# Building a Geographic Information System for Acid Mine Drainage Remediation Planning

## *A Manual for Nonprofits*

THE CENTER FOR

Rural Pennsylvania

*A Legislative Agency of the Pennsylvania General Assembly*

# Building a Geographic Information System for Acid Mine Drainage Remediation Planning

## A Manual for Nonprofits

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The Center for Rural Pennsylvania is a bipartisan, bicameral legislative agency that serves as a resource for rural policy within the Pennsylvania General Assembly. It was created in 1987 under Act 16, the Rural Revitalization Act, to promote and sustain the vitality of Pennsylvania's rural and small communities.

# TABLE OF CONTENTS

# INTRODUCTION

You've seen the signs of acid mine drainage (AMD) contamination in your watershed: the orange or milky-white water, the absence of aquatic life, the degraded landscapes. As a member of a group that is concerned about the many negative impacts of AMD contamination, you probably spend a great deal of time thinking about the steps you can take to improve this situation for the people of your region. This manual is designed to assist local, nonprofit organizations in understanding how they can take concrete steps to mitigate AMD and help improve water quality. It focuses on how to develop a Geographic Information System (GIS) about your watershed in the context of using the GIS to extract information that will be needed for a comprehensive AMD remediation plan.

You may be asking why you need a comprehensive watershed plan for AMD remediation since you know where the problem areas are. The short answer is that, presently, the agencies and organizations that provide funding for AMD remediation projects want to see planning for contamination cleanup at the watershed level. Rather than approaching remediation efforts on a piecemeal, project-by-project basis, many funding agencies such as the Pennsylvania Department of Environmental Protection (DEP) want a longer-term plan that shows how AMD contamination is going to be cleaned up throughout a watershed. This approach, they believe, will help achieve more positive results from the money spent for AMD cleanup. This manual explains how your group can build a GIS to organize the information needed to develop a watershed remediation plan and ultimately obtain funding for projects that can positively impact water quality.

A GIS will help with the four main steps necessary before beginning AMD remediation:

1. Problem classification – the most complex step is describing and defining the acid mine drainage contamination situation
2. Benefit assessment – what positive affects will come about if remediation is completed
3. Cost assessment – calculating financial costs of constructing and implementing an effective remediation project
4. Worth determination – analysis of whether the benefits are worthy of the costs

These steps are discussed later in this manual.

## *What Is a GIS?*

A Geographic Information System (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). In other words, information about an area is linked to where that area is on a map. 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. Why is GIS relevant or especially useful for AMD remediation planning? The most important reason is that a GIS can store information about the nature of AMD contamination (such as pH, Iron, and Aluminum concentrations) as well as about the *location* of the source of the contamination. Because of these capabilities, GIS provides information to decision-makers about where the worst AMD contamination is coming from and can pinpoint the best places to treat it in the watershed, based on factors such as upstream or downstream locations in the watershed and distance of stream impacted by a single discharge.

# CHAPTER 1: THE DECISION TO USE GIS AS A TOOL FOR REMEDIATION PLANNING

The decision of whether or not an organization uses GIS as a tool for AMD remediation planning is an important one. Organizations may ask why they would want to spend time and money on building and using a GIS when it is not *directly* related to cleaning up AMD. This same question has been asked by many organizations over the last 20 years when weighing the benefits and costs of using GIS. A large part of the answer is that a GIS is the best way to organize, store, and present data about the nature of AMD contamination. Ultimately, using GIS will ensure that your limited resources are targeted to the appropriate sites.

In fact, many state and federal governmental entities have made GIS the basis of how they will store and access data in the 21$^{st}$ century because of its ability to manipulate and analyze data relating to location(s). For example, DEP has invested heavily in GIS technology, launching an Internet GIS application called the Pennsylvania Environmental Navigator Network (PENN) system. DEP is using the system to provide "efficient, user-friendly…query and GIS analysis for natural resources and permits throughout the state." The federal Environmental Protection Agency (EPA) has also made a large investment in GIS as the mechanism to house and analyze its environmental data. In its National GIS Program overview, EPA states "Protecting the environment is a job that is inherently geographic in nature…Achieving an informed understanding of the often complex spatial inter-relationships of natural resources and human population as they relate to potential or known pollution sources is critical to successfully accomplishing the mission of the EPA." Thus, the largest environmental organizations in Pennsylvania and the United States have made the decision to implement GIS.

Building and implementing a GIS for any purpose is a significant undertaking. As noted by the following four factors, however, there is more support than ever before for nonprofit groups who want to pursue GIS development as a means to achieve AMD remediation.

## Factor 1: Environmental Stewardship and Watershed Protection Act

The passage of the 1997 Pennsylvania Environmental Stewardship and Watershed Protection Act, which is part of Pennsylvania's Growing Greener initiative, authorizes DEP to award grants for watershed AMD contamination assessment, watershed AMD planning, and AMD remediation projects (www.dep.state.pa.us/growgreen/defaultdep.htm). Grant money available through the program can make it possible for your group to undertake watershed assessment activities, including collecting data about AMD and incorporating it into a GIS. Once watershed data is housed in a GIS, analysis of that data for the development of an AMD remediation plan becomes feasible. A watershed AMD remediation plan that is a product of accepted data collection and analysis methods makes the mitigation projects more competitive among grant makers. To conclude, money is available in Pennsylvania for GIS development as part of AMD watershed assessment and planning activities, and once the GIS is implemented, its capabilities may help your group get grants to fund the construction of mitigation projects.

## Factor 2: Hardware/ Software Grants

Opportunities presently exist to obtain GIS software and/or hardware through grant programs for no cost. DEP has an ongoing grant program called the Geographic Information System Software Grant Program that is targeted specifically to providing GIS capabilities to nonprofit organizations. The program provides software licenses, free (mandatory) training sessions, and statewide and regional data sets to awardees as part of a grant (www.dep.state.pa.us/external_gis/gis_information.htm).

Another program that provides GIS capabilities for nonprofits is the Conservation Technology Support Program. This program provides hardware and GIS software and is available to nonprofit groups working actively to protect and restore the natural environment (www.ctsp.org/guidelines.html).

Some software companies also provide software and data to groups that are actively involved in conservation efforts and can articulate their need for GIS (www.conservationgis.org/ecpstory/ecpform.html).

## *Factor 3: Partnerships*

Another positive factor for nonprofits implementing GIS is the openness of many local, regional, state and federal organizations to partnership and cooperative relationships. Since nonprofit groups in most cases consist of volunteer members who may have full-time jobs and cannot devote all of their time to the group's activities, and since most groups do not have funds to hire consultants to collect and analyze data for them, cultivating partnerships with organizations that can provide some needed capabilities and services can be very beneficial. The good news is that many of these organizations exist throughout Pennsylvania so nonprofit groups should be able to reach out to them for assistance with remediation planning and associated activities. Other organizations may be interested in partnering with your group because it may help them to accomplish their goals. Your potential partners might also recognize AMD contamination as a problem in your region and want to help do something about it.

### Local and Regional Partners

Local and regional planning agencies are some of the best and most productive partners to help with AMD remediation planning. These agencies know the region that you are working in and know the "lay of the land" in terms of local planning and political issues. In addition, planning agencies are among the largest group of GIS users in the United States. Planning agencies in your region may already have started developing GIS data that your group could use for AMD remediation planning purposes. Other local and regional partners may include utilities, Regional Economic Development Corporations (REDCs), Local Development Districts (LDDs), and county conservation offices.

### Federal and State-Affiliated Partners

Many state and federal agencies recognize that the key to improving environmental conditions is the involvement and cooperation of the local community. They know from experience that local citizens tend not to respond well to outsiders

**Pennsylvania Colleges and Universities with GIS Curricula**

Bloomsburg University of PA
California University of PA
Clarion University of PA
Indiana University of PA
Kutztown University of PA
Millersville University of PA
Pennsylvania State University
University of Pittsburgh-Johnstown
Shippensburg University of PA
Villanova University
West Chester University of PA
Wilkes University

imposing regulations and solutions. In fact, these agencies recognize that, in many cases, they need to enlist the help of citizens to be successful. This approach is also cost effective for state and federal agencies. In most cases, state and federal agencies will embrace your concern and cooperate with your group in an effort to forward your objectives and theirs.

The ways in which state and federal partners may participate include becoming members of the organization, serving as subwatershed coordinators, providing data, providing expertise, providing land, and providing grants.

Faculty and students from state system and state-related universities can be instrumental in helping to collect and analyze biological data and appraise the environmental impacts of AMD. Universities with these capabilities exist throughout Pennsylvania, and faculty at these institutions may be open to working with your group. The list on the bottom of page 8 may not be comprehensive but it provides a place to start.

### Private Sector Partners

No one wants to live in a region obviously blighted by AMD, and most people recognize that contaminated sites, discolored water and dead streams only serve to negatively impact prospects for economic development and job creation. Private sector enterprises in your region may already be looking for an opportunity to help do something about the problem. In Indiana County, the Blacklick Creek Watershed Association (BCWA) has received significant support from regional private sector firms including companies involved in energy, civil engineering and planning, and constructed wetlands and mitigation design. These firms have provided machinery and labor for building mitigation systems, system design expertise, and monetary support. The energy companies are presently involved in reclaiming two major coal waste piles (removing major sources of AMD) and are experimenting with methods of burning coal waste in a mixture with “new” coal. These partnerships have leveraged the activities of the BCWA and contributed to a positive view of these firms in the region.

Identifying partners that are willing to cooperate with your group’s efforts and determining what they can do to help can be a major step in building a GIS and developing a comprehensive watershed AMD remediation plan.

## *Factor 4: Data Availability*

Public access to the type of GIS data needed for AMD remediation planning has increased dramatically since 1998.

## Where to get data

Before beginning data collection, your group should explore the possibility of a partnership with another group that may already have spatial data sets for your region. In fact, you may find that using these data sets makes a lot of sense and that the rest of your data gathering will correspond to the characteristics of what you have obtained locally.

If you have to start from scratch, the Pennsylvania Spatial Data Access, or PASDA, website at www.pasda.psu.edu is a very important source of spatial data for Pennsylvania relating to a variety of phenomena. PASDA is the official geospatial data clearinghouse for the Commonwealth of Pennsylvania and provides free access to geographic data produced by a variety of local, regional, state and federal agencies. This site makes the capital and knowledge requirements of starting a GIS database lower for nonprofit groups than they have ever been before. PASDA data is available via direct download from the web site and, in most cases, can be used with commercial GIS software with minimal processing.

## What to get

Upon visiting the PASDA web site, it becomes apparent that there is a large amount of data available for public use - what may not be apparent is the data you actually want. To begin developing base map layers, the following spatial data will be useful:

1) streams (networked);
2) roads (PENNDOT); and
3) watershed boundaries. [1]

These spatial data layers available at the PASDA site have the following common characteristics:

1) they have been developed from the United States Geological Survey (USGS) 7.5 minute, 1:24,000 scale quadrangle map series, which are widely used;
2) they are based upon the North American Datum of 1927 (NAD27);
3) no map projection has been applied to them; and
4) their map coordinate systems are latitude-longitude (specified in decimal degrees).

These data layers may be used together without further processing in a GIS to help you begin building your base maps. An advantage of files with the above spatial data characteristics is that a large amount of free accessible data at PASDA and other similar sites have these characteristics as well. Keep in mind

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[1] Additionally, you may want to download the digital raster graphics files (DRGs), which are simply digital image representations of the 1:24,000 series quadrangle maps. These are nice as “backdrops,” and the spatial data that has been suggested for download will match up with features on the DRGs. DRGs are referenced and listed by their USGS quadrangle sheet name.

that many of these files are very large and require a fast internet connection, so contact the source directly if you cannot download them.

How can you figure out what characteristics a spatial data set has? The answers are found in a document that should always be available for spatial data sets – the *metadata* document. Metadata supplies information that a data user will need to use a spatial data set. In fact, you should always review the metadata document for a data layer so that you are familiar with its spatial characteristics (such as map projection, coordinate system, scale, datum) and the methods used to develop the digital data. For an example of a metadata document, go to http://www.pasda.psu.edu/documents.cgi/coal/anthracite/ant-ashland_pa.xml.

## After obtaining the basics

If you choose to use the data layers suggested above, your base map configuration is set. Any further data collected will be based upon the stream, road, and watershed boundary layers that you have downloaded. You may want to look at these layers and make some decisions regarding their local accuracy and completeness. Chances are they will be fairly accurate and complete, however, a few smaller tributaries may be missing, or your watershed boundary may not correspond exactly to the one you get from PASDA. If this is the case, rely on partners such as regional universities or consulting firms with experience in editing spatial data to help you analyze and update before proceeding. In general, you probably will either want to clip one or more of your layers to correspond with an areal boundary (like a watershed) or add some features such as small stream tributaries.

Remember, free data is not likely to be perfect, but at least you don't have to "reinvent the wheel" and spend large amounts of money that you may not have. Using appropriate methods, you can build on the suggested layers to develop usable spatial data. Even if your group feels that some spatial data editing is in order, you can delay it if necessary and move forward with some other important data gathering.

# CHAPTER 2: DATA COLLECTION

The two steps necessary before a classification can be given to an AMD problem are locating the contamination sources and gathering data on them. In these steps, GIS is extremely helpful.

## *Locating AMD Contamination Sources/Discharges*

Perhaps the most important information that will aid in the description and definition of the contamination problem in your watershed is the source location of the AMD. Specifically, you need to know *where AMD is originating* and *where it discharges into main stem rivers and streams*. How should you go about obtaining this information? The two sources likely to be most helpful are DEP and local citizens.

DEP monitors water quality at locations throughout Pennsylvania that have active mining permits. The DEP staff in your region should have a very good idea of where many of the AMD discharge locations are located, even if DEP is not presently monitoring them. County conservation district employees and Natural Resources Conservation Service (NRCS) agents, although not specifically concerned with AMD contamination, also know what is going on in watersheds. In addition, there exist digital statewide spatial databases produced by DEP's Bureaus of Abandoned Mine Reclamation (BAMR) and Mining and Reclamation (BMR) that include information on abandoned coal refuse sites, permitted mining sites, deep mine entry locations (BAMR) and active permitted mining sites and coal seam locations organized by USGS 7.5 minute quadrangle sheet, called Statewide Coal Seam Coverages (BMR). BMR data is available through the PASDA site, and BAMR data may be obtained by contacting the Bureau's Harrisburg office. BAMR data sets are not housed at PASDA because they are very large statewide files that are constantly changing. Together, data sets from BAMR and BMR may provide a start and/or a reference for locating AMD contamination. However, in some cases they may not be complete and can be difficult to understand because it is not always readily apparent what the codes associated with the features mean. These files may also require processing to use directly with the spatial data layers described above as data may have a different map projection and coordinate system.

In all likelihood, the people who live in the watershed and are familiar with it will have the best idea of where mine openings, boreholes, seeps, and pipe discharges are located. This personal knowledge must be translated into digital geographic data so that that the nature of the problem in your watershed can be explained to anyone. There are two ways to do this:

1. Identify locations on a widely used base map series: Identifying AMD contamination origins and discharges on a base map (for example, USGS 1:24000 quadrangle maps) involves determining their locations relative to some other features shown on the map, such as streams, roads, or intersections. This is a fairly straightforward process, and in many cases this method will allow the location of a majority of the AMD discharges. For example, if there are several contaminated tributaries that flow into a higher order stream and all of these are shown on a USGS quadrangle map, you would specify the intersection of each tributary and the stream as an AMD discharge location. If you have downloaded the DRG files, you can bring them up in a GIS software program and specify locations directly "on top of" them to create a layer of AMD contamination points. The origins of AMD are sometimes more difficult to specify in this manner. In many instances, old mine openings, boreholes, and strip mines are in isolated areas that are not close to the main drainage channels. In these areas, roads and streams shown on a USGS quad map may not be nearby, and it can be more difficult to use relative location to get a decent approximation of the AMD emanation. In these circumstances, another method may be more useful.

2. Global Positioning Systems (GPS): Global positioning systems (GPS) are a method of determining location on the earth's surface. A user carries a GPS unit to the desired spot and the unit receives and records a digital definition of that location via a system of orbital satellites. If you feel that GPS data collection is necessary, consulting with partners with expertise in this area is advisable. In general, however, these are the steps to incorporating GPS data into your GIS:

a. identify appropriate output of GPS-collected spatial data to correspond with base mapping layers;

b. collect data with a GPS unit that has file storage capability;

c. perform real-time or laboratory differential correction on the data collected; and

d. process the GPS data files into a format that can be read by GIS software.

A specific discussion of the GPS collection methods that should be used to correspond with the base mapping layers recommended in this manual is found in Appendix A.

In general, the more AMD locations that you can ascertain using existing base maps, the better. Developing a partnership with a local university or consulting firm to help with GPS data collection could be very useful. However, as the above discussion illustrates, without some help from partners, GPS data gathering can be a costly and complex proposition that may not be necessary to get your project off the ground. If you do not have partners, initially, that can help with GPS, start by recording the locations of discharges that can be identified on USGS base maps. You may even want to estimate where other AMD locations are using the quadrangle maps and noting that these are "guesstimates." Over time, your group may be able to develop relationships with partners that will provide GPS data collection and processing consulting or services. When this happens, you can ask for help in updating or improving the spatial data you have about AMD.

## What Attribute Data Do You Need to Describe Your AMD Problem?

The data that will be important to your group for describing and analyzing your AMD problem will relate to water chemistry and biological ecosystem health. Your analysis of this data will provide funding agencies with the information they want to make decisions about which AMD remediation projects they will fund. Again, draw on your partners to provide data, expertise and facilities, if possible. Specifically, biology and chemistry departments at regional universities could be very helpful in assisting your group in collecting and processing samples.

**Pennsylvania Guidelines for AMD-related Substances in Water**

| Chemical Criteria | Acceptable Values |
|---|---|
| pH | 6.0 – 9.0 |
| Total Iron | Maximum 1.5mg/L |
| Total Aluminum | If pH is > 6.0, Al levels > 0.7 mg/L are unacceptable<br>If pH is <6.0, Al levels > 0.6 mg/L are unacceptable |
| Total Manganese | Maximum 1.0 mg/L |
| Sulfates | Maximum 250 mg/L |

## *Water Chemistry*

Chemical testing of water is a method that is often used to determine water quality. With respect to acid mine drainage contamination, there are five chemical parameters that are normally used to gauge water quality:

1) acidity (pH)
2) aluminum
3) iron
4) manganese
5) sulfates.

Water chemistry results are generally reported in two ways: the concentration of a substance in water, which is often recorded in milligrams per liter (mg/L); and the loading of a substance, or the total amount contributed to a water body or watershed over a particular time period, which in many cases is recorded in pounds per day (lbs./day). For the purposes of analyzing AMD contamination patterns and remediation, both methods of reporting are useful as they provide a total description of water quality and contamination contribution for sampling locations. Loading data can gauge the total amount of contamination and is important in evaluating remediation that may be required and in prioritizing locations for AMD remediation. See Appendix B for a detailed discussion of the recommended analytical water chemistry testing methods.

Water testing for the above chemical parameters should be conducted at four types of locations:

1) where AMD discharges into streams;
2) where AMD originates;
3) upstream of AMD discharge locations; and
4) downstream of AMD discharge locations.

For AMD remediation analysis and planning purposes, AMD "discharges" are defined as locations where contamination is entering stream channels (many times from smaller tributaries). Contamination "origins" are defined as locations where AMD originates (many times not adjacent to streams). In general, water chemistry is evaluated in terms of state guidelines for particular substances. The state guidelines for AMD-related substances in water are shown in the chart on page 14.

Sampling upstream and downstream from AMD discharges provides data on water quality before and after the location where contamination enters the stream, lending some insight to the impact of any discharge on the chemical characteristics of stream water.

### Acidity

An important factor in determining the health of aquatic ecosystems is pH. A key impact of AMD in many cases is to create acid conditions identified by lower water pH. Most aquatic organisms have a defined range of pH tolerance within which they can survive. For AMD testing purposes, a pH reading of below 6 is considered indicative of acid contamination based on water quality guidelines adapted from Chapter 93 Water Quality Standards of the Pennsylvania Code (PA DEP 1997).

## Aluminum

Under pristine conditions, aluminum rarely occurs in water at concentrations of greater than a few tenths of a milligram per liter. In combination with low pH, aluminum can have severe adverse effects on stream aquatic life. Aluminum ions compound the effect of low pH. Research results reported by Earle and Callahan (1998) indicate that a combination of a pH of less than 5.5 and dissolved aluminum concentrations greater than 0.5 mg/L will generally eliminate all fish and most macroinvertebrates. Precipitated aluminum is also a problem as it coats stream substrate ruining macroinvertebrate habitat, accumulates on fish gills interfering with breathing, and under some conditions can be directly toxic to macroinvertebrates and fish (Brown and Sadler 1989).

## Iron

Iron is commonly present in acid mine drainage and can have detrimental effects on stream ecosystems and aquatic organisms. Although dissolved iron is not generally considered as toxic as aluminum in solution, severe impacts have been documented in water with pH lower than 3.5 (Letterman and Mitsch 1978; Wiederholm 1984). This is because iron stays in solution at low pH but precipitates out when pH rises. Iron precipitate from acid mine drainage may result in complete coverage or armoring of a stream bottom (called "yellow boy"), adversely affecting both macroinvertebrates and fish. The severity of impacts from iron armoring in general are linked to the acidity of water – the lower the pH, the more severe the impact of iron (Earle and Callahan 1998; Hoehn and Sizemore 1977).

## Manganese

Manganese is another heavy metal contaminant that is often associated with acid mine drainage. Manganese is persistent and can be carried long distances downstream from a source of acid mine drainage. This persistence is due to the fact that manganese is usually difficult to remove from contaminated water since the pH must be raised to above 10 before the metal will precipitate out. The specific impacts of manganese itself on aquatic life are not clear as it tends to be associated with other metals that have a more pronounced impact (see above) or which may mask the effects of manganese. Research indicates that manganese tolerance of various fish species varies widely and that the toxicity of dissolved manganese is lowest in water with low levels of hardness (Earle and Callahan 1998; Kleinmann and Watzlaf 1988).

## Sulfates

Sulfates do not necessarily have specific negative impacts. Their presence, however, may indicate whether AMD is, or has been, a problem at a particular location. Since AMD results in the formation of sulfuric acid, even if acid is neutralized, sulfates will be left behind providing evidence of the past impacts of AMD. Sulfates may also have effects on organisms, which could be detected.

## *Biological Data – Macroinvertebrate Sampling*

Macroinvertebrate sampling is a method of gauging existing biological conditions in terms of determining what species and/or families of macroinvertebrates are *observed* in a particular location(s). The presence or lack of a benthic macroinvertebrate[2] community is a significant indicator of the chemical, physical, and biological characteristics of a stream (DEP 1997a; EPA - Plafkin, Barbour, Porter, Gross, and Hughes 1989; Koryak, et al. 1972). It has been scientifically established that macroinvertebrates are sensitive to pollution and therefore serve as indicators of a variety of biological sensitivities that may be caused by pollution sources (Buikema and Voshell 1993; Johnson, Wiederholm, and Rosenberg 1993). Using benthic macroinvertebrates as a stream quality indicator has several advantages. They have limited migration patterns, they respond quickly to stress, they are easy to identify, and they are relatively abundant (EPA - Plafkin, et al. 1989).[3] See Appendix C for a discussion of recommended macroinvertebrate sampling and identification methods.

Once the macroinvertebrate samples are collected and the organisms are identified, a classification scheme is applied based on the level of AMD contamination impact implied by the characteristics of macroinvertebrate communities observed at sampling locations. All benthic macroinvertebrate sampling sites can be ordinally ranked from 1 to 5, where: 1 = Little to No AMD present, 2 = Slight AMD impact, 3 = Moderate AMD impact, 4 = Heavy AMD impact, and 5 = Severe impact. These classifications allow a characterization of the biological impact of AMD contamination at particular locations based upon observations of organisms that typically are good indicators of aquatic ecosystem health. See Appendix C for details of the classification scheme.

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[2] Benthic refers to inhabitants of stream substratum, macro indicates the size (>0.2-0.5mm), and invertebrates are organisms without vertebrae. Macroinvertebrates have an important ecological role because they are the primary link in the food chain between microorganisms and fish.

[3] Biological data such as macroinvertebrate sampling is not specifically addressed in DEP BAMR's *Pennsylvania's Comprehensive Plan for Abandoned Mine Reclamation*. Therefore, if one were trying to comply strictly with the data requirements set out in the Comprehensive Plan document, it would not be necessary to collect and analyze macroinvertebrate data. The investigators for this project felt that macroinvertebrate data was important to understanding the impacts of AMD in streams.

# CHAPTER 3: ANALYSIS OF THE GIS DATA

## *BAMR Water Pollution Classification*

It is recommended that GIS analysis based on DEP Bureau of Abandoned Mine Reclamation's (BAMR) project classification methods be followed to determine which AMD sites to tackle first. In the document, found at www.dep.state.pa.us/dep/deputate/minres/bamr/complan1.htm, many different types of problems relating to abandoned mine lands are discussed, and the information may be applied to AMD for your project.

In terms of your group's GIS applications, the most important aspect of AMD impact is water pollution. BAMR describes water pollution problems as those relating to streams that do not meet state water quality standards, where impact on streams is the key impact to be considered (DEP 1997, Appx C). BAMR's suggested characterization of AMD-related water quality problems is based on two parameters:

1. Distance of stream impacted by water pollution from any discharge or source: The discussion on locating AMD contamination sources above describes how you can determine where AMD discharges and origins are. This locational data, in combination with the stream layer that you have downloaded from PASDA or obtained from another source will allow the calculation of stream distance between each contamination location.[4]

   To perform a stream distance calculation, the stream system in the watershed is used to determine linear distance between locations where contamination is entering the network. The primary piece of data needed is the distance of stream downstream of any AMD discharge/source. Each length of downstream distance ends at the location where the next source of contamination enters the stream.

   The stream distance data allows a comparison of AMD contamination locations in terms of the amount of stream impacted. Many GIS software packages have features that can be used to calculate stream distance between AMD discharge locations. The GIS can calculate the distance between any contamination discharge/origin and the next downstream contamination location by using a data model called, "dynamic

[4] The method described for calculating stream distance in this manual does not take into account elevation. Length is derived by calculating the distance over a network between two points in X,Y space, based on the notion that this approximation should be sufficient for the application described.

segmentation." Dynamic segmentation allows for the "re-segmentation' of a network based on user specification or based on the location of "events." For this application, the locations of AMD contamination discharges and origins are events, and the GIS measures the distance of the stream segments between them. Once this distance is calculated, it can be stored as a piece of data associated with each AMD contamination discharge point.

2. Percentage of stream pollution load contributed from any discharge or source: The second factor can be calculated as a product of the loading of acidity, aluminum, iron, manganese, and sulfates recorded at any discharge location divided by the loading of those contaminants in the main stem stream at a location directly upstream (remember the above discussion about choosing where water sampling should be done). One method to obtain one percentage value for contamination contributed by any discharge would be to calculate the average percentage of all AMD contaminants contributed (you may or may not feel that this is appropriate). The combination of stream distance data and AMD contaminant loading percentage derived by the GIS allows a characterization of the water pollution problem caused by contamination at any AMD discharge site. A query statement(s) of the GIS will allow the selection of AMD discharges and origins that meet DEP BAMR criteria. The criteria used by BAMR to classify AMD discharge sites based on the level of water pollution problems they create are shown in the chart below.

**BAMR AMD Water Pollution Problem Classifications**

| | |
|---|---|
| Moderate | Discharge pollutes < 1.0 miles of stream and contributes < 25% of the pollution load to the stream. |
| Serious | Discharge pollutes > 1.0 miles of stream and contributes > 25% of the pollution load to the stream. |
| Very Serious | Discharge pollutes > 1.5 miles of stream and contributes > 50% of the pollution load to the stream. |
| Critical | Discharge pollutes > 3.0 miles of stream and contributes > 75% of the pollution load to the stream. |

Now that the AMD problem has been defined and classified, you can move on to planning for remediation. There are four steps to this process: benefit assessment, cost assessment, worth determination, and incorporating biological data.

## Benefit Assessment

The benefit criteria that BAMR has established are based upon the reduction or elimination of problems as defined during the problem assessment phase. See the chart below.

GIS database capabilities make it fairly straightforward to assign benefit classifications based on subjective approximations of what percentage of a particular type of problem would be eliminated by implementing a remediation project at any site. The AMD discharge and origin sites that are prioritized highest for treatment using BAMR's method are those with *very important* or *significant* benefit classifications.

## Cost Assessment

The next step in assessing potential project areas outlined by BAMR in *Pennsylvania's Comprehensive Plan for Abandoned Mine Reclamation* involves calculating 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 treatment systems, requires specialized knowledge in treatment system design and planning. The people that have this expertise and are most accessible to your group are likely employees of the USDA Natural Resources Conservation Service (NRCS), BAMR, or your county conservation district officer. You will need to do some investigation to find out who in your area is qualified to determine the appropriate specifications of an AMD mitigation system that will be sufficient to handle the contamination at any site and to

**BAMR Project Benefit Classifications**

| | |
|---|---|
| Moderate | A *serious* problem will be substantially reduced > 75%; or a *moderate* problem will be eliminated. |
| Important | A *very serious* problem will be substantially reduced > 75%; or a *serious* problem will be eliminated. |
| Very Important | A *critical* problem will be substantially reduced > 75%; or a *very serious* problem will be eliminated. |
| Significant | A *critical* problem will be eliminated; or a *very serious* problem will be eliminated and a significant functional *wildlife habitat* will be created. |

**BAMR 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 |

provide an accurate estimate of the cost to construct and operate such a system.

Once this person is identified, your group should make efforts to request site visits to the AMD discharge/origin locations where you have determined through GIS analysis that remediation projects will have very important or significant benefits. For AMD-related water pollution control, any project with costs exceeding $800,000 is considered *high* cost, between $250,000 and $800,000 is considered *moderate* cost, and less than $250,000 is *low* cost. With AMD remediation cost estimates for these sites, you will be able to move to the final stage of the analysis based on the DEP BAMR methodology.

### *Worth Determination*

When cost estimates are calculated for proposed projects, they are incorporated into the final step of BAMR's appraisal process – determining *project worth*. The characterization of project worth is a product of comparing a project's benefits to its costs as defined and determined above. The chart above shows the benefit-cost classifications defined by BAMR to define project worth. In *Pennsylvania's Comprehensive Plan for Abandoned Mine Reclamation*, BAMR states that in most cases it will only consider *exceptional* and *high worth* projects for funding.

The data gathering and analysis based on BAMR guidelines described above will allow the identification of AMD origins and discharges in your watershed that would be classified as *high* or *significant* worth AMD remediation projects based on the criteria in the chart above. These are the projects that your group will prioritize the highest in the comprehensive watershed AMD remediation plan that you will use as the basis of your funding requests for specific mitigation projects.

## *Integrating Biological Data*

GIS data manipulation can illuminate other geographic patterns useful to the watershed AMD remediation planning process. BAMR's project assessment process, because it was not designed specifically for AMD discharge and remediation, does not incorporate any data related to current biological conditions. Comparing the BAMR analysis based on water chemistry and stream distance with geographic patterns of aquatic ecosystem health based on biological (macroinvertebrate) data can help in the development of a prioritization plan that is logical in the context of the watershed.

Upon examining the macroinvertebrate data collected, you may discover that biological patterns in the watershed dictate a re-examination of your initial prioritization. For example, a discharge (discharge X) may be ranked priority 4 initially (say, out of 8 locations), but macroinvertebrate results upstream indicate that this discharge should be moved down the prioritization list. At two sampling locations upstream of discharge X, either moderate or severe impact on biological communities may have been documented. It would be evident from these results that there is significant AMD contamination upstream of discharge X and that treating it before upstream areas would probably have limited positive impact on aquatic ecosystems. In this case, it seems that remediating discharges classified as having moderate benefit farther upstream before a discharge at this type of downstream location (classified as having important benefit) would be in order. A revised AMD remediation prioritization based on the incorporation of biological data could move discharge X down to priority 6, although it was categorized a *serious problem* discharge. And the upstream discharge locations may become the priority 4 and 5 projects. The reason for these changes is simply that the upstream discharges, although only classified as moderate problems/benefit discharges using the BAMR method, are upstream of the study discharge and seem to be having significant negative impacts on biological communities.

# CHAPTER 4: USING THE PRODUCTS FROM YOUR GIS FOR AMD REMEDIATION PLANNING

When you have used the methods and performed the analyses described in Chapters 2 and 3, you should have derived some information that will be very useful in the development of a comprehensive watershed AMD remediation plan. The GIS will not develop the remediation plan for you, but provides access to the data and information you need to determine a logical and efficient way to prioritize areas within the watershed for mitigation. In effect, GIS analysis will allow you to identify those areas on which you should focus your efforts.

Developing the watershed plan itself will involve focusing on the details of implementing projects at identified sites. Scoping projects will involve:

1) evaluating what type of treatment systems will ameliorate the specific problems at sites;

2) determining whether landowners will cooperate with project implementation;

3) appraising whether the physical conditions of the site are conducive to constructing the type of treatment systems that is needed; and

4) taking into the account the cost of various treatment options.

Thus, there is still a significant amount of work to be done. A document, called *A Model Plan for Watershed Restoration,* addresses the above topics and others related to watershed remediation planning (www.dep.state.pa.us/dep/deputate/minres/bamr/documents/modelplan.html) and may be useful in helping your group fashion a remediation plan from the data you have developed.

This manual has provided a suggested framework for nonprofit groups to undertake GIS development for AMD remediation planning. The utility of GIS as a tool for remediation planning is that it changes the dimensions of the AMD problem from one that seems excessively massive and widespread to one that has short- and long-term solutions. Getting to the point where we can see that six discharges in our watershed are the major problem areas and plan specifically to remediate the contamination at those locations over a specified time period is very important progress. Plan development is facilitated to a large degree by the type of data that can be developed and analyzed by a GIS. Once the AMD problem becomes "manageable," in the sense that local people can conceive its dimensions, local people are empowered to bring about positive change in their regions to improve the quality of life.

# REFERENCES


Brown, D.J.A. and K. Sadler. 1989. "Fish survival in acid waters." In *Acid Toxicity and Aquatic Animals*, eds. Morris, R. et al. Cambridge University Press: pp. 31-44.

Buikema, Arthur L., and J. Reese Voshell, Jr. 1993. "Toxicity Studies Using Freshwater Benthic Macroinvertebrates." in *Freshwater Biomonitoring and Benthic Macroinvertebrates*, eds. David M. Rosenberg and Vincent H. Resh. Chapman & Hall: pp. 344-385.

Pennsylvania Department of Environmental Protection. 1997a. *Standardized Biological Field Collection and Laboratory Methods*: 1-31.

Pennsylvania Department of Environmental Protection. 1997b. *Pennsylvania's Comprehensive Plan for Abandoned Mine Reclamation*. 1-5.

Pennsylvania Department of Environmental Protection.1997c. Chapter 93 Water Quality Standards. *Pennsylvania Code*: pp. 14-18.

Earle, J., and T. Callahan. 1998. "Impacts of Mine Drainage on Aquatic Life, Water Uses, and Man-Made Structures," in *Coal Mine Drainage Prediction and Pollution in Pennsylvania*, eds. K. Brady, W. Smith, and J. Schueck. Pennsylvania Department of Environmental Protection: pp. 4-1 – 4-10.

Environmental Protection Agency - Plafkin, Barbour, Porter, Gross, and Hughes. 1989. Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. *Assessment and Watershed Protection Division*.

Hoehn, R.C., and D.R. Sizemore. 1977. "Acid mine drainage (AMD) and its impact on a small Virginia stream." *Water Resources Bulletin*. v. 13,. pp. 153-160.

Kimmel, W.G. 1983. "The Impact of Acid Mine Drainage on the Stream Ecosystem" in *Pennsylvania Coal: Resources, Technology, and Utilization*, eds. S. K. Majumdar and W. W. Miller. The Pennsylvania Academy of Science. pp. 424-437.

Koryak, M., A. Shapiro, and J.L. Sykora. 1972. Riffle Zoobenthos in Streams receiving Acid Mine Drainage. *Water Research*. Chapman & Hall: 1239-1247.

Letterman, Raymond D., and William J. Mitsch. 1978. Impact of Mine Drainage on a Mountain Stream in Pennsylvania. *Environmental Pollution*. Applied Science Publishers: 53-72.

Merritt, Richard W., and Kenneth W. Cummins. 1996. *An Introduction to the Aquatic Insects of North America* 3rd Edition. Kendall-Hunt.

Pennak, Robert W. 1978. *Fresh-Water Invertebrates of the United States*. Wiley & Sons, Inc.

Wiederholm, T. 1984. "Responses of aquatic insects to environmental pollution," in *The Ecology of Aquatic Insects*, eds. Resh, V.H. and D.M. Rosenburg. Prager: pp.508-557.

# APPENDIX A

## *GPS Data Collection Methods*

A GPS unit will often initially collect data based on the WGS-84 (World Geodetic System of 1984) datum and will store latitude-longitude coordinates. The important issue is to process the output GPS spatial data so that its characteristics (datum, coordinate system, and map projection) correspond with the base data layers that you are already using.

To integrate the GPS data that is collected with existing digital spatial data (such as your streams, roads, and watershed boundaries), the GPS unit that is used must have the capability to store and upload data files. GPS units that can be bought at retail outlets for $100-200 may be good for hiking and hunting, but they do not have sufficient capabilities to gather data for integration in a GIS. The price range for GPS units that have the minimum capabilities for data collection for GIS purposes is presently $2,000 and above.[5] The GPS unit that is used to collect data must be able to store files and the files must be uploadable to a computer so that a process called “differential correction” can be performed (unless a significantly more expensive GPS unit is purchased that has “real-time” differential correction capabilities). Differential correction[6] is a method of increasing the accuracy of GPS data, which 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 that is normally part of the package of GPS unit, such as that described above, is used to perform the differential correction. This software is also normally used to process the corrected GPS files into formats that can be read by GIS software.[7] This will allow the AMD contamination point locations to be viewed and manipulated in GIS software along with other spatial and attribute data developed for your project.

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[5] The Department of Geography and Regional Planning at IUP uses Trimble GeoExplorer II units (low end, full functionality) to gather data for watershed GIS applications. Other companies sell comparable units at comparable prices.

[6] 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.

[7] Pathfinder Office software comes with Trimble GeoExplorer II GPS units and runs on standard Windows 95/98/NT platforms.

# APPENDIX B

## *Analytical Water Chemistry Methods*

Since there are various testing methods, the lab you are using will determine instruments and protocol. Presented here are those used in the Blacklick Creek Watershed project.

All containers for collection of water samples for analytical chemistry are acid washed in 10% nitric acid. Samples for metal analyses are collected in 125 ml high-density polyethylene jars and acidified to 1% concentrated nitric acid. Samples for analyses of non-metallic inorganic and physical properties are collected in 300 ml BOD bottles and transported from field to laboratory in a cooler.

All water samples are handled, prepared and analyzed according to U.S. EPA-approved methods (USEPA 1983) listed in the 40 Congressional Federal Record, Part 136. Total metals are determined by direct aspiration in unfiltered samples after vigorous acid digestion. Aluminum, iron and manganese are measured by methods 202.1, 236.1, and 243.1, respectively, using a model 403 atomic absorption spectrophotometer (Perkin-Elmer, Norwalk, CT, USA). Dissolved oxygen in the field is measured by membrane electrode method 360.1 using a model 50B dissolved oxygen meter (YSI, Yellow Springs, OH, USA). The pH is measured by electrometric method 150.1 using a model EC10 pH meter (HACH, Loveland, CO, USA) in the field and a model 340 pH meter (Corning) in the laboratory. Hot acidity and alkalinity to pH 4.5 are measured by titrimetric methods 305.1 and 310.1, respectively. Sulfate is measured by turbidimetric method 375.4 using a Spectronic 21D spectrophotometer (Milton Roy, Rochester, NY, USA).

Stream discharge is calculated by multiplying average velocity by cross-sectional area and correcting for stream bottom characteristics as described by Hynes (1970). Average velocity is determined by dividing stream width into thirds and measuring water velocity in each one-third section using a model 2030 mechanical flowmeter equipped with standard rotor S2030-R (General Oceanics, Miami, FL, USA). Cross-sectional area was determined by multiplying average depth by width. Average depth is determined by dividing stream width into sixths and measuring depth in each one-sixth section. Stream bottom characteristics are taken into consideration by multiplying flow rate by either 0.8 for rough bottom or 0.9 for smooth bottom. Loading is calculated by multiplying the concentration of chemical by stream discharge.

# APPENDIX C

## *Macroinvertebrate Sampling and Classification Techniques*

Since there are various sampling methods, the personnel you are using will determine instruments and protocol. The following were used in the Blacklick Creek Watershed project.

The techniques recommended for benthic macroinvertebrate sampling and sorting were taken from the Standardized Biological Field Collection and Laboratory Methods of the DEP (1997). Benthic macroinvertebrates are sampled using a semi-quantitative scale. At each discharge site, samples are collected in the nearest riffles upstream and downstream. Riffle areas are sampled because they are the most favorable habitat for benthic macroinvertebrate populations (DEP 1997; EPA-Barbour, et al. 1997). Samples are collected from the fast velocity and slow velocity part of each riffle development and combined to form a composite sample. This composite sample is preserved in a jar containing 70% ethyl alcohol.

A D-frame net[8] is used to collect the samples. The net is placed on the substratum of the riffle and the substratum is disturbed in an area that is 1x3 feet upstream of the net. In order to standardize this technique, it is necessary to disturb the substratum two minutes at each site. All large substratum materials collected in the net are examined for benthic macroinvertebrates and then returned to the streambed. The remaining material is emptied into an enamel tray. The net is then thoroughly picked clean of any remaining benthic macroinvertebrates and deposited in the sampling jar along with the organisms in the enamel tray. In order to limit bias, the net is cleaned by running clean stream water through it several times before sampling from the next location (EPA-Barbour, et al. 1997).

### Macroinvertebrate Identification Methods

Before the identification process begins, it is necessary to separate the macroinvertebrates from the substratum material contained in sampling jars. The first step, rinsing the sample through a 500 mm sieve, helps to eliminate fine residual and remaining preservative (DEP 1997). Next, the samples are placed in a 14" x 8"x 2" pan where they are floated. Floating facilitates the process of sorting the macroinvertebrate from the substratum material because it separates the macroinvertebrates from the substratum material. The DEP Standardized Biological Field Collection and Laboratory Methods manual suggests that a saturated solution of magnesium sulfate be used to float the sample (Epsom salt).

When samples are collected and preserved, the tissue of the organisms becomes less dense due to the permeation of the ethyl alcohol preservative, and the macroinvertebrates float on the more dense saturated salt solution. This solution is added to the rinsed sample. The sample is stirred and all floating organisms are removed and counted. Then all of the material in the pan is inspected using an illuminated magnifying viewer so that even small organisms are removed. Before a sample is placed in it, each 14" x 8"x 2" pan is divided into 28 two inch grids. Enough water is used to cover the macroinvertebrates and then stirred to

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[8] The net, shaped like a “D”, is 1 foot wide and attached to a long handle.

spread them evenly throughout the pan. In order to limit bias, index cards are numbered from one to 28 and then shuffled, which provides a method of random sampling. A card is chosen and its number determines the grid in the pan from which to collect the macroinvertebrates. When a grid cell is selected, all organisms contained in the cell are removed and placed in a jar containing 70% ethyl alcohol. This process is continued until a random sample of n = 100 is collected. Some sample locations may not contain 100 macroinvertebrates (due to severe AMD impacts). When n is less than 100, all of the macroinvertebrates from that location are collected as part of the sample.

Most macroinvertebrates yielded from the sampling techniques described above are identified to the *order* or *family* levels. Order identification is often possible with the naked eye, however, family level identification requires a microscope. All benthic macroinvertebrate samples are identified to the taxonomic level recommended by EPA Rapid Bioassessment Protocol 1, which means using Pennak (1978) and Merritt and Cummins (1996) as identification references.

When the identification process is complete, a ranking system can be used to interpret the results. To develop a classification system that is meaningful for the study watershed, reference locations should be selected as control sites to evaluate macroinvertebrate populations at other sites in the study area (DEP 1997). Control sites are those in the study area that exhibit overall good habitat quality and a substantial benthic macroinvertebrate population indicative of the watershed. The macroinvertebrate identification results can be analyzed using EPA Rapid Bioassessment Protocol I (RBP I) (EPA - Plafkin, et al. 1989). All benthic macroinvertebrate sampling sites can be ordinally ranked from 1 to 5 where: 1 = Little to no AMD, 2 = Slight AMD impact, 3 = Moderate AMD impact, 4 = Heavy AMD impact, and 5 = Severe impact.

This ranking system is a modification of the “EPT” taxa system outlined in EPA RBP I (EPA - Plafkin, et al. 1989). Where: ”E” is Ephemeroptera (mayfly), “P” Plecoptera (stonefly), and “T” is Trichoptera (caddisfly). The rationale is that the presence of Ephemeroptera suggests that a particular area has very good water quality (Little to no AMD present). It has been scientifically established that Ephemeroptera are the most sensitive of the EPT taxa system to AMD contaminates (Letterman and Mitsch 1978; Buikema and Voshell 1993). Rank 2 suggests that although there are not any Ephemeroptera present, the water is still of a relatively high quality (Slight AMD impact). For a site to be ranked 2 there has to be Plecoptera and Trichoptera (the PT of EPT) present, but their presence does not dominate the sample. Generally speaking, the presence of Plecoptera and Trichoptera suggests that the overall water quality is good (Lettermen and Mitsch 1978). Rank 3 requires that Plecoptera and Trichoptera are present and dominate the sample (Moderate AMD impact). The ranking of the “P” and “T” are divided into separate ranks because there are certain families of Trichoptera that are pollution tolerant. Therefore, if they are present in large quantities it can be generalized that the water quality is compromised. If a site does not exhibit any EPT taxa, but other benthic organisms are present, it can be considered to be of very poor quality (Heavy AMD impact) and assigned rank 4. Finally, if a site does not yield any benthic macroinvertebrates it is ranked 5 (Severe AMD impact), indicative of the worst water quality.

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