Impact of Acid Mine Drainage on Streams in Southeastern Ohio: Importance of Biological Assessments

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Abstract

Acid mine drainage (AMD) forms from oxidation of iron disulfide minerals, pyrite and marcasite, when they are exposed to air, water and chemosynthetic bacteria. Oxidation occurs through the mining process, which allows air entry and increases the surface area for reactions. Formation of AMD involves xseveral reactions beginning with oxidation and hydrolysis of pyrite producing soluble hydrous iron sulfates and acidity.

Coal has been mined in Ohio since 1804 and AMD has been a major problem. Various chemical studies have been performed on watersheds throughout the Ohio River basin. Recently the need for biological assessments has been stressed due to their reflection on the overall integrity of the watershed in terms of chemical, physical and biological composition.

Integrating the study of the biological communities with other aspects has been found to be a more valid approach to ecosystem studies.

The goal of the study is to examine stream quality and to assess the impact of AMD on the organisms. This paper evaluates streams in Southeastern Ohio using chemical, physical, and biological assessments. Comprehensive chemical characterization was completed and the Qualitative Habitat Evaluation Index (QHEI) used by the Ohio Environmental Protection Agency (OEPA) was incorporated during site characterization. Fish are selected as the studied organisms due to their high sensitivity to changes in water quality. The fish populations in the stream are evaluated for species diversity, presence of any anomalies, and quantitative changes. These fish evaluations are converted to an Index of Biotic Integrity (IBI) to allow for comparisons between streams. In this paper, comparisons are made between contaminated portions of the streams and sections not impacted by AMD.

Introduction

Mining has been a significant component of the Appalachian economy for about 200 years (Robert et al, 1995). Both abandoned and active mines may cause considerable damage to streams and rivers stretching over thousands of miles. Most of the problems arise from high acidity, sulfate and various metals such as iron, manganese and aluminum. Contaminated drainage from abandoned mines is considered to be the most significant non-point source of pollution.

Chemistry of Acid Mine Drainage (AMD)

Acid mine drainage is caused by the following series of equations (Sobek et al, 1978):

$$FeS_2 + 3.5\ O_2 + H_2O \circledR\ Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \quad (1)$$

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \circledR\ 15\ FeS^{2+} + 2\ SO_4^{2-} + 16\ H^+ \quad (2)$$

In this process more acid is produced when ferric iron oxidizes pyrite. From these reactions ferrous iron is oxidized to ferric in the presence of oxygen as shown in the following equation (Sobek et al, 1978):

$$Fe^{2+} + 0.25\ O_2 + H^+ \circledR\ Fe^{3+} + 0.5\ H_2O \quad (3)$$

Some bacteria, which thrive in the mines with minimum oxygen act as a catalyst in generating AMD, resulting in a precipitation reaction (Sobek at al, 1978):

$$Fe^{3+} + 3\ H_2O \circledR\ Fe(OH)_3 + 3\ H^+ \quad (4)$$

Methods

Study Areas

Two creeks were selected for the study from different watersheds. These streams were selected mainly due to their extreme conditions, which will show diverse water and habitat quality. The first watershed in the study is the Upper Pine Creek watershed. Pine Creek is a 48-mile long tributary to the Ohio River in Lawrence and Scioto counties. The drainage area is approximately 184 square miles. The Upper Pine Creek hydrologic unit begins slightly upstream from the mouth of Hales Creek at the Poplar Road bridge at river mile 38.5. The Upper Pine Creek hydrologic unit drains 33.3 square miles of primarily forested land, 60 percent of which is controlled by the United States Forest Service. The stream gradient is low throughout the watershed. The Upper Pine Creek hydrologic unit includes; Kimble Creek, Painter Creek, Saw Mill Run, Negro Creek, Olive Creek, Bukhorn Hollow, Brushy Fork, and Young Branch tributaries.

The tributaries that are significantly affected by AMD are Kimble Creek, Upper Pine Creek (from Negro Creek down stream to Young's Branch) and in Negro Creek (Figure 1). Two sites, one upstream and one downstream of Kimble Creek, were assessed for the present study. The upstream site was at river mile 0.8 and down stream site was at river mile 0.6. The Kimble Creek discharge averages 8.6 gpm with maximum flows up to 20 gpm (ODNR, 1998).

The second watershed in the study is the Moxahala Creek watershed (Figure 2). The watershed has a 106 square mile basin area located in Perry, Muskingum, and Morgan Counties (Eberhart, 1998). Moxahala Creek flows towards Zanesville, where it enters the Muskingum River, which in turn enters the Ohio River. The Moxahala Creek watershed has numerous tributaries, including; Black Fork, Andrew Creek, McLuney Creek and Bear Creek. Combined, these four streams comprise 50% of the total flow to Moxahala Creek, 89% of the acid load, 78% of the sulfate load, and 92% of the iron load. Two points in Black Fork were chosen for the study. Black Fork was selected because it was the only one of the four tributaries having a net alkalinity and a pH greater than 5.5 prior to discharge into Moxahala Creek. The other tributaries had no locations of substantial flow able to support a fish population, and would therefore not provide a basis for comparison. The upstream location was at river mile 3.4 and the downstream location was at river mile 0.01 (Eberhart, 1998).

Qualitative Habitat Evaluation Index (QHEI)

The QHEI is based on five general classes of landscape characteristics; land use, riparian zone, substrate cover, and channel morphology (Rankin, 1989). These characteristics are important for describing the overall system and have been shown to correlate with stream fish communities in Ohio (Rankin, 1989). The QHEI was developed as an intermediate index between completely subjective habitat descriptions and the more labor-intensive habitat suitability indices, which were developed for individual species (Rankin, 1989). Undisturbed sites are reference locations, scoring high values, where as drastically affected streams receive low scores. When scores of the metric from all five classes are summed, a maximum score of 100 may be obtained. The lowest value a stream could score is 12. For our study, the QHEI data sheet was adapted from the Ohio Environmental Protection Agency.

Index Of Biotic Integrity (IBI)

The integrity of water resources can best be assessed by evaluating the degree to which water provides beneficial uses (Karr, 1981). A balanced biotic community indicates the sanctity and beneficial use of the water resource. Biological communities reflect watershed conditions since they are sensitive to changes in a wide array of environmental factors. Various organisms were considered as indicators of environmental conditions. Usually, a biological assessment must include an integrative approach in evaluation. However, due to limited funds and time, it is usually confined to a few selected taxa. Taxa other than fish, such as macroinvertebrates or diatoms, have been widely used in monitoring because of the availability of a theoretical substrate that allows an integrated ecological approach (Vannote et al, 1980). Unfortunately, diatom and macroinvertebrate use in assessments is difficult, time consuming and requires expert knowledge for identification. Fish assessments have several advantages, including extensive life information, a wide range of communities representing various trophic levels, ease of identification, general public awareness, stress effects, omnipresence, and the ability to relate data directly to fishable waters (Karr, 1989). The major disadvantages are the manpower and monitoring problems, which are also present in any other taxa.

Various criteria are considered when calculating an IBI value. These include diversity indices, species richness, and abundance of species. Each species have different tolerance limits. Presence of intolerant species indicates a healthy the stream. For example, the presence and abundance of green sunfish species or a high number of Johnny darters usually indicates a degraded environment, while the presence of other darter species requires low sedimentation environments. Hybrids may also indicate the presence of degraded conditions. Decline in stream quality may be due to water quality, habitat degradation, or both (Karr, 1989). Karr assumes three major factors in the classification process; fish sample, sample site, and local fish fauna details. Generally an excellent stream will have an IBI value of 57-60, and a completely degraded stream will have values less than 20. Rankin (1989) related the IBI to the QHEI and found significant correlation for streams in the Ohio River Valley.

Fish Shocking Method

Fish shocking is the principle method used by Ohio EPA to obtain relative abundance and distribution data. Pulsed direct current electrofishing is a widely used method for sampling. Among the different fish shocking methods, the long line generator unit method was utilized. This is mainly due the low pool and riffle depth, which made boat or sportyak methods impossible. The longline-generator method uses 100 meters of a heavily insulated 4 wire electrical line. The anode is the net ring, and the cathode is the aluminum plate attached to the net pole. The unit is powered by 12 VDC power source. An on/off safety switch is placed on the pole. The electrofishing unit produces a 200 VDC output.

Results and Discussions

The chemical, physical, and biological properties of both sites are summarized in Table1. For the upstream locations, it can be seen that similar values are obtained for nearly all indicators. The exceptions were that the conductivity and sulfate values for Black Fork were approximately twice those of Kimble Creek.

From the indicators presented, the healthy conditions of the upstream location on Black Fork and Kimble Creek can be seen. Both have an optimum pH above 7. The alkalinity values are with in standard limits. The iron concentrations are only slightly elevated. The conductivity at the upstream location of Black Fork was slightly higher than Kimble Creek, but not unreasonable for natural waters. The elevated sulfate, a conserved AMD indicator, is present in both upstream locations. This suggests probable AMD in the upstream, but not enough to negatively impact other chemical or biological indicators. The QHEI value in Black Fork was slightly higher than Kimble Creek, however, both values indicate a pristine macrohabitat environment. The high IBI values substantiate all of the above parameters, with both streams exhibiting richness in species quantity and quality.

The downstream sites of both Kimble and Black Fork were heavily affected by AMD. In Black Fork, the pH decreased by 0.6 units, the alkalinity was one fifth of the upstream value, the conductivity tripled, and the sulfate concentration was six times higher. It is interesting to note that the iron concentration remained unchanged. Kimble Creek demonstrated substantial deterioration in water quality. The impact of the AMD is seen in all water quality indicators, especially in the pH of 2.69 and a net acidity over 700 mg/L. The conductivity was seven times greater, sulfate was more than 20 times higher, and the iron concentration was almost 100 times greater.

Table 1. Chemical, Biological, and Physical Data.

Alkalinity, iron, and sulfate are reported as mg/L, conductivity as m S/cm.

	Black Fork		Kimble Creek	
WQI	Upstream	Downstream	Upstream	Downstream
pH	7.46	6.86	7.14	2.69
Alkalinity	112	22	90	Acidity = 705
Conductivity	403	1260	270	2010
Iron	3.3	3.16	4.02	373
Sulfate	99	605	47	1100
IBI	44	28	46	12
QHEI	65	61.5	57	36

The downstream values of the Kimble Creek water quality indicators show a considerable deterioration to the stream from the AMD. A very low pH and the high net acidity verifies a heavy inflow of acid into the stream. The sulfate and iron content are quite high and those species are also reflected in the high conductivity. A QHEI value of 36, although slightly lower than the upstream location, suggests a fairly good macrohabitat. This would suggest that the macrohabitat is unaffected by even substantial AMD discharges. However, since the lowest possible value for IBI is 12, Kimble Creek at the downstream location shows a complete impairment of fish species in the stream, clearly indicating the disturbed aquatic environment.

The downstream location in Black Fork is a perfect example for stressing the need for biological assessments. The pH and alkalinity of the stream are well inside acceptable limits. The iron is only slightly above the permissible limit. The high sulfate content is the only indicator of an AMD impacted stream. Even the QHEI value demonstrates a near pristine macrohabitat, again stressing the fact that AMD does not significantly impact the macrohabitat. However, an IBI of 28 indicates the presence of few fish and low species diversity, which clearly confirms the poor quality of water (Rankin, 1989). From the chemical and physical data, one can easily assume that Black Fork is not severely impacted by the acid mine drainage, but the biological assessment confirms the presence of water which is not able to sustain aquatic life.

Conclusion

This paper suggests that chemical data may indicate some AMD impacted streams are biologically viable, however, comparisons of chemical and physical assessments to biological assessments are not always consistent with expected results. The IBI value verifies the biological viability of a stream. A complete remediation strategy for AMD affected streams should not focus solely on chemical indicators, but requires biological and habitat recovery as evaluated by IBI and QHEI.

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References

Eberhart, J.R. 1998. Characterization Of A Highly Acid Watershed Location Mainly In Perry County, Ohio. Masters Thesis, Ohio University, Athens, Ohio. 25-30.

Hocutt, C.H. 1989. Fish As Indicators Of Biological Integrity. Fisheries. 6:28-30.

Karr, J.R. 1989. Assessment Of Biotic Integrity Using Fish Communities. Fisheries. 6:21-27.

Karr, J.R. 1991. Biological Integrity: A Long–Neglected Aspect of Water Resource Management. Ecological Applications. 1:66-84.

Kleinmann, Robert L.P., Richard A. Allwes, Paul W. Jeran, Perry M. Jones, R.J. Matetic, and Robert Statnick. 1995. Environmental Issues of the Appalachian Coal Region. Mining Engineering. Dec:1120-1123.

Ohio Department of Natural Resources, Division of Mines and Reclamation. February 1998. Upper Pine Creek Watershed Acid Mine Drainage Abatement And Treatment Plan.

Ohio Environmental Protection Agency. 1989. Standardized Biological Field Sampling And Laboratory Methods For Assessing Fish And Macro-Invertebrate Community. Volume III.

Rankin, E.T. 1989. The Qualitative Habitat Evaluation Index (QHEI): Rationale, Methods, and Application. Ohio Environmental Protection Agency, Ecological Assessment Section, Division of Water Quality and Assessments. Columbus. Ohio.

Sobek, Andrew A., W.A. Schuller, J.R. Freeman, and R.M. Smith. March 1978. Field and Laboratory Methods Applicable to Overburdens and Minesoils. EPA600/2-78-054, PB-280495.

Stuaffer, Joseph C., and Robert M. Goldstein. 1997. Comparison of Three Qualitative Habitat Indices And Their Applicability to Prairie Streams. North American Journal of Fisheries Management. 17:348-361.

Thompson, Kevin G., and Eric P. Bergersen. 1997. Long Term Effects of Electrofishing on Growth and Body Conditions of Brown Trout and Rainbow Trout. North American Journal of Fisheries Management. 17:154-159.

Vannote, R. L., G. W. Minshall, K.W. Cimmins, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130-137.

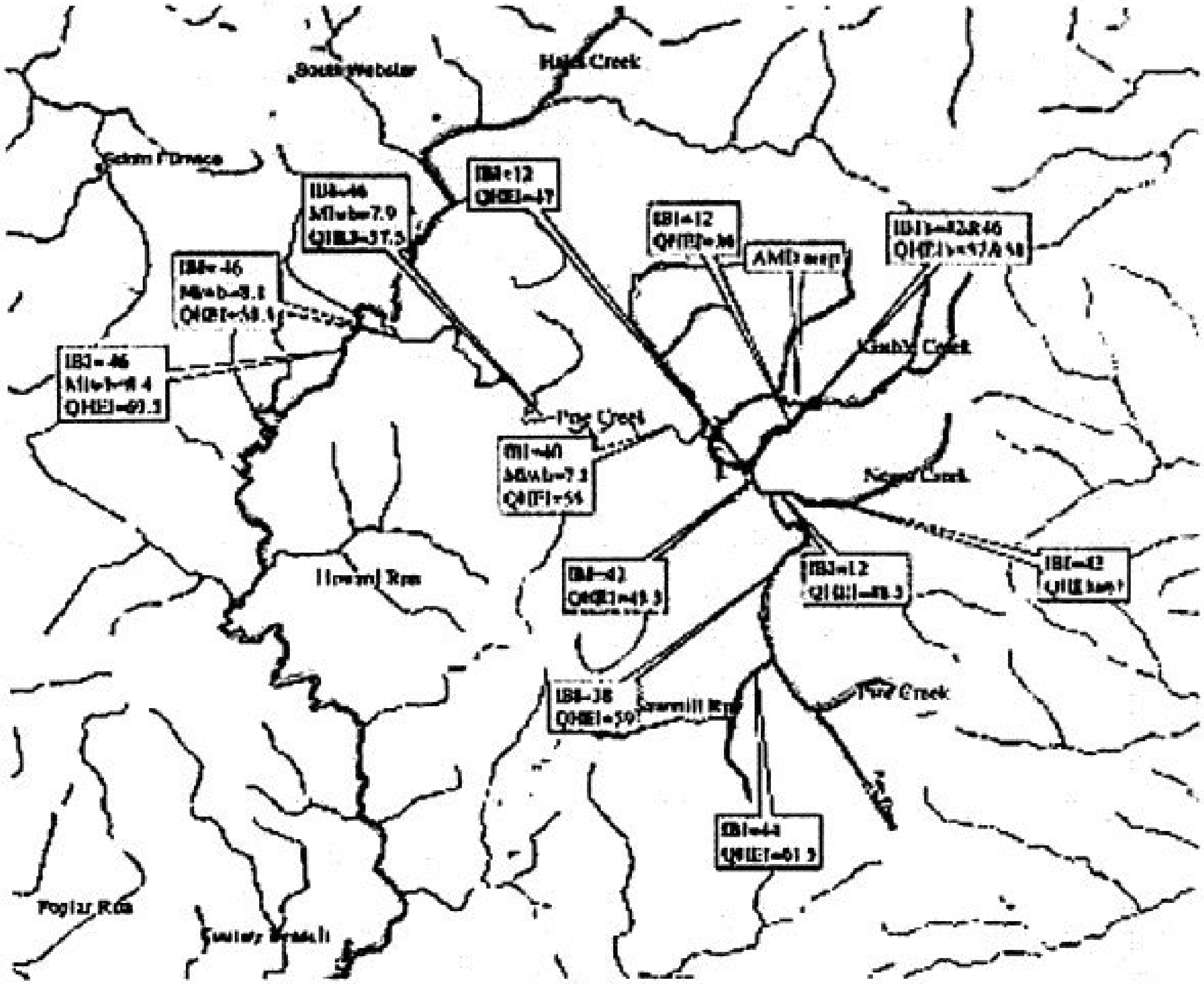

Fig 1. Upper Pine Creeek Watershed

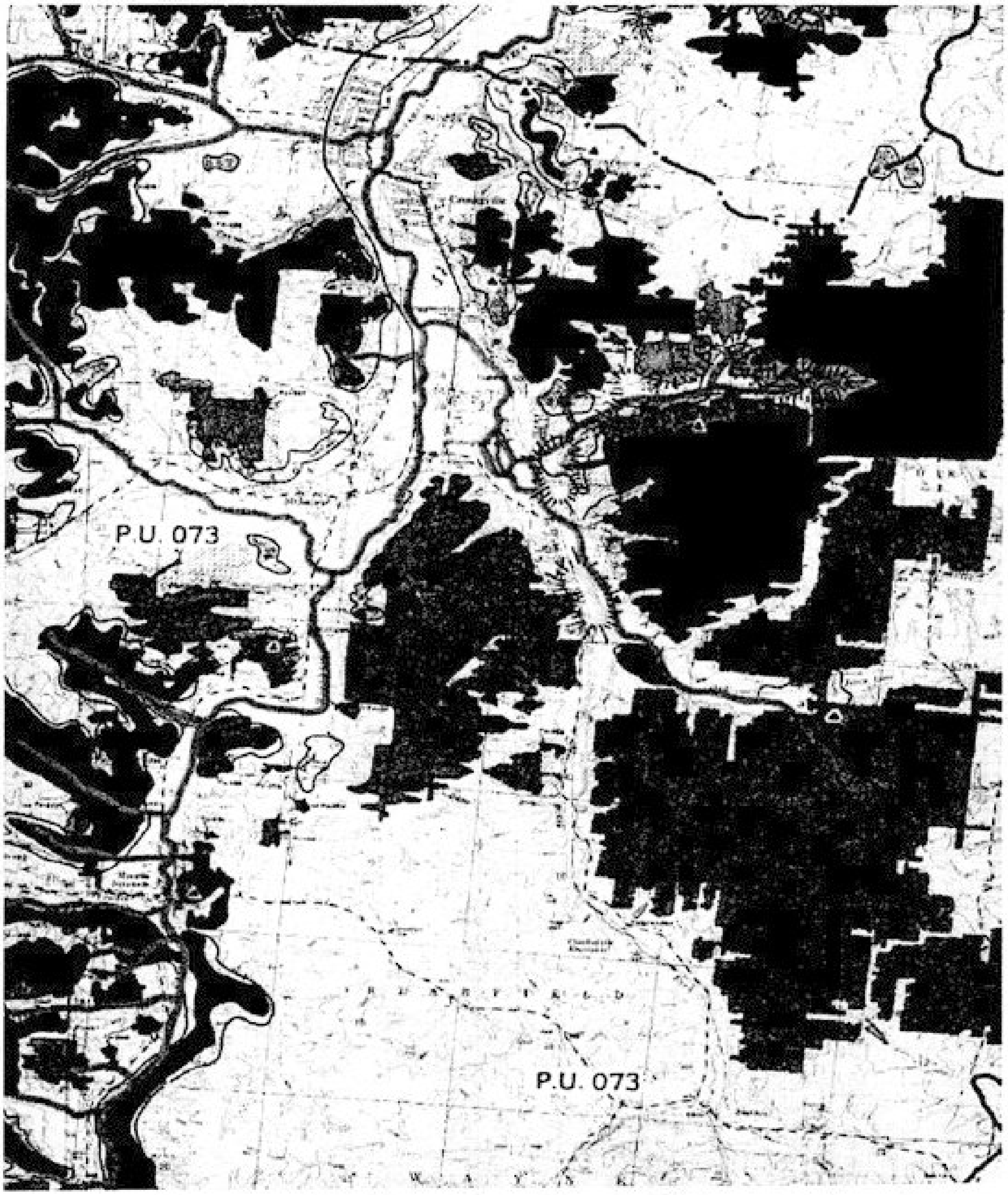

Fig 2. Moxahala Watershed

Long Line Method of Fish Stocking