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**Acid Mine Drainage:  
Studies in Remediation**

*THE CENTER FOR*



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*Rural Pennsylvania*

*A Legislative Agency of the Pennsylvania General Assembly*



# **Acid Mine Drainage: Studies in Remediation**

## ***Watershed Scale Assessment of an Acid-Mine Drainage Abatement Project in Clarion County***

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**AND**

## ***Developing a Geographic Information Systems (GIS) Methodology for Acid Mine Drainage Remediation Planning***

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These projects were each sponsored by a grant from the Center for Rural Pennsylvania, a legislative agency of the Pennsylvania General Assembly.

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## **PREFACE**

This report presents the results of two grant projects on acid mine drainage remediation, sponsored by the Center for Rural Pennsylvania.

The first grant project, conducted by Dr. Andrew M. Turner and a team of researchers with the Department of Biology at Clarion University, evaluated passive treatment systems for their effectiveness. Dr. Turner used the Mill Creek Watershed in Clarion and Jefferson Counties as a study area.

The second project, conducted by Dr. John Benhart Jr. with the Department of Geography and Regional Planning and Dr. Thomas Simmons with the Department of Biology at the Indiana University of Pennsylvania, developed a Geographic Information System (GIS) methodology for acid mine drainage remediation prioritization. Dr. Benhart used the Blacklick Creek Watershed in Indiana County as a study area.

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## INTRODUCTION

Mining has long been an important part of Pennsylvania's rural economy. In many cases, however, past mining activities have left a legacy of environmental degradation, and rural communities are now struggling to cope with the economic burdens associated with these problems. Perhaps the most acute problem is acid mine drainage (AMD).

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AMD is formed when mining activities fracture the bedrock that is situated over coal seams, allowing rain and ground water to percolate through the overburden and bringing the rock into contact with water. The water can become contaminated with high concentrations of dissolved metals, including iron, manganese, and aluminum. If neutralizing compounds are absent, the water can become quite acidic. When the metal laden water leeches from the soil and is exposed to oxygen, the metals will precipitate, creating even more acid. The metal precipitates deposit on stream bottoms, choking the substrate. The high levels of acidity and lethal levels of iron and aluminum in AMD can completely eliminate fish from streams while threatening drinking water supplies and choking streambeds with iron and sulfur precipitate.

In Pennsylvania, stream degradation has had far-reaching economic impacts, including the erosion of property values, loss of sport fisheries, and the impairment of other recreational activities. For example, the Pennsylvania Fish and Boat Commission estimates that the commonwealth loses \$67 million per year for recreational fishing due to AMD pollution.

In general, the term remediation refers to activities undertaken or treatment methods employed to minimize or remove pollution from a contaminated area. With respect to AMD remediation, the principal goals are to reduce metal loadings, such as iron, aluminum, and manganese, in streams and to reduce water acidity or raise water pH to acceptable levels.

This report will first present the findings of the research that evaluated passive treatment systems as a viable solution for AMD remediation. It will then

present the findings from the research on how GIS may provide assistance on determining where to begin treatment in a watershed.

### *WATERSHED SCALE ASSESSMENT OF AN ACID-MINE DRAINAGE ABATEMENT PROJECT IN CLARION COUNTY*

In the past, damaged streams were considered unrecoverable and an unavoidable consequence of energy development. The only treatment for AMD was by the direct addition of strongly alkaline materials, such as caustic soda, to the acidic discharges. Caustic soda treatment is effective, but is also expensive, so AMD was treated on a limited scale.

Alternative approaches called "passive treatment systems" were developed about 15 years ago. These systems are designed to funnel the AMD through limestone drains and artificial wetlands of various designs, thereby removing the acidity and metals. While there are potential drawbacks to these systems, passive treatment potentially offers several advantages over other treatment methods. For example, while passive treatment systems usually require larger areas for construction, they may cost less than alternative methods, allowing more effective use of the limited funds available for AMD treatment. Also, they generally require a greater initial capital investment but much less maintenance. Usually, they are designed to last 25 years, based on the rate of use of the materials placed into them when they are constructed; none that old exist, however, so the actual life span for the systems is unknown. Recognizing the many advantages of passive treatment, government agencies, watershed associations, and coal companies across Pennsylvania have increasingly employed these systems.

Given the large investment in AMD treatment, much of which is financed with public funds, there is a clear need to evaluate the effectiveness of these systems. However, because this is a new technology, there have been relatively few studies of its perfor-



mance in the field. In particular, there are no systematic studies as to whether intensive implementation of these systems can successfully remove enough AMD to allow an entire watershed to recover. Further, there are no studies monitoring the longevity of passive treatment systems.

### The study area

The Mill Creek Watershed uses two basic types of passive treatment systems; anoxic limestone drains (ALDs) and successive alkalinity producing systems (SAPS). These systems can be used individually or in combination. The objective of both types of systems is to generate alkalinity and to provide areas for the metals to precipitate.

Specifically, an ALD consists of a trench containing limestone. The ALD is covered by soil and is anaerobic (lacks oxygen). The AMD is channeled through the limestone, and as it passes through the ALD, the limestone dissolves and adds alkalinity to the water. Alkalinity additions as great as 300 parts per million can be achieved. As the water leaves the ALD and is exposed to oxygen, the increased pH promotes metal precipitation and the bicarbonate alkalinity neutralizes the acidity produced by metal hydrolysis (Hedin et al. 1994b). ALDs function particularly well when the water to be treated has a pH greater than 4.5 and contains no aluminum. Aluminum will precipitate in ALDs and clog them. Therefore, ALDs are generally only used where there are discharges very low in aluminum.

Prototype ALDs were first built by the Tennessee Division of Water Pollution control in 1988, as described by Turner and McCoy (1990). At the same time, Tennessee Valley Authority (TVA) personnel found that AMD from coal refuse was being neutralized by calcium carbonate limestone in an old road buried beneath a dam (Brodie et al. 1993).

About the same time that ALDs moved into the mainstream technology, it was observed that incorporation of bacterial sulfate reduction into constructed wetlands could increase alkalinity and the precipita-

tion of metals (McIntire et al. 1990). Kepler and McCleary (1994) used these early observations and incorporated bacterial sulfate reduction into a new passive treatment technology termed “successive alkalinity producing systems” (SAPS). The systems usually consist of a layer of limestone two or three feet thick overlaid with a couple of feet of rich organic matter. Mushroom compost, a byproduct of the commercial mushroom industry, has been used with success. A piping system is laid under the limestone to carry water from the bottom of the system. Usually there is one to six feet of standing water over the compost layer, so the AMD percolates down through the compost and then through the limestone.

These systems produce alkalinity by two different mechanisms: bacterial-mediated sulfate reduction and limestone dissolution. In the organic layer, sulfate-reducing bacteria oxidize organic compounds and reduce sulfates. The result is the creation of metal sulfides and alkalinity in the form of bicarbonates. The metals converted to metal sulfides remain in the sediment and are thus removed from the AMD. As the water then passes through the limestone layer, more alkalinity is created as the limestone dissolves. The microbial action in the compost ensures that the water entering the limestone is anaerobic and reduced, so no metals will precipitate in the limestone, clogging it. Through these two mechanisms that produce alkalinity, SAPS can produce a neutralizing capacity. A significant feature of SAPS is that they precipitate aluminum in the compost layer, so the limestone below isn’t clogged. Due to the precipitation of aluminum, SAPS must be flushed periodically. Some consultants have developed systems to recover the aluminum to prevent it from entering the stream into which the system discharges. ALDs and SAPS can be used individually or placed in a series to accomplish high treatment levels. Theoretically, with enough space, any quality and quantity of AMD water should be treatable by using multiple ALDs and/or SAPS in a series. However, in actual AMD

***THE OBJECTIVES OF THE PROJECT WERE TO ASSESS THE EFFICIENCY, STREAM WATER CHEMISTRY, COST-EFFECTIVENESS, AND RECOVERY OF BIOLOGICAL VALUES FOR SELECTED PASSIVE TREATMENT SYSTEMS IN THE MILL CREEK WATERSHED.***

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situations, space is usually limited, as are financial resources, so passive treatment systems are usually sized based on water quality, space and the financial resources available. The organic matter in SAPS seems to be the limiting factor in the amount of bacterial-mediated sulfate reduction that occurs (Demchak 1998). The two layers of SAPS work in a related manner. When sulfate reduction is less active, as occurs in winter when low temperatures slow down bacterial action, limestone dissolution in the SAPS increases. Conversely, when bacterial sulfate reduction mediated alkalinity production increases, limestone dissolution decreases. A number of people have suggested that the life of the compost layers in SAPS may be extended by the periodic addition of organic matter to the top layer. A number of experiments conducted in labs indicate that this is theoretically possible (Stark and Williams 1994).

Most of the passive treatment systems in the Mill Creek Watershed also include settling ponds and channels. These areas are designed to oxygenate the water so the metals will precipitate out. Frequently these areas become colonized by cattails and sedges, which provide more surface area for metals to precipitate.

### **Objectives and methodology**

The objectives of the project were to assess the efficiency, stream water chemistry, cost-effectiveness, and recovery of biological values for selected passive treatment systems in the Mill Creek Watershed.

The project began with an assessment of the current performance of passive treatment systems between four and eight years old relative to their initial performance. A water chemistry database was developed for each treatment system in the watershed. This included source water data collected before the systems were built as well as data collected from the systems after their construction. The data was derived from a number of sources including Clarion University, the state Department of Environmental Protection (DEP), and the U. S. Bureau of

Mines. Samples were taken in the summer 1999 as a part of this study. All samples were analyzed using the U.S. Environmental Protection Agency's (EPA) approved methods. Parameters entered into the database included acidity, alkalinity, aluminum, pH, iron, manganese, sulfate, specific conductance and temperature. Some data sets entered into the database did not contain data for all the parameters. The database was used to calculate each system's ability to remove selected contaminants over time. System efficiencies were calculated on the basis of percent removal of contaminants and total contaminant removal over time. Since the data sets for the systems did not have uniform densities of data, averages were taken of whatever yearly data were available to calculate the percent contaminant removal. In particular, the data for 1997 are sparse, resulting in the 1997 average values not corresponding well with the values of the other years. This lack of correspondence suggests that these values do not reflect the true performance of the systems in 1997, and it would be best to exclude these data from further analyses.

The second objective of the study was to assess the impact of installed systems on water quality in a stream degraded by AMD. To achieve this, a database was developed containing water chemistry data for 24 monitoring sites on Mill Creek and Little Mill Creek. Data included in this database came from Clarion University and DEP. In April and August 1999, additional samples were taken from 20 of the monitoring points, measuring the same chemical parameters as in the analyses of treatment system performance described above. The data were then used to analyze the effects of the passive treatment on water chemistry parameters in Mill Creek.

The third objective was to evaluate the cost-effectiveness of passive treatment relative to alternative methods of treatment. The cost effectiveness of passive treatment was evaluated by using the model developed by Skousen, Hilton and Faulkner of West Virginia University (Skousen and Ziemkiewicz 1996). They have developed a series of tables that estimate annual treatment costs for various active treatment modalities based on flow rates and acidity loading.





This model is widely used in the industry to develop cost estimates for active treatment. The first step calculated the amount of acid removed by each of the passive treatment systems and then calculated the cost of removing the same amount of acid using several different active methods. The comparison was annualized using a projected 20-year lifespan for the passive treatment systems.

To achieve the fourth objective of documenting the extent to which long-term passive treatment has led to the recovery of the biological values of the Mill Creek Watershed, macroinvertebrate and fisheries surveys were conducted. The Mill Creek Watershed is ideal for study because it is substantially impacted by AMD; it has received a relatively large number of treatment facilities, some of which have been in place for some time; and there is a substantial amount of baseline data. Ultimately, the recovery of Mill Creek or any other AMD impacted watershed is gauged on the return of a diverse aquatic fauna, and a large portion of the research was directed towards documenting the extent to which the biological features of the Mill Creek watershed have recovered. Clarion University faculty and students have surveyed invertebrate communities in the watershed since 1994, and these studies were compiled into a common database. The macroinvertebrate community was surveyed at 20 sampling stations. Invertebrates were sampled in May and again in August 1999, using the Rapid Bioassessment methodology developed by the EPA. In brief, four kicknet (D-frame sweep net, 1-mm mesh) samples were taken at each site, with 30 seconds of kicking expended for each sample. Two of these samples were taken from riffle habitats and were pooled together. The third sample was taken in pools, and the fourth was taken from vegetative debris. These samples were supplemented with a time-constrained effort to hand pick invertebrates from wood and other submerged substrates. The number of invertebrates sampled at a site was recorded on a large spreadsheet.

The effectiveness of passive treatment in restoring the fish populations of Mill Creek was assessed by comparing the current populations to the historical

database built by Clarion University faculty and students who have monitored fish populations in Mill Creek since 1992. Fish populations were surveyed in the spring and fall of 1999 by electrofishing through a 100 meter long transect at each of the 20 sampling stations. A single pass was made through each transect with a pulsed-DC backpack shocker equipped with two circular probes. Because the capture efficiency was less than 100 percent, the catches reflect the relative abundance of fish among sites, but underestimate absolute abundance. Captured fish were identified by species, enumerated, measured, and returned to the stream. Fish were surveyed in May and again in October 1999.

## Results

### ***Assessment of the performance of passive treatment systems over time***

Since the efforts in the Mill Creek Watershed entered their second decade in the year 2000, some of the systems built during the early years of the effort have a history of performance that can be assessed. The eight systems that have been functioning since 1996 or before were chosen for analysis of long-term performance. The data clearly demonstrates that the passive treatment systems built to date in the Mill Creek Watershed remove significant amounts of contaminants but vary in efficiency. Some have worked very well over a long period of time while others have shown signs of lower efficiency over time. It is not unreasonable to believe that the same degree of variation will occur among passive treatment systems built in many watersheds. There are many variables that contribute to this variation. They include, but are not limited to, ambient water quality and quantity, treatment system type and design, space, and money available for construction. A reasonable conclusion from the data collected on the treatment systems in the Mill Creek Watershed is that, as a rule, passive treatment systems do not always produce water that will consistently meet the Pennsylvania effluent standards applied to mine operators (iron concentrations less than seven parts per million, manganese less than five parts per million,

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pH greater than six, and alkalinity greater than acidity). Since most passive treatment systems built by watershed groups are on abandoned sites, it is not a requirement that their discharges meet state discharge requirements.

The treatment systems with the very best long-term results are those treating discharges with pH values greater than 5.5 and no significant amounts of aluminum. Those with the worst results are those with very low pH values, around 3.5, and significant amounts of acidity and aluminum, although some treatment systems are functioning well while treating this sort of water.

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### ***Assessment of the impact of passive treatment systems on stream water chemistry***

A database was developed for 24 instream sampling sites in the watershed; 11 on Little Mill Creek and 13 on Mill Creek. These sites were selected so that the effects of treating the 60+ AMD sites in the watershed could be assessed over the coming years. This analysis is of the stream monitoring sites located in positions that allow an evaluation of the effects of the treatment systems built to date.

Several stream monitoring sites in the Mill Creek portion of the watershed are particularly important for determining the effects of the passive treatment systems constructed on Mill Creek. Before any systems were constructed on Mill Creek, the stream still supported fish populations from its headwaters to where it joined Little Mill Creek. However, the input of AMD was easily detectable from the precipitated iron hydroxides on the stream bottom. The AMD entering Mill Creek from Little Mill Creek degraded the water quality in Mill Creek to the point that all fish and most invertebrates were eliminated from the stream. Treatment systems were built in two areas on Mill Creek. The water quality in Mill Creek above its confluence with Little Mill Creek has remained relatively consistent over the period of 1992 to present. The limited number of passive treatment systems constructed in Mill Creek have improved water quality, albeit only slightly. After treatment

system additions were completed in 1993, the Pennsylvania Fish and Boat Commission determined that the treatment system had improved water quality to the point where it would be possible to stock that section of Mill Creek. It has been stocked ever since.

The improvement of water quality in a stream that is impacted by a large number of AMD seeps can only be incremental as treatment systems are built to treat those seeps. On the upper part of Little Mill Creek there are 13 distinct AMD seeps. The picture that emerges in this area of Little Mill Creek is that when treatment systems were new and working well, there were demonstrated improvements in water quality at the monitoring sites below those sites. As the treatment sites declined in efficiency, the water quality at the downstream monitoring sites declined from its peak in 1996. This shows that during the period from 1995 to 1996 the stream was receiving enough treatment to produce positive results. The pH values were still below seven and the stream was just on the cusp of improvement. With the loss of treatment efficiency at lower sites, the stream data showed how important this last bit of treatment was. This suggests that as the newer upper stream treatment systems come on line and as the lower ones are modified, the water chemistry at these monitoring sites will improve significantly. Clearly, these data show that passive treatment systems can provide improvement in water quality in receiving streams.

A confounding issue that always rears its head when considering stream chemistry is flow. The anecdotal observation is that seep flows do not decline proportionately to stream flows. This means that as the water table drops, the chemistry in the streams will become worse as less dilution of the AMD occurs. Another confounding factor is infiltration of AMD directly into streambeds. This is a variable that cannot be controlled and may not be evident immediately from the stream data.

### ***Cost-effectiveness of passive treatment systems***

Acid mine drainage discharges can be treated using active treatment methods or passive treatment



methods. Passive treatment system technologies do not always meet state effluent requirements, but they are a cost-effective means of reducing contaminant loads from AMD discharges. Active treatment technologies, although more expensive, can assure that effluent water meets water quality standards. Almost exclusively coal companies have used the active treatment approach because they are required to meet those standards. The primary negative to active treatment is the extreme cost.

To treat AMD, one must choose between a more cost-effective alternative that is not always guaranteed to meet state effluent criteria (passive treatment) and a very expensive alternative (active treatment) that always will if enough money is spent. Of course passive treatment systems can be designed to get at least close to state effluent standards if conditions allow.

Many watershed organizations are attempting to treat AMD problems that come from abandoned discharges. By current DEP policies, those watershed groups are not required to meet the state standards and in fact should not be expected to, since whatever improvement they can make in the watershed is a plus over what existed before they became involved.

An analysis was developed that compares the cost of passive treatment in the Mill Creek watershed to the cost of removing an equivalent amount of contaminants using active treatment. For this comparison, the tables calculated by Jeff Skousen of West Virginia University were used (Skousen and Ziemkiewicz 1996). These tables allow a calculation of active treatment costs using a variety of treatment options. The calculation of cost is based on the flow of the system and the acidity in parts per million. Through this, the amount of money required per year to treat a particular flow at a particular acidity level can be calculated. The calculation of the annualized cost for the passive treatment technologies is based on a 20 year projected life span for the passive treatment systems although they are usually designed with a 25 year life expectancy. Three active treatment technologies were compared: caustic soda, lime, and ammonia.

There are two additional costs that should be figured into the annualized passive treatment system costs. The first is the cost of any maintenance that must be done on the system. Passive systems are designed to be as maintenance-free as possible, but some maintenance is required. It usually involves handwork with a shovel but sometimes can include heavy machinery. The specific maintenance activities will vary greatly from system to system. It might be reasonable to assume an additional 10 percent increase in the annualized costs for maintenance. Another additional cost is the cost of the capital to build the passive treatment systems. Active treatment occurs over a period of years and may be paid for as it occurs. Passive treatment systems, however, require an up-front investment of funds. Since most of the construction of passive treatment systems in Pennsylvania is being done by watershed groups with grant money, it is not clear that this is a totally appropriate cost to assign to passive treatment. However, if a coal company, which is a business, is considering using passive treatment as an alternative to active treatment, then this would be an appropriate consideration.

Even with 10 percent added to the annualized cost for the passive treatment systems, the cost of passive treatment to remove equivalent amounts of contaminants is generally one-half to one-third of the cost of active treatment. This fraction assumes that the active treatment technology used is the cheapest of the three. If one uses the most expensive active treatment technology listed, the cost of passive treatment becomes one-third to one-fifth the cost of active treatment.

### ***Effects of passive treatment on fish communities***

The effects of AMD on fish populations in the Mill Creek Watershed are clear: both Mill Creek and Little Mill Creek contain fish in their headwaters, but the fish disappear from both streams as they are impacted by AMD. To identify any effects of passive treatment on the fish populations of Mill Creek, the researchers examined the population sizes of fish at the long-term monitoring sites below the passive

treatment systems on Mill Creek. This data set dates back to the installation of the first passive treatment system and encompasses the time period that some of the last treatment systems came on line. With the exception of the 1999 surveys, these data show a steady increase in fish population sizes through time as would be expected as a result of improving water quality. However, this trend abruptly reversed in 1999, as most species declined in abundance that year. No strong statements can be made about the cause of this decline, but the severe drought in the fall of 1998 may have had a negative effect on Mill Creek fish populations.

The long-term data set shows that several species of fish that were formerly rare in Mill Creek are increasing in abundance throughout the watershed. Because these fish are increasing in abundance throughout the watershed, their success cannot be definitively linked to the installation of passive treatment systems, but it is certainly likely that the improved water quality in the watershed has played some role in their increases.

#### ***Effects of passive treatment on invertebrates***

Although improvement in water quality following the installation of passive treatment systems is clearly demonstrated in Mill Creek, a corresponding rapid recovery of biotic components of the watershed, in particular the macroinvertebrate populations, is less easily detected. This is not too surprising, as recovery of macroinvertebrates following mine-acid impacts can be very slow. Since the earliest passive treatment system in Mill Creek went on-line in 1992, it may not be realistic to expect to see dramatic changes in the macroinvertebrates inhabiting the watershed at this time. A diverse macroinvertebrate fauna was documented in the headwaters of both streams, and the northern tributaries to Mill Creek also harbor a diverse fauna (Ploski and Harris, unpublished data). As well, invertebrates are drifting out of the tributaries and are moving through the system (Royal and Harris, unpublished data). This would suggest that as water quality continues to improve in the watershed,

there should be a substantial recovery of macroinvertebrates over time as they move from areas of refugia into the main stream channels.

This is not to say that there has been no improvement in aquatic macroinvertebrates as a result of bioremediation in the watershed. There have been improvements, both in total numbers of invertebrates and in overall diversity, following the installation of passive treatment systems. These improvements have been detected over time following installation and by comparing populations above and below the facilities, but these improvements have been slight when compared to the undisturbed sections of Mill Creek and Little Mill Creek.

#### **Conclusions**

In short, passive treatment systems have the potential to treat AMD successfully over at least nine years as seen in the fact that most of the systems in the project area have accomplished significant reduction of contaminants. There has been some decline in effectiveness of some of the systems over time but mainly in sites treating water with significant levels of aluminum and a low pH. Given the cost comparison with active treatment, it is clear that passive treatment systems provide the most reasonable solution to watershed-scale reclamation projects.

The responses of fish and invertebrate populations have been modest and limited in scale. Most fish and invertebrates are quite sensitive to the contaminants in AMD, and thus water quality must be quite high before one would expect to see any large-scale recovery of the streams biota. Although the treatment has resulted in improved water quality, only a portion of the discharges in the watershed have been treated to date, and the remaining untreated discharges limit the scale of biological recovery. These results highlight the importance of complete and thorough treatment in order to recover the biological values of a watershed.

The construction of these treatment systems also has a positive impact on local economies since most of the construction activities are performed by local firms. Because most of these monies are spent on



labor and regionally available materials, the majority of this money ends up in the local community. In contrast, money spent on active treatment systems is largely used to purchase expensive chemicals, most of which are manufactured outside the local area.

A hidden cost of mining is that the residents of the area pay the cost of cleaning up AMD impacted water that is used for household or municipal water supplies. Homeowners often end up with water treatment bills of \$100 per month. Municipal water suppliers pass the cost on to consumers and it becomes a hidden “tax” on them. Improving the water quality in streams will improve groundwater quality and should reduce water treatment costs for residents of coal mining communities.

## Recommendations

1. *Passive treatment technology should be emphasized for the recovery of AMD impacted watersheds.* At this time, passive treatment is the most economical way to deal with AMD remediation. It will not guarantee complete removal of contaminants but can significantly improve the watershed.

2. *Specific treatment design should match the flow and chemistry of the water to be treated.* Very low pH water with high contaminant load requires SAPS of sufficient size for effective treatment since efficiencies at sites with this type of water can decline over time. Some sites were undersized due to space and financial constraints. As more people, firms, and government agencies become involved in the design of passive treatment systems, it is critical that the people involved be knowledgeable about the best designs available.

3. *Reclamation efforts should be made on a watershed basis.* Clearly, the people living in a watershed have the most interest in its health. Effective watershed organizations are critical to the success of any effort to reverse the effects of AMD. Also, treating one site in a watershed does little good if many others further downstream ruin the streams again.

4. *Serious attention should be paid to the operation and maintenance of passive treatment*

*systems.* It has become clear that even though these systems require much less attention than active treatment systems, they require some maintenance. To date, DEP, funding agencies, and watershed groups have paid little attention to the eventual removal of contaminants like iron and aluminum which are deposited into the systems. System efficiencies decline as they fill up and to maintain those efficiencies, appropriate disposal methods must be developed. New flushing and recovery methods have been developed for removing contaminants from systems, and designers must begin to take metal removal and recovery into account in their designs. There are three important changes that should be made in building passive treatment systems in Pennsylvania.

A. Each system should have an “owners manual” provided by the designer of the system. This manual would outline maintenance procedures to be done and methods for deciding when certain maintenance activities should occur.

B. Funding mechanisms should be put into place that provide for the long-term maintenance and perhaps eventual replacement of the system. To date, many systems have been built by watershed groups who have no means of maintaining them. Some of the decline in performance in several of the systems could be reversed with maintenance and replenishment of materials in the system.

C. Since volunteer watershed groups may not be able to operate and maintain passive treatment systems alone, government, such as DEP, should provide personnel to work with local watershed groups to handle this job. One professional could probably look after 50 to 75 systems as his/her regular job.

5. *A statewide registry of passive treatment systems should be developed.* The registry should include information on the treatment methodology, the quality and quantity of the water being treated, and some indication of the system’s efficiency. The specific location of each site should be listed for possible inclusion in a GIS database.

## **DEVELOPING A GEOGRAPHIC INFORMATION SYSTEMS (GIS) METHODOLOGY FOR ACID MINE DRAINAGE REMEDIATION PLANNING**

### **Background**

12 Until very recently, AMD remediation efforts in Pennsylvania were piecemeal and largely based on the requirements of funding sources. In June of 1997, the Pennsylvania Department of Environmental Protection's (DEP) Bureau of Abandoned Mine Reclamation (BAMR), the state agency specifically charged with addressing the abandoned mine land (AML) problem in Pennsylvania, published *Pennsylvania's Comprehensive Plan for Abandoned Mine Reclamation* to establish a framework for organizing AML reclamation and remediation efforts (this publication was updated and revised in June 1998). The premise of this publication was that to effectively address the AML problem in Pennsylvania, the resources of participants would need to be coordinated and priorities would have to be set to ensure cost-effective results. Some of the stated goals in BAMR's Comprehensive Plan are to: focus expenditures for AML reclamation on maximizing benefits; develop partnerships involving local citizens, local government, and other groups that promote abandoned mine reclamation; and develop an area approach to reclamation planning that will result in reclamation and rehabilitation of an entire geographic area.

Geographic, biological, and chemical data are all necessary for prioritizing AMD contamination sources for remediation. The question is: "How can organizations access, organize, and analyze the needed data in an effort to develop comprehensive watershed plans for AML remediation?" Part of the solution is the development of an explicit Geographic Information Systems (GIS) methodology for prioritizing AMD remediation sites that will be applicable to watersheds in Pennsylvania.

A GIS is an information system that has the unique capability to effectively handle spatial data (data

linked to a geographic map through coordinates or identifiers) as well as attribute data (data not explicitly linked to the earth's surface through coordinates or identifiers). A GIS allows the user to perform specialized spatial analysis operations such as distance measurement and multi-layer analysis in addition to more common database functions.

The purpose of this project was to serve as a pilot using the Blacklick Creek Watershed study area in Indiana County to develop a methodology for the prioritization of sites for AMD remediation.

### **Objectives and methodology**

Objectives in this study included gathering, preprocessing, and analyzing relevant data and developing a manual to help other groups follow the same process.

To gather relevant data, the researchers developed a database of information relating to AMD remediation prioritization and comprehensive watershed planning as outlined in BAMR's Comprehensive Plan for Mine Reclamation. This was the most complex and time consuming step and involved gathering relevant data for the study watershed (contamination sources, existing remediation projects, habitat assessment, macroinvertebrate sampling, location of present DEP stream sampling points, metal loadings and pH data from present stream sampling points), organizing and updating existing data, and conducting field work to gather new data (locating contamination sources, doing habitat assessment and macroinvertebrate sampling).

Data related to the location/characteristics of contamination sources came mostly from consultation with local citizens. The knowledge of watershed association members, regional DEP specialists, Natural Resources Conservation Service agents, and County Conservation District officers was the most important source of information relating to the location of AMD contamination sources.

*Rapid habitat assessment* was conducted on selected stream segments in the study area. This assessment allowed for the evaluation of the characteristics of the physical habitat that influences water quality of streams and the condition of the resident



aquatic communities. Macroinvertebrate sampling data allows a comparison of observed biological diversity to expected diversity based on rapid habitat assessment. The techniques used for benthic macroinvertebrate sampling and sorting were taken from DEP's Standardized Biological Field Collection and Laboratory Methods.

The next step was to preprocess the data gathered for use in a GIS. Here, the data gathered was incorporated into a GIS so that it could be geographically referenced, organized and analyzed. Preprocessing is a set of techniques for inputting data in digital format or converting it to digital format from hard copy so that it can be used within the GIS. This includes:

a) The development of *digital locational information* [sometimes through a Global Positioning System (GPS)] for contamination sources, existing remediation projects, and stream segments<sup>1</sup>. A GPS is an operational system of satellites in orbits that allows a user with a receiver to decode time signals and convert the signals of several satellites to calculate a position on the earth's surface. It may be necessary to travel to each of the AMD contamination and water sampling locations to collect positional data and bring the field-gathered files back to the GIS lab for differential correction processing.

b) *Differential correction*<sup>2</sup> to increase accuracy of GPS data. This process uses error data of satellite-reported coordinates for locations for which the exact coordinates are known (called a base station) to correct coordinate data gathered in a proximate area. Software is available for GPS units to perform the differential correction and to process the corrected

GPS files into a usable format for the GIS. This allows the sampling point data to be viewed and manipulated in the GIS along with other spatial and attribute data developed for the project.

c) *Keyboard entry of attribute data* about the characteristics of contamination sources, existing remediation projects, and habitat assessment and macroinvertebrate sampling of stream segments recorded in the field into relational database files.

Next, GIS analysis used gathered data to develop a logical and efficient prioritization plan for AMD remediation in the study watershed. This involves query, measurement, and overlay operations within the GIS to determine which areas are the most contaminated, the impact remediating a site(s) will have on the watershed, and which areas have the most biological potential if contamination is remediated. This information will be integrated so that it can be used in the development of an AMD remediation comprehensive plan for the study watershed area.

The capability of a GIS to organize, handle, and analyze the aforementioned data makes it an effective tool for addressing AMD remediation prioritization and comprehensive watershed planning issues. Query, measurement, and overlay operations were used to determine: a) which areas are the most contaminated; b) which areas have the most biological potential, regardless of contamination levels; c) which contamination areas are "downstream" in relation to which others, such as the amount of stream distance that will be cleaned by treating which contamination sources; and d) the derivation of

1 United States Geological Survey (USGS) 7.5 minute quadrangle maps served as the base to georeference (locate and record coordinates for) the above spatial features. The 1:24,000 scale quadrangle maps [USGS Digital Raster Graphics files (DRGs)] were used as the mapping base for the project for three major reasons: 1) their level of horizontal accuracy is high enough for watershed AMD remediation planning purposes (40 feet) 2) their cartographic characteristics (datum NAD27, scale 1:24000) correspond with significant amounts of spatial data accessible to the public free of charge via PASDA and other state and federal agencies 3) many local organizations have used USGS quadrangle maps as their mapping base in the past, therefore their data can be integrated into the GIS easily. Initially, spatial data was recorded in geographic (latitude-longitude) coordinates. Later, the data was processed into a State Plane projection and coordinate system (Pennsylvania South) for large-scale mapping and analysis purposes.

2 The U.S. Department of Defense (USDOD) intentionally degrades the coordinate reporting from its satellite constellation (NAVSTAR). Without using differential correction techniques, the best accuracy one could expect would be positions within 100 meters of a true location. To use differential correction as described in the text, a base station needs to be within 300 miles of the area where the data is being gathered, and the less distance from the base station, the better the correction.

***THE CAPABILITY OF A GIS TO ORGANIZE, HANDLE, AND ANALYZE CERTAIN DATA MAKES IT AN EFFECTIVE TOOL FOR ADDRESSING AMD REMEDIATION PRIORITIZATION AND COMPREHENSIVE WATERSHED PLANNING ISSUES.***

information that will be crucial to conducting cost/benefit analysis of site remediation, a requirement under the DEP Bureau of Abandoned Mine Reclamation (BAMR) Comprehensive Plan for Mine Reclamation initiative.

Finally, to assist other watershed groups in learning to use this technology, a manual was developed. *Building a Geographic Information System for Acid Mine Drainage Remediation Planning: A Manual for Nonprofits*, available through the Center for Rural Pennsylvania, provides detailed information about data development, GIS implementation, and partnership agreements that is directly applicable to watershed associations and other organizations in AMD-impacted areas.

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**Results**

In comparing the geographic distribution of habitat assessment and macroinvertebrate sampling results, it seems clear that something other than habitat conditions is negatively impacting aquatic biological conditions in the study area. The results suggest two things: 1) there is a good chance, based on conditions in the study region, that AMD contaminants in particular are causing significant negative impacts on biological

communities in the study watershed; and 2) targeted remediation of AMD contamination holds the potential to significantly improve biological conditions to create productive aquatic ecosystems in the study watershed. The water chemical assessment shows that all 6 potential chemical problems (acidity, aluminum, iron, manganese, sulfates, and low pH) are present in varying concentrations at different sites in the watershed. The GIS system was critical in collecting, organizing, and storing this data and would also be important in the next step – analyzing.

Locations of AMD origin in the watershed were ranked in terms of their chemical degradation based on distance of stream impacted and pollution load contributed by them. The BAMR problem assessment system of moderate, serious, very serious, and critical was employed, and seven sites were found to be very serious/critical.

The next step in comprehensive planning is a benefit assessment. The benefit criteria that BAMR has established are based upon the reduction or elimination of AMD-related problems as defined during the problem assessment phase. Benefit classifications are moderate, important, very important, and significant as per Table 1 below.

**Table 1: Project Benefit Classifications**

<b>MODERATE</b>	A <i>serious</i> problem will be substantially reduced > 75%; or a <i>moderate</i> problem will be eliminated.
<b>IMPORTANT</b>	A <i>very serious</i> problem will be substantially reduced > 75%; or a <i>serious</i> problem will be eliminated.
<b>VERY IMPORTANT</b>	A <i>critical</i> problem will be substantially reduced > 75%; or a <i>very serious</i> problem will be eliminated.
<b>SIGNIFICANT</b>	A <i>critical</i> problem will be eliminated; or a <i>very serious</i> problem will be eliminated and a significant functional <i>wildlife habitat</i> will be created.





No site rated significant in the benefit assessment, but seven sites were classified as very important.

A cost assessment should then be used to calculate the approximate cost of constructing and implementing a mitigation project that would ameliorate the contamination from any AMD discharge. Determining the cost of an AMD remediation project, based on the size and types of a treatment system(s), requires specialized knowledge in treatment system design and planning. Unfortunately, the local agent was not available to visit AMD discharge sites during the project period after the above problem and benefit assessments were completed. Costs are rated low, moderate, or high. For AMD-related water pollution control, any project with costs exceeding \$800,000 is considered high cost, between \$800,000 and \$250,000 is considered moderate cost, and less than \$250,000 is low cost.

Table 2, below, shows how to join costs (vertical) with benefits (horizontal) to determine a worth classification of low, moderate, high, or exceptional. Those with the highest worth receive highest priority for remediation treatment.

The pilot study of the Blacklick Creek Watershed provides a useful example of the advantages of GIS in prioritizing AMD remediation sites. The data gathering and analysis based on BAMR guidelines that have been completed for this study indicate three locations in the study watershed that would be classified as high-worth AMD remediation projects based on the above criteria (cost estimates of AMD treatment systems would determine the final worth

classification). One discharge appears to be the worst source of AMD contamination and therefore the highest priority treatment site. It contributes the largest absolute amount of any discharge of all five AMD-related contaminants (acidity, aluminum, iron, manganese, and sulfates). It also contributes over 86 percent of the loading of all of these contaminants to the local creek, obviously having severe negative impacts on water quality. Treating this discharge would have a positive direct impact on approximately 1.3 miles of water downstream, however, taking into account water quality upstream could be important as well. There are more than five miles of much higher quality water upstream that could be made into a longer continuous corridor of productive aquatic habitat by mitigating the contamination at this site. In addition, this site is upstream from other AMD discharge sites, which makes it a logical high priority location based on DEP's traditional policy of treating headwaters contamination sites before those farther downstream. Details on this process are in *Building a Geographic Information System for Acid Mine Drainage Remediation Planning: A Manual for Nonprofits*, developed for this project.

Integrating biological data is vital at this point. In this pilot project, one site was moved down the priority list below two others because it was determined through biological data that it would be better to treat discharges classified as having moderate benefit farther upstream before the one at the downstream location classified as having important benefit.

**Table 2: Benefit-Cost Project Worth Classifications**

COST/BENEFIT	MODERATE	IMPORTANT	VERY IMPORTANT	SIGNIFICANT
Low	Moderate Worth	Moderate Worth	High Worth	Exceptional Worth
Moderate	Low Worth	Moderate Worth	High Worth	Exceptional Worth
High	Low Worth	Low Worth	Moderate Worth	High Worth

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## Conclusions

The GIS developed was able to handle and manipulate spatial and attribute data in ways that provided crucial information for prioritization and decision-making. AMD discharge and origin locations in the study area were successfully prioritized for remediation through the project methodology, providing the basis for the development of a comprehensive watershed plan. Finally, a GIS methodology was developed that should allow other organizations

concerned with AMD contamination in Pennsylvania to derive data useful for the development of comprehensive watershed remediation plans.

For example, we must know the geographic location of AMD discharges in relation to each other, as it is crucial to know the upstream-downstream relationships of discharges. A GIS can handle and derive such spatial data and, in fact, this ability is what sets them apart from other types of information systems. Attribute data is stored in the database of a GIS and can be used in concert with spatial data to search for the answers to questions such as: “Which discharges contaminate X miles of stream and contribute greater than X percent of AMD contamination load?” Thus, the results of this study demonstrate that not only is GIS useful for AMD remediation prioritization, but that it provides the capabilities that are needed to integrate the geographic and non-geographic dimensions of the decision-making process.

The project also has high potential for replication. The positive factors are: 1) the availability of money to undertake the methodology through the *Environmental Stewardship and Watershed Grant Program* in Pennsylvania; 2) access to spatial data; 3) availability and willingness to cooperate with potential partners; 4) GIS grants programs for the acquisition of software and hardware exist for nonprofit groups; and 5) State System of Higher Education (SSHE) schools with geography and biology programs are located throughout Pennsylvania.

The major barriers to the adoption of this methodology appear to be difficulty in collecting data needed for GIS analysis and prioritization; and the lack of knowledge of GIS software and procedures.

See *Building a Geographic Information System for Acid Mine Drainage Remediation Planning: A Manual for Nonprofits* available from the Center for Rural Pennsylvania for detailed information on these assets and barriers.

## Recommendations

1. DEP and Pennsylvania universities with appropriate geographic information systems and/or biology programs should enter into a formal agreement to facilitate cooperation with nonprofit group activities under the Watershed Protection and Stewardship Act. The agreement would be a means of getting information to universities that watershed assessment and planning activities are being funded through the Watershed Protection and Stewardship Act and that they can play a significant role in their regions. For universities, this will be an institutional agreement indicating cooperation with the type and scope of activities outlined in this report. The agreement would provide an explicit opportunity to universities to fulfill their service mission in the commonwealth, which will benefit both institutions and citizens. In addition, the agreement could serve as a formal “introduction” for nonprofits that would like to approach universities for cooperation and support.

2. DEP should continue to give particular emphasis to funding watershed assessment and watershed planning projects under their Watershed Protection and Stewardship grant program. Certainly, projects that involve the construction of mitigation systems are very tangible and would have direct benefits in terms of water quality. However, the issue of equity and access funds for AMD remediation is equally as important. Some nonprofit groups know that their region is contaminated but have very little data to quantify the nature of the situation. Providing funds for watershed assessment and planning helps these groups “catch up” and will make it possible for a spectrum of nonprofits to develop competitive proposals and create positive change in their regions. In the long term, this approach will improve the data available about AMD in Pennsylvania and facilitate the development of a larger number of implementation

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proposals based on benefit-cost evaluation.

3. Nonprofits should partner with regional universities to use their knowledge about GIS and access Global Positioning System (GPS) capabilities for GIS data collection. Faculty and students would be involved with GIS development from the beginning and could answer some of the questions that nonprofit group members may have. As the GIS is built, universities can assist with data collection at low or no cost (students and class projects) and also serve as ongoing consultants to nonprofits.

In addition, universities may have GPS, which are sometimes needed by nonprofits for field data collection, and expertise related to differential correction of GPS data to incorporate in a GIS.

4. Groups such as the Environmental Alliance for Senior Involvement (EASI) should be trained and equipped to test for substances that are indicative of AMD contamination. Presently, EASI members collect data on the following: temperature, pH, dissolved oxygen, specific conductance, total phosphate, nitrates, total alkalinity, and sulfates. If such members had the capability to sample for more AMD-related substances (specifically total acidity, concentration and loading of aluminum, concentration and loading of iron, and concentration and loading of manganese, in addition to the above), increased amounts of chemical data would be available to nonprofit groups to characterize their watersheds without the expense and time required for large data gathering efforts. The other major positive aspect of this recommendation is that these groups have already been formed and are operating throughout Pennsylvania. They have already volunteered and are willing to spend their time collecting data to improve environmental conditions in their watershed. Following through with training and equipment to test for AMD-related substances would leverage the effectiveness of groups that have already been formed and might actually spur the formation of new EASI chapters when people in coal mining regions realize that water testing might help them.

5. To limit confusion and to provide direction, DEP should set out parameters and criteria for the GIS

data that they would like nonprofits to use for AMD remediation planning. DEP could provide recommendations similar to the ones in *Building a Geographic Information System (GIS) for Acid Mine Drainage Remediation Planning: A Manual for Nonprofits*. Spatial and attribute data sets available through the DEP-funded Pennsylvania Spatial Data Access (PASDA) website could be cited, encouraging public internet access to standard data. Specific recommendations would take away some of the uncertainty from the GIS development process and give nonprofit groups something to “shoot for” in terms of their data development. These recommendations would be only guidelines, so nonprofits would not be expected to reprocess data that did not follow the guidelines to be eligible to submit a remediation proposal.

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