an iron concentration of 22 mg/L, and a sulfate concentration of 1000 mg/L. The iron concentration is lower than expected because the distance from the collection channels to the mouth has allowed much of the iron to precipitate out. Without a source of alkalinity, the acidity at the mouth of Dry Run remains relatively the same as the sum of the contributors. Sulfate is still at a high concentration because it is a conservative species, therefore it is not removed by sedimentation. This difference in expected values and actual values is illustrated in Figures 5, 6, and 7, which compare the chemical loads of the sum of the three contributors to Dry Run (the two collection channels and the headwaters), and the mouth of Dry Run.

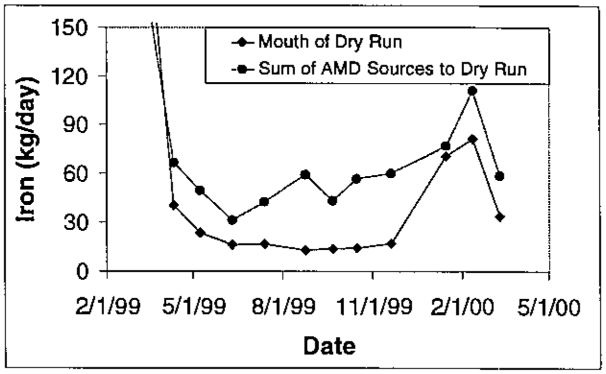

Figure 5. Dry Run Iron Load

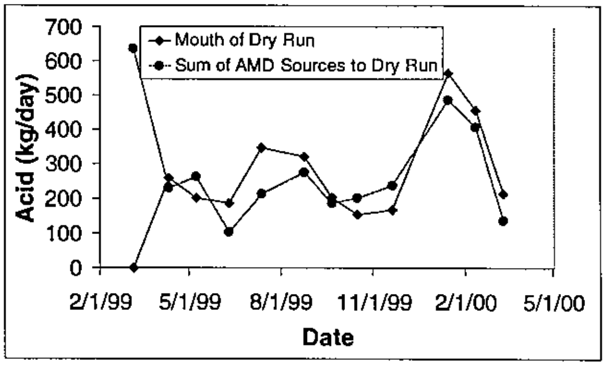

Figure 6. Dry Run Acid Load

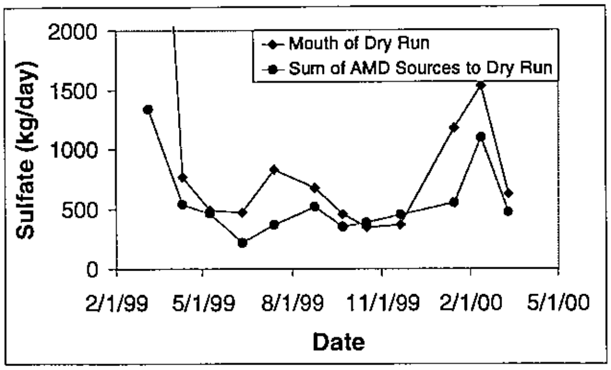

Figure 7. Dry Run Sulfate Load

Evaluation

After the sources of AMD were identified, researchers determined sampling locations. Key locations, such as the point just before Black Fork enters Moxahala, as well as each of the AMD sources (gob piles, Tropic wetland discharge, Whitehouse seep, Dry Run) were chosen first. These locations allowed researchers to calculate total loads of pollution contributed by each stream and source. Other sampling locations were selected in order to perform mass flow calculations or for background water quality determination.

Black Fork just before Moxahala flows at 1287 gpm and has a pH of 6.3, 10 mg/L of acidity, 5 mg/L of iron, and 500 mg/L of sulfate. The sources of AMD were outlined above, with water quality indicators included. A comparison of the chemical loads discharged from Black Fork into Moxahala Creek to the sum of the individual source loads (Table 1) shows that although substantial quantities of poor water are being discharged into Black Fork, some natural attenuation is taking place.

A large quantity and diversity of healthy fish was found in the streams of the sub-watershed at a location prior to their confluence with AMD-affected streams. In Ogg Creek, hundreds of fish belonging to fourteen different species were found. In Black Fork, hundreds of fish belonging to eighteen different species were found. At the mouth of Black Fork, however, only four fish of one species were found (Ramachandran 1999). While the quality of the habitat was found to be impacted minimally, the lack of fish demonstrates the severity of the impact AMD has on water capacity to sustain certain biological species.

The stream environment and the upstream biological quality suggest that Black Fork could accommodate aquatic life if the AMD negative water quality impacts were lessened.

Conclusions and Recommendations

In order to improve the overall water quality of Black Fork, each of the identified and studied sources of AMD in the Black Fork sub-watershed need to be addressed through treatment systems. Potential methods for abating or treating the drainage at each source are outlined below.

First, the burning gob pile should be extinguished. Subsequent capping has been shown not to be a sufficient solution, however. The reclaimed gob pile was capped and even flourishes with vegetation, which makes it appear as a successfully reclaimed area, but erosion and infiltration of precipitation waters have lessened the cap's effectiveness. Furthermore, water from the impounded lake behind the burning gob pile continues to infiltrate the gob pile, producing AMD and discharging it to Bennett Run. One recommendation is to excavate a large portion of land adjacent to the gob piles. The gob material would then be quenched and placed in a clay-lined pit and covered with additional clay acting as a hydraulic barrier. The material excavated would be distributed between the previously reclaimed gob, the area above the sequestered refuse, and the area where the burning gob was previously located. Vegetation would be established over each of

Table 1. Flowrates and contaminant loads from identified sources to Black Fork. High is defined as the average of high flow conditions and Low is defined as the average of low flow conditions.

	Flow (gpm)		Iron (kg/d)		Acidity (kg/d)		Sulfate (kg/d)	
	High	Low	High	Low	High	Low	High	Low
Burning gob	103	22	222	104	1003	307	1069	453
Whitehouse seep	751	102	445	90	546	153	2712	583
Tropic wetland	125	38	84	11	248	50	1244	416
Dry Run	771	51	198	62	1030	242	2269	432
Sum of sources	1750	213	949	267	2827	752	7294	1884
Mouth of Black Fork	3874	547	411	9	638	99	7716	2237

these areas in order to reduce erosion effects, which could allow for penetration of water into the spoil, thus producing AMD. This removal of the burning gob pile would prevent a large portion of AMD from being created. A portion of Bennett Run would be lined with limestone to add alkalinity to the stream, which would treat the minimal amount of AMD that could be formed by any remaining spoil. The burning gob is a priority to abate because although it accounts for only 6 to 10% of the flow of the AMD sources, it contributes 23 to 39% of the iron, 35 to 41% of the acidity, and 15 to 24% of the sulfate being discharged into Black Fork.

Tropic wetland, its removal capabilities, and recommendations for system improvements are described in "Evaluation of a Constructed Wetland for Treatment of Acid Mine Drainage in Southeastern Ohio", which is also being presented at this conference.

Whitehouse seep has the largest contributing flow of the sources, consisting of 43 to 48% of the flow, but only adds 24 to 47% of the iron, 19 to 20% of the acidity, and 31 to 37% of the sulfate. With its high flows, remediation of this source could significantly increase the receiving water's quality. Currently, ODNR and Ohio University are discussing abatement measures that could be taken with the Whitehouse seep. One possible method for treating the seep could be to use a successive alkalinity producing system (SAPS). SAPS consist of a series of ponds that have layers of organic material, which reduce oxygen and ferric iron concentrations, and limestone, which adds alkalinity. Since SAPS can be put in series, they can be designed to accommodate different areas and shapes of land.

A SAPS system is also recommended as the best treatment alternative for the Dry Run area. Since the entire hillside is oozing with AMD, Dry Run cannot be treated at the source and the water must be collected before treatment can be performed. Once the two collection channels have entered the stream formed by the headwaters, a SAPS can be put into place to minimize the seeps' effects to Black Fork.

The goal is to return the waters of Black Fork to fishable quality through use of these treatment systems. In doing so, the contaminant load to Moxahala could be significantly reduced. Further studies will evaluate the effectiveness of treatment methods put in place as a result of this study.

Acknowledgements

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