OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Mineral Resources Management
Acid Mine Drainage Program

Acid Mine Drainage Abatement and Treatment Plans

AMDAT Guidance Document

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ACID MINE DRAINAGE ABATEMENT AND TREATMENT (AMDAT) PLANS GUIDANCE DOCUMENT

INTRODUCTION

This guidance document provides the framework for the Acid Mine Drainage and Abatement (AMDAT) plan process for Division Abandoned Mine Land (AML) staff and watershed groups. It assumes the user has field experience with water sampling, flow measurements, Global Positioning System (GPS), and some understanding of biological monitoring and the indexes that support it. This guidance is meant to be used in tandem with the "Field Methods for Watershed Characterization", Bowman et al, 2006. The AMDAT process uses a watershed-based approach similar to Ohio Environmental Protection Agency's Total Maximum Daily Load (TMDL). In fact, several AMDATs have served as "mine drainage" TMDLs for the Ohio EPA. TMDL can be defined broadly as the entire process of determining how the various sources of a pollutant to the water body should be reduced and thereby meet water quality standards. An AMDAT exclusively addresses planning for waters affected by acid mine drainage for the purpose of selecting remedial treatments. While much in this guidance document can be implemented by watershed groups, technical assistance, direction, and ODNR Division of Mineral Resources Management and other assisting agencies and educational institutions provide coordination.

AUTHORITY

The Ohio Revised Code Chapter 1513.37 (E) provides the authority to fund the Acid Mine Drainage Abatement and Treatment program. Title IV of the Surface Mining Control and Reclamation Act (SMCRA) of 1977 establish grants.

PURPOSE OF THE AMDAT

The AMDAT funds may be used to restore watersheds impacted by coal mine drainage. Coal mines in this case refers to abandoned coal mines; i.e. those mines active prior to 1977. The purpose of such restoration activities is to improve the watershed to a condition that provides for the recovery of its streams to their potential aquatic life designated use class. Such activities may include the chemical improvement of stream water quality from entering streams whenever such impairments are related to abandoned coal mining. Water quality is the result of pollutant load inputs, stressors, in-stream conditions, and physical, chemical and biological processes.

In general, the AMDAT approach identifies mine drainage pollution in a watershed and assigns a load ranking regarding the relative impacts on water quality. This avoids the hit-or-miss approach of singling out projects without consideration of pollutant load. It takes the guesswork out of allocating funds to be spent on the highest priority problems. It also captures the interaction between upstream and downstream sources and impacts.

Due to water quality considerations or budget constraints, some AMDATs only evaluate limited sections of a watershed.

Create a Dynamic Plan

The first step in stream restoration is to begin to establish some goals with the knowledge that they may change over time. Whether the goals are to improve water quality in specific stream segments or to restore aquatic life, the watershed must be capable of producing these goals regardless of mining impacts. If the goal is a healthy fish population, the streams would have to be able to provide a perennial source of water and maintain a viable breeding habitat for fish and macroinvertebrates. This may not be possible for some streams. Thousands of dollars could be spent eliminating acidity from a tributary to restore fish, only to find out that the community upstream is using the stream for its raw sewage, which would negate the goals for healthy aquatic life.

The work of rehabilitating a watershed can be a long and ongoing process. While it is important to assess the watershed for where the bulk of the problems are, it would be prohibitive to determine the definitive solution for the entire watershed (including the location of every source, reclamation strategies and costs, and preliminary engineering designs, etc). In a watershed that has extensive problems, conduct work in places that are commensurate with the fiscal ability and technical realities to solve a problem and also with the goals of the group. Landowners should be brought into the process early. This piecemeal approach may be the only realistic approach and would need to be a dynamic plan that allows for change over time.

Other non-point sources of pollution may exist in the watershed. Ideally, these problems should be incorporated into a holistic watershed management plan. Consideration of other nonpoint source pollution problems is not required for AMD abatement plans. However, in competing for matching Section 319 funds, OEPA rates plans that address all nonpoint sources of pollution with a higher priority.

AMD Impacts on Stream Health

Acid mine drainage has the potential to effect many different aspects of a stream's biological integrity. The chemical and physical changes to the stream from mine drainage result in the impacts on the biological and ecological functions listed in Figure 1. AMD is a complex contaminant effecting streams in many different ways. The full scope of these impacts should be considered in any watershed remediation strategy.

Figure 1. Major effects of acid mine drainage on lotic (stream) systems

(Modified from Gray, 1997)

Chemical	Physical	Biological	Ecological
Increased acidity	Substrate modification	Behavioral	Habitat modification
Reduction of pH and buffering capacity	Turbidity	Respiratory	Niche loss
Increase in metal concentrations	Sedimentation	Reproduction	Bio-accumulation in food chain
	Absorption of metal into sediment	Acute and chronic toxicity	Loss of food source
	Decrease in light penetration	Acid-base balance in organisms	Elimination of sensitive species
		Migration or avoidance	Reduction in primary productivity
			Food chain modifications

ELEMENTS OF THE AMDAT PLAN

In order to fund specific projects for remediation of AMD in a watershed, a comprehensive abatement and treatment plan must be developed. It is this comprehensive plan that provides the basis for a watershed being qualified as a hydrologic unit in the AMDAT program.

Each AMDAT plan must include at a minimum the following elements:

1. An identification of the qualified hydrologic unit
2. The extent to which AMD is affecting the water quality and biological resources within the hydrologic unit
3. An identification of the sources of acid mine drainage within the hydrologic unit
4. An identification of individual projects and the measures proposed to be undertaken to abate and treat the causes or effects of acid mine drainage within the hydrologic unit
5. The cost of undertaking the proposed abatement and treatment measures and an analysis of the cost-effectiveness and environmental benefits
6. An identification of existing and proposed sources of funding for individual projects
7. A monitoring plan for assessment of actual environmental benefit realized

1. An identification of the qualified hydrologic unit

The hydrologic unit refers to the area of the watershed within which projects are proposed to be abated. In general the U.S. Geological Survey Eleven Digit Hydrologic Unit (HU) watershed classification represents the optimum size for an AMDAT, however in some cases the Fourteen Digit HU may also be appropriate. These watershed boundaries may not be appropriate for all AMDAT planning purposes, especially where the *extent* of mining impacts is limited to a very small area within a specific watershed. Individual projects may focus on a limited area within these watershed boundaries, and such limited areas may be approved as qualified hydrologic units upon documentation of the areas in which acid mine drainage is a significant problem.

2. The extent to which AMD is affecting the water quality and biological resources within the hydrologic unit.

The AMDAT plan will define which streams and to what extent they are impaired from mine drainage. The plan must include sufficient data to determine the acid and metals loading within the watershed over seasonal conditions and the effects of mine drainage on aquatic biological communities. Such data may exist in the form of previous hydrologic assessments and studies. In the event a complete picture of the proposed hydrologic unit is not available from historical data sources, then additional data collection will be needed in areas where AMD data is lacking. All affected tributaries within the proposed hydrologic unit should be evaluated for prioritization and to establish a restoration plan. Evaluation of unaffected tributaries may help in establishing the restoration goals for a watershed.

3. An identification of the sources of acid mine drainage within the hydrologic unit.

Once the major mine drainage tributaries are located, it is necessary to locate the actual sources of AMD within the watershed that are causing the overall problem. In some cases, a tributary may have only one major source that is the limiting factor for that stream; while another tributary may have multiple and diverse sources that are in combination causing the stream to be degraded. All of the major sources must be physically identified, and an assessment of their contribution to the overall loading must be conducted.

An effective abatement strategy will depend upon the degree to which all of the significant sources have been identified and characterized as to their role in causing AMD within the watershed. It is quite possible that upon completion of the watershed assessment another water year of data collection will be necessary in order to assess the loading and the percentage contribution from individual sites within the tributary or watershed or to establish design parameters for treatment facilities. Provide adequate preconstruction water quality and biological data that allows for proper design and project justification.

Once all significant sources have been identified and the loading determined from each site, a determination should be made of the cumulative reductions needed to meet restoration goals. Based upon this assessment, a prioritization of the individual sites can commence. Whenever data is collected for the individual sites, they should be collected such that an abatement strategy for that site can be formulated. At this point the overall strategy should begin to emerge such that individual sources or tributaries can be targeted for remediation.

4. An identification of individual projects and the measures proposed to abate and treat the causes or effects of acid mine drainage within the hydrologic unit.

This point marks a transition from the assessment stage to the remediation stage in the AMDAT plan. Those individual projects within the watershed which represent the highest priority for achieving in-stream water quality improvements should be evaluated as to the alternatives that may be used to abate the problem. Where the stream system is complex and where multiple sources of AMD exist, modeling of overall watershed quality improvements should be considered. Such modeling should examine what-if scenarios, such that anticipated changes at a given point in the watershed can be projected into a known water quality improvement within a certain downstream reach of a stream. In this manner it may be possible to better define which individual projects will have the most potential to improve downstream reaches to the greatest degree. All possible alternatives should be considered, ranging from conventional reclamation to in-stream treatment. Always consider source control, closure of subsidence holes, mine sealing, and standard reclamation techniques first.

Another approach frequently used in Ohio is to use fresh water as a means of introducing alkalinity through steel slag ponds. Fresh water in ponds or tributaries is an important component of assessing the watershed. Clean water in an impacted area should be monitored for chemistry and seasonal flow.

The proposed treatment areas will be evaluated based on the prospects for reclamation, cost factors, the site's potential to contribute good water to the system, the site's accessibility, maintenance required, electrical access, land ownership, and mining history.

As the plan is developed it should be brought forward to an advisory committee for review. The committee can be comprised of appropriate technical experts from agencies such as DMRM, USFS, OSM, and Ohio EPA depending upon the stage of development and the geographic location of the watershed. Ideas and suggestions from the advisory group will provide guidance as to the next steps or processes necessary to complete the plan.

5. The cost of undertaking the proposed abatement and treatment measures and an analysis of the cost-effectiveness and environmental benefits.

Those Best Management Practices (BMPs) that appear to be feasible should be developed to the point where a preliminary cost-estimate can be produced. Such cost estimates

should include all engineering design and estimated construction costs, including long-term maintenance, if any. These cost estimates, compared to the anticipated water quality improvements for each alternative, will serve as the basis for selecting the most cost-effective alternative with the best corresponding environmental benefit. One assessment of cost vs. benefit that is relatively straightforward is to determine the overall project abatement cost, and to calculate the reduction in acidity and metals loading anticipated from the project per year. This will result in a figure of cost per unit of water quality improvement anticipated (e.g. dollars/lbs of acidity), which can be used for comparative purposes with other BMPs. In addition to initial remediation costs, additional long-term costs should be evaluated, such as system maintenance or actual treatment costs.

6. An identification of existing and proposed sources of funding for individual projects

All available sources of funding for a reclamation project should be identified. If a watershed group is conducting the AMDAT plan, then they must identify existing and proposed sources, and if applicable have a written commitment for funding prior to actually listing such funds as a potential source. The total funds determined to be available through such commitments should cover the anticipated costs of the project. It is important at this stage to understand that funds from different sources may have time restrictions placed upon their expenditure. Careful planning is required in order to assure that projects are actually constructed during the time period when funds are actually available. Comprehensive watershed projects will require a staged long-term funding approach. Initially the project may only entail assessment and prioritization of AMD sources; this would be followed by the actual design and construction of remediation projects over an extended period.

7. *A monitoring plan for assessment of actual environmental benefit realized.*

Each AMDAT plan must contain specific objectives to be realized in relationship to specific projects. These objectives, quantified as environmental benefit (such as reductions in chemical loadings for acidity and metals), should be specific enough to be measured, and the specific methodology utilized to measure the benefit must be identified. As an example, the chemical improvement from a BMP may be expected to cause a certain reduction in acidity loading per day at the site; and that water quality improvement may then be expected to cause a resultant increase in biological integrity (IBI), diversity, MAIS scores or more immediate incremental changes in pH, at a certain point downstream at some period of time. In addition, multiple projects within a watershed may be expected to have a cumulative effect on improving the biological recovery of the stream. Thus the watershed may have a variety of monitoring needs that must be addressed, i.e. short-term monitoring at the project site, as well as upstream and downstream from a project site. Long-term monitoring will have to assess the overall changes in the watershed as multiple projects are implemented.

Thus, monitoring plans will have to address water chemistry, flow, and biological recovery within the watershed. Monitoring must be planned for a sufficient period of

time to demonstrate results. For example, quarterly for two years as post construction monitoring. Each year during winter, the DMRM will review monitoring plans for the next year. Future funding of projects may depend upon the effectiveness of the monitoring plan demonstrating that the AMDAT plan is producing the intended results. The costs of such monitoring must be assessed and funded as a component of the AMDAT plan. In addition to collecting data, the plan should address data analysis and reporting of results on a quarterly, annual and/or 5-year basis for biology. At a minimum, implement post-reclamation water sampling quarterly for two years.

WATERSHED CHARACTERIZATION

Preparing an AMDAT plan requires a thorough understanding of the watershed characteristics, available data, causes of impairment, sources, water quality standards, and potential targets. Some of this information will be available through a state's 303(d) list. Watershed characterization provides a basic understanding of the impairments of concern, the sources of impairment, and the desired levels for restoration or targets.

Several attributes as listed below provide useful information about the watershed and should be included in the AMDAT report. These are

- History
- Geographic and land-use information
- Geology and soils (soils on site specific locations only)
- Coal mining history
- The presence of regulated streams (such as exists at the Burr Oak Dam – release of water)
- The presence of waste water treatment plants
- AMD impacts in watersheds
- Summary of other existing studies such as the EPA 303(d) report
- USGS water resources reports
- Other resident agencies such as the USFS
- Student theses and projects
- State and local environmental agencies such as local Soil and Water Conservations Districts

Online sources of physical, chemical and biological monitoring data include

- STORET: EPA's database for the storage and retrieval of water quality data and biomonitoring data on fish, macroinvertebrates, and habitats. www.epa.gov/STORET/index.html.
- The National Water Information System Website (NWISWib) is USGS's online database for water flows and quality data. http://waterdata.usgs.gov/nwis.
- EPA's Total Maximum Daily Load (TMDL) reports for specific watersheds promulgated under the authority of Section 303(d) of the 1972 Clean Water Act and amended in 1992
- Past Technical Service Documents (TSDs)

A PHASED APPROACH TO SAMPLING

Due to the diversity and complexity of problems within watersheds, a phased approach is recommended in which the sampling regime can quickly pinpoint problems by initially measuring field parameters. The assessment then becomes more rigorous as the source areas contributing to the problem are identified. In general, three phases of investigation will guide the AMDAT process:

- Phase I – Initial screening
- Phase II – Identification of AMD affected streams and sources
- Phase III – Sampling for design

The three phases of investigation require field measurements, laboratory water quality parameters and biological sampling. Phase I is limited to field parameters. Phase II and Phase III require the measurement of field and laboratory parameters over an extensive portion of the watershed, also known as "hollow crawling".

Phase I - Initial Screening

The purpose of Phase I is to determine which tributaries are mine impacted and which ones are not. This initial characterization of the watershed should be completed rapidly. Existing topographic maps give the first clues to locating AMD seepage within each sub-watershed. Sampling field parameters begins at the mouth of the mainstem and continues upstream toward the headwaters in an attempt to "sniff out" the mining impacted waters. Field parameters of pH, oxidation-reduction potential (ORP), conductivity, and temperature are easily obtained and a visual assessment of flow determined. Acidity and alkalinity can be titrated in the field. Field parameters are measured above and below incoming tributaries in the receiving stream to identify the offending tributaries and any mine drainage sources on the stream. No samples are collected for laboratory analysis at this phase but all information may be mapped.

It is important to note visual condition of the streams. And not all streams with metal contaminants are visually obvious. When metals are suspended and dissolved in the water under low pH conditions, they will not be obvious. Figure 2 shows the pH at which metals will begin to precipitate out of solution and become visually obvious.

Figure 2. Metal hydroxide precipitation

Metal	pH
Fe^{2+}	8.5
Fe^{3+}	3.2
Al^{3+}	4.5
Mn^{2+}	9.0
Mn^{4+}	5.5

Information gained from Phase I is used to identify areas with AMD and develop a working map for Phase II. During Phase I, the sampling team becomes familiar with the

watershed and identifies access points, future sampling points, and obvious sources of AMD. Take note if there are other factors that affect site location such as runoff or discharge from agricultural, residential or industrial point discharges. Take road and topographic maps and GPS into the field. Record geographic positions in NAD 83 or WGS 84.

Phase II - Identification of AMD Affected Streams and Sources

In Phase II, the objective is to learn about metals pollution from mine drainage and that requires taking water samples for laboratory analysis. The laboratory parameters for Phase II typically includes Group I analysis (pH, total acidity, total alkalinity, specific conductance, total suspended solids, sulfate, calcium, magnesium, iron, manganese, aluminum, hardness, and total dissolved solids).

Figure 3. Chemical parameter analyzed at the DMRM Laboratory

Group I	Group II
pH	pH
Alkalinity	Alkalinity
Acidity	Acidity
Conductivity (US/cm)	Conductivity (US/cm)
Total Dissolved Solids (TDS)	Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)	Total Suspended Solids (TSS)
Sulfate	Sulfate
Calcium	Calcium
Magnesium	Magnesium
Iron	Iron
Manganese	Manganese
Aluminum	Aluminum
Hardness, S elements analyzed	Total Hardness
	Sodium
	Potassium
	Hardness as CaCO3
	Chloride
	Total Solids

Phase II investigations are conducted within impacted tributaries to identify acid/alkaline and metal loadings from the tributaries and sources of AMD. This level of reconnaissance is often referred to as “hollow crawling” and is equipment intensive. Where there are many sources together, it may not always be necessary to determine their individual loadings but simply a single loading just before the sources enter a tributary or the tributary enters into the stream.

Recent findings in some streams with water quality and biologic recovery assessments suggest that when chlorides complex with aluminum, the aluminum can be kept in

solution. This becomes a toxic problem for fish populations (Urabe et. al, 2007). Therefore, water sampling using the Group II parameters is advised in streams on a limited basis for the analysis of chlorides. The chart below shows parameters for Group I and Group II.

While metal and acid loadings are a critical determinant in stream health, it is the concentration of metals that has deleterious affect on stream biology. Loadings indicate which tributaries or sources should become priority areas for treatment. These constituents vary seasonally and when the flow component becomes large, such as during excessive rainfall events, loadings increase, but concentrations may decrease.

A review of loadings and concentrations will show how they correlate, and how each tells a different story. As the watershed becomes restored, the reduced loadings and concentrations of pollutants become indicators of success. In order to develop the long-term recovery strategy it will be important to assess the potential load reductions relative to the overall water quality improvement needed within a stream in order for the stream to recover biologically.

Figure 4. Acid load

Acid Load

- Dynamic
  flow (gpm) x acidity (mg/L) x 0.0022 = tons/year
  flow (gpm) x acidity (mg/L) x 0.012 = lbs/day

- Static
  volume (ft^3) x acidity (mg/L) x 3.11485 x 10^{-10} = tons
  volume (gal) x acidity (mg/L) x 4.16383 x 10^{-11} = tons

The same formulas can be used to estimate the mass of alkalinity

Some AMD streams are driven by flow from continually draining underground mine pools. Other streams are affected by the flushing of strip pits that may cause increased AMD due to increased precipitation and during high flow. Each area should be characterized during different flow regimes because they are not all the same. Critical conditions are those which limit the biological recovery of a stream or otherwise impede the goals of restoration. Thus, an important part of watershed characterization is to assess when and how critical conditions occur.

Acidity concentrations are determined by titration in the laboratory and can also be calculated from the dissolved metal concentrations (mineral acidity) and pH values. Estimates of acidity are based on the amount of dissolved metals present in the stream. This provides a handy check for laboratory acidity values and should be calculated whenever the laboratory data is suspect. In waters where manganese concentrations are high, acidity can be calculated leaving out the manganese component as manganese is

typically not treated. The formula below is from Hedin (1994) and found in Skousen and Ziemkiewicz (1996) and can be programmed right into the sample analysis spreadsheet.

Calculated Acidity

$$= 50\ (2\ [Fe^{+2}]/56 + 3\ [Fe^{+3}]/56 + 3\ [Al^{+3}]/27 + 2\ [Mn^{+2}]/55 + 1000(10^{-pH})).$$

The concentrations of metals in milligrams per liter are used for iron (Fe), aluminum (Al), and manganese (Mn), denominators are molecular weight, multipliers are species charge, and the 50 factor transforms milliequivalents (meq) of acidity into mg/l $CaCO_3$ equivalent.
Assume that the iron is in the ferric form (Fe^{+3}) if it is oxidized. If issuing from a mine pool and unoxidized it may be ferrous iron (Fe^{+2}). When in doubt, have the laboratory analyze for total and ferrous iron. The pH is not an indicator of the ionic species of the iron.

Source Assessment

The acid sources and tributaries are prioritized based on their loading impact to the receiving stream. A source assessment can significantly influence the AMDAT development, and subsequent treatment implementation. These assessments define their location, behavior, magnitude and influence.

The assessment should identify the major sources of AMD are contributing to impairment; which sources are contributing which pollutants and which sources have an impact on stream segments, especially regarding biological impacts. The information necessary to understand their location and discharge behavior is completed and reviewed during this step. The characterization may include point and nonpoint sources as well as non-mining impairments.

After tracking the acid mine drainage seeps, mapping the source, and measuring the total input each source has on its receiving stream in terms of loads, this data is used to develop a ranking from which to prioritize each site for remediation. In addition to acidity loadings, alkalinity concentrations and loadings are also important indictors of stream health.

Mass Balance Sampling

A loading mass balance equates the acidity produced in the watershed (or subwatersheds) with the loading at the mouth. To obtain loadings, discharge (Q) measurements are multiplied by acidity concentrations (C) that are determined at the laboratory. A constant factor gives the product in pounds per day or kilograms per day.

Flow (gpm) x Acidity (mg/l) x 0.012 = loadings (lbs/day).

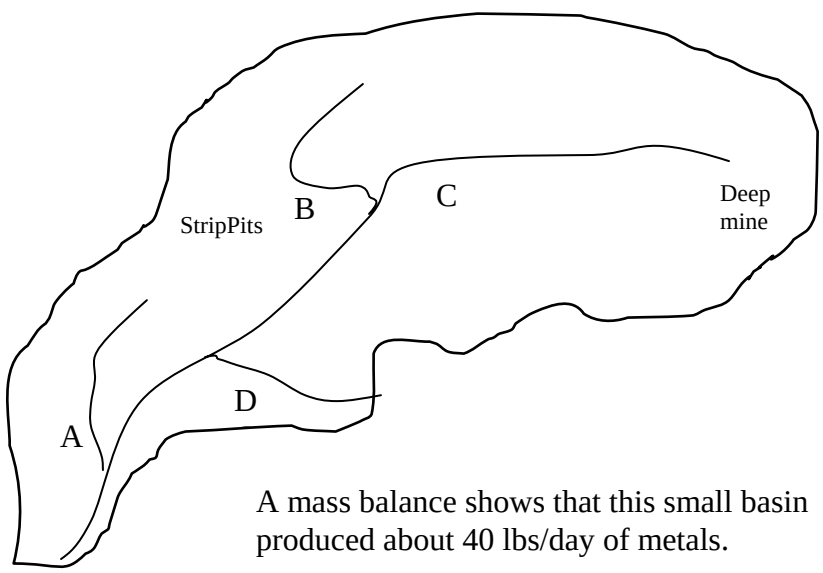
Metals loadings can be similarly determined.

Q Mouth x C Mouth = (Q1 x C1) + (Q2 x C2) + (Q3 x C3) . . . . ,
where 1, 2, 3, . . . represent the tributaries.

It is useful to conduct this analysis during high and low flow as the conditions will change under each flow regime. Mass balances are conducted on the entire watershed and also the sub-basins. **Figure 5** is a simple example that illustrates the concept. Note, Tributary D does not have mine drainage, therefore, that flow is not included in the total flow at the mouth.

Figure 5. Determining metal loads from concentrations and flow

Tributary	Concen. (mg/L) metals	Flow (gpm)	Metal load (lbs/day)	lb/yr
A	42	20	**10.10**	3685.332
B	32	30	**11.54**	4211.808
C	30	50	**18.03**	6580.95
D	0	10		
Total	0	110	39.67	14478.09

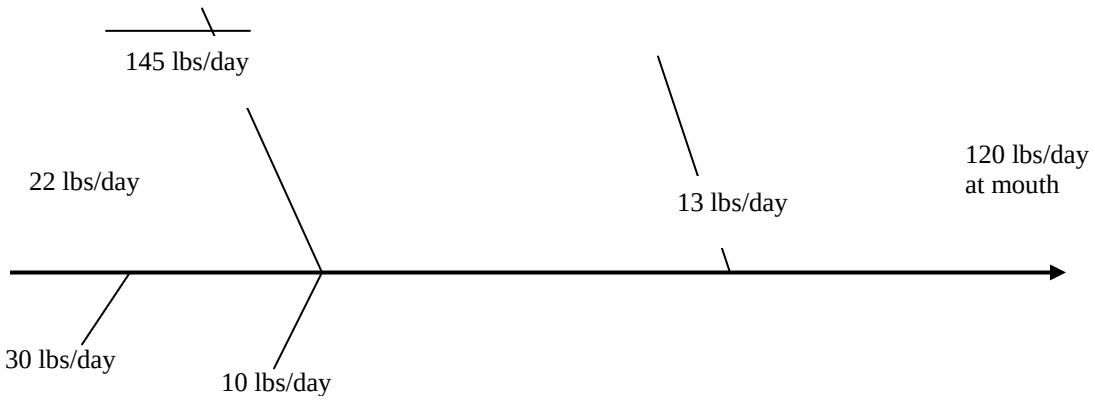


Conducting a watershed wide or sub-basin mass balance requires that all field personnel collect samples and flow under the same flow regime. Therefore, try to gather all of this

information in the same day and preferably, a day without rain. If more than one day is required, the sampling must not be interrupted by rainstorm events. Usually, teams of samplers gather all the information in a day if possible. Measuring a stream for flow can typically take up to an hour, thus a team may realistically be obtaining 6 to 8 site locations per day. Preplanning is imperative and will usually take a day to calibrate meters, pre-label water bottles, and ready the equipment.

The use of a graphical aid as shown on Figure 6, is convenient for sorting out loading sources. The stick figure shows the highest loading is 145 lbs/day. Treatment may be most productive in that location of the basin.

Figure 6. Useful stick figure schematic



Goals and Targets

After a review and analysis of all the loadings and data, realistic goals will begin to emerge for the watershed. Goals will be general at first. It is likely that goals will change through the process of watershed assessment. The more that is known about the watershed, the more carefully defined the goals become.

Example of goals can be varied.

- Restore stream to its “designated use” criteria, as specified by OEPA.
- Restore the watershed to fishable and swimmable conditions.
- Restore only certain sections of the watershed to target levels of metals and acidity.
- Ameliorate all pre-law mine site discharges.
- Don’t attempt to restore the tributaries, but restore the mainstem by cutting loadings of the tributaries.
- Restore certain segments by allowing for sacrifice zones where metals precipitation will impact streambeds.
- Conduct standard reclamation on pre-law strip mines only.

Targets are an indicator that can be used to evaluate attainment of water quality standards or simply the reduction of certain metals. It may also be the attainment of a certain concentration of alkalinity in the stream. In streams with mine drainage, we are typically trying to eliminate metals and/or improve or introduce alkalinity. Often, a numeric target value will be assigned based on the water chemistry of a reference stream within or near the affected watershed. Targets can be set based on an understanding of upstream and downstream conditions and reference stream conditions. Once the watershed has been characterized for water chemistry**,** targets for water quality parameters are assigned based on comparisons of affected streams to unaffected or reference stream segments.

A useful tool for developing targets is the Ohio EPA Technical Bulletin MAS//1999-1-1, *The Association Between Nutrients and the Aquatic Biota of Ohio River and Streams* http://www.epa.ohio.gov/portals/35/documents/assoc_load_apps.pdf . This document shows the chemical concentration of various parameters in streams that are meeting the WWH use designation. It is especially useful when no ideal reference reaches are available in the watershed.

Most watersheds develop targets based on alkalinity. Many streams have both alkalinity and acidity, therefore, net alkalinity must be calculated. The net alkalinity or acidity concentration is easily calculated in the database spreadsheets by subtracting the alkalinity concentration from the acidity concentration, i.e. acidity - alkalinity = net acidity. Alkalinity is usually shown as a negative number. The net result multiplied by discharge rate results in loadings. These loading calculations can be programmed directly into the excel spreadsheet used for storing and manipulating the water quality data. Figure 7 provides examples of remediation targets for various watersheds:

Figure 7. Remediation targets for several watersheds in Southeast Ohio

Watershed	PH	Aluminum	Iron	Manganese	Alkalinity	TDS
Monday Creek	7.07	0.72	1.09		30	609
Sunday Creek	----	0.30	1	0.50	67	280
Raccoon Creek	6.5	0.75	1	2	30	---
Moxahala	6.5 – 9.0	-----	1	2	67	1500
Leading Creek	----	0.75	1	0.60	70	500
Ohio EPA benchmark	6.5 – 7.5	-----	0.8	0.2	145	1500

Units in milligrams per liter except for pH.

Phase III - Sampling for Design

Up to this point, the streams contributing the greatest pollution load in terms of metals and acidity have been identified. The purpose of Phase III is to select those sources that that may eventually be turned into a project. Project sampling determines the type and amount of treatment necessary to remediate the problem. Questions are answered such as

how much acidity and metals are produced through seasonal variations and how much alkalinity will be necessary to treat the problem. How much sludge would be anticipated with certain treatment systems? Most importantly, what affect would this project have on obtaining the stated goals?

By the time sampling for design begins, the field parameters should already be well established. These include: pH, Conductivity, Temperature, Dissolved Oxygen, Titrated alkalinity and or acidity. Design parameters typically include Group I but may utilize Group II so that the cation – anion balance can be attained.

Additional parameters such as ferrous/ferric, dissolved oxygen, depend on the location and type of treatment systems being considered. Carbon Dioxide is also a desirable parameter to determine, specifically for underground mines drainage. In some instances we don't include manganese in acidity calculations, as we don't want the added expense of treating for metals that won't precipitate out. Magnesium concentrations may be important if its precipitation would contribute to a big sludge problem.

A chemical loading is imperative from which project effectiveness can be judged. Therefore, flows are also required. All manner of flow meters and flumes are used.

Duration and frequency of sampling may be dependent on the site complexity, and the thoroughness of the design. It can range from just a few samples of flow and chemistry at a simple site for a conceptual approach, to one in which much sampling is necessary in a treatment approach requiring several treatment cells built in series (From SAPS to settling ponds, to steel slag treatment cells). In general, six months (monthly) to a year pre-construction sampling is required.

During this time we strive to collect samples and flows both above and below the mean annual flow. The mean annual flow is determined based on drainage area size as described by the USGS (Koltun and Whitehead, 2001).

If flows cannot be measured in the field, they can be estimated based on drainage area size, (Techniques for Estimating Selected Streamflow Characteristics of Rural, Unregulated Streams in Ohio by Koltun and Whitehead, 2001). The main point is to capture samples during a variety of flow regimes to understand how their chemistry changes with flow. The design must be able to handle the volume of water passing through the system. However, while metal and acid loadings are a critical determinant in stream health, it is the concentration of metals that has deleterious affect on stream biology.

When sampling mine pool discharges, look for chemistry that reflects conditions in the mine pool or underground sources. If the water is anaerobic (not exposed to oxygen, < 1 mg/L) there would be more ferrous iron ($Fe2^{+}$) than ferric iron (oxidized - $Fe3^{+}$). When collecting a sample that seeps directly out of a mine, the laboratory should analyze for ferrous iron. This requires different handling than other metals. Testing for both types of iron is important when considering a possible treatment system such as an anoxic

limestone drain (ALD) or a successive alkaline producing system (SAPS). The sample should be collected as close as possible to the source due to the rapid oxidation of metals that occurs immediately upon exposure. Ferrous iron is collected in a 125 ml brown plastic bottle and acidified with 2 ml of HCl (20%). Dissolved oxygen should also be determined at the source in the field.

SAMPLE COLLECTION AND DATA

The following sections provide some suggestions when planning for field sampling. Proper planning before going into the field will yield time saved, and less chaotic data to sort through later. Refer to the "Watershed Characterization Manual" (Bowman et al 2006) for template field data sheets.

Develop a Numbering/Naming System for Samples

Developing a system to name and or number the sample points (sites) is extremely important. This should be established before sampling begins. Depending on the size and complexity of the watershed, the system can be extremely simple or complex.

Each site where a sample is collected requires a number or unique identifier so that it can be stored and retrieved from a database or spreadsheet. It is useful for the naming system to follow a logical protocol for ease of naming. For example, the mainstem numbers may begin with MS for mainstem while the tributary numbers might be the first two letters of the tributary. In any system, there should be a logical progression of numbers, not a random scattering. Numbers/names can be spatially distributed beginning at the mouth and working upstream. Bear in mind that more samples will likely be collected at a later time so those numbers need to fit into the numbering scheme.

Site numbers may have components that provide a spatial identity (mainstem or tributary name). It may follow the ordering of tributaries. It may identify an attribute (seep, stream, pond, mouth of tributary).

Site numbers and sample numbers are not the same. The sample number is a consecutive number used on the chain of custody with the sampler's initials and identifies the sample brought to the Laboratory. Laboratories also have their own numbering system. The appendix contains an example of sample and site naming protocol.

The following is an example of a naming system for Monday Creek that was written by Scott Miller.

The Naming System of Sampling Sites in the Monday Creek Watershed

The name of a monitoring site is made up of two parts: the initials of a sub-watershed name and a four-digit site number. The initials of the sub-watershed name are made up of two capital letters. They identify the sub-watershed where a monitoring site is located. For example, RR0010 is a site name, RR is the initials of Rock Run, indicating that this

site lies in Rock Run, and 0010 is the four-digit site number. The four-digit site number shows the detailed location information of a particular site, such as the exact tributary where the site lies, and its distance from the mouth of a branch. There are several rules to give the four-digit site number.

Of the four digits of a site number, the first two digits identify the mainstream or tributary where a site locates. If a site lies in the mainstream, the first two digits are 00. If the site lies in tributaries, the first two digits range from 01 to 99. The number is counted from the mouth to the end of the sub-watershed. The further a tributary is from the mouth, the larger the number. For example, 03 means the third tributary counted from the mouth of a sub-watershed, and 16 indicates the 16th tributary. It is mainly based on the topological map from USGS to judge mainstreams and tributaries of a sub-watershed. In a topographic map of a watershed, perennial streams are indicated with solid blue lines and intermittent streams by line-dots-line. By looking at the first two digits of the site number, people can tell whether this site is on the mainstem or on a tributary, and the exact tributary can also be identified. For example, in SF0020, the first two digits in the site number of 00 means the mainstream of Snow Fork, and in SF0340, 03 means the third tributary counted from the mouth of Snow Fork.

The last two digits of the site number ranges from 01 to 99. They indicate the relative distance of a site from the mouth of a tributary or mainstream. The numbers are counted from the mouth to the end of each tributary or mainstream, given arbitrarily by the person who names these sites. The further a site is from the mouth, the larger is the number. For example, in a site name of JH0010, JH means a site in Jobs Hollow, the first two digits of 00 means the site is on the main stream, and the last two digits of 10 means this site is the 10th site on the main stream. JH0005 means the 5th site on the main stream of Jobs Hollow. It is not necessary that there are four other sites between JH0010 and JH0005. Instead, the difference between the numbers simply indicates that JH0005 is nearer to the mouth of the main stream on Jobs Hollow than the site of JH0010. Similarly, JH 0130 means the 30th site on the first tributary of Jobs Hollow, and JH0140 means the 40th site on the first tributary of Jobs Hollow. By looking at their names, people can tell that JH0130 is closer to the mouth of the first tributary of Jobs Hollow than the site of JH0140.

The purpose of the site number system is to leave enough space for future sites to be included between current sites, for example, between JH0010 and JH0005. In each tributary, the last two-digit number ranges from 01 to 99, thus providing 100 possible site spaces for this tributary, which is far more enough than actual needs. For example, the two sites of JH0005 and JH0010 are currently sequent to each other.

Sampling Protocol

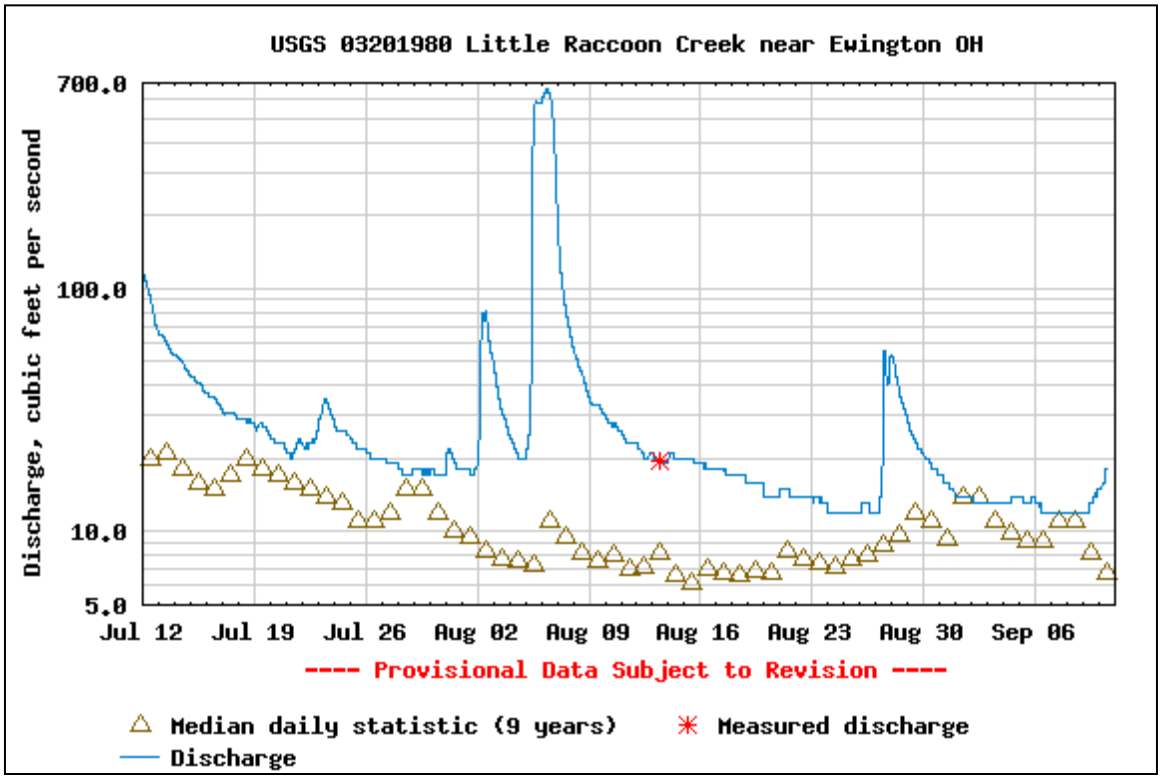
All samples must be collected according to established protocols and using DMRM chain-of-custody forms. Use of the DMRM system will provide a standard methodology for analyzing the data, for geo-referencing the data, and for obtaining an electronic copy of the sample results. The DMRM provides assistance for watershed groups interested in collecting samples and submitting them to the ODNR DMRM laboratory. All such

sampling plans require DMRM oversight. A sampling guidance document "Watershed Sampling and Characterization Guidelines" is available from the Division and should be used in conjunction with this guidance. The EPA requires a Quality Assurance Project Plan (QAPP) prior to awarding a Clean Water Act section 319 grant or for any federally funded monitoring program. It is an excellent way to plan a sampling program. A contact is listed at the end of this document. The Division requires that watershed groups submit an annual water quality monitoring plan for approval.

Sample Collection Timing

In order to provide a true water year assessment, data for each tributary should cover a twelve-month period. The data need not be consecutive, as long as base flow and high flow variations can be documented. For high flow sampling, it is prudent to wait until the runoff peak has passed which can take a day or two after a storm under normal conditions. The chart below was obtained from the USGS website (http://waterdata.usgs.gov/oh/nwis/rt). Flow is indicated for specified time periods.

Figure 8. U.S. Geological Survey hydrograph



Flow measurement (indicated by red star) occurred after the peak had subsided yet still above the annual mean flow.

Flow measurements can be made from a bridge if water levels are too high for wading. The DMRM and the OEPA have bridgeboards and cranes that suspend the current meter in the water. Measurement during high flow measurement can be hazardous therefore,

other methods using reference books or web-based methods such as the USGS method of determining flow statistics can also be used (http://water.usgs.gov/osw/streamstats).

Types of Chemical Data

Water chemistry such as pH, specific conductance, temperature, oxidation/reduction potential (ORP) and flow should be collected with field equipment coupled with laboratory analysis of grab samples. The ODNR DMRM laboratory may be used to analyze such samples. In any case, an EPA certified laboratory is required to conduct all analyses.

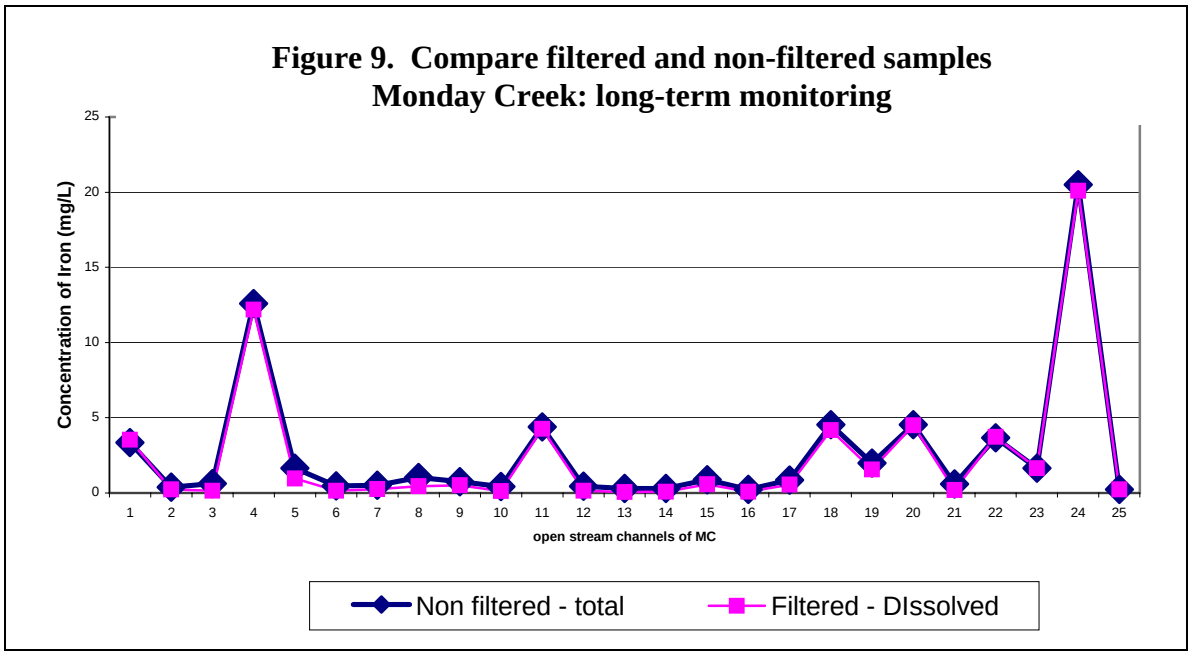
Group I Analyses are generally recommended. Flow measurements are determined at all long-term monitoring sites, and at seeps or other discreet discharges. Group II parameters would be appropriate for specific sites that may require chemical treatment. An "ionic chemical" mass balance is a useful check on the laboratory analysis report. The laboratory performs a chemical mass balance (equivalents per million - EPM) ratio that compares the anions against the cations.

Filtered vs. Non-filtered Metals Samples

In a world unhindered with time and budget constraints, it may be preferable to collected filtered samples for metals and non-metals. This practice would double the cost of analysis and more than double the time to collect them. When collecting samples in stream channels with flowing water and exposed to oxygen, the samples should not be filtered. It is assumed that the oxidized metals in this type of environment have precipitated out of solution and that the water collected will contain dissolved metals. When collecting your sample, avoid collecting water near the streambed and inadvertently picking up precipitated metals or colloidal particles with metals attached. The exceptions to collecting non-filtered samples are the following:

- Samples from sources used for design purposes, where the amount of acidity produced is critical to a successful treatment plan, or,
- When the water in the stream channel is turbid. How turbid? If there is obvious turbidity in the sampling container.
- If the water collected is from a deep mine or base flow into a pit or pond where the water does not have a chance to flow and does not become oxygenated.
- When collecting ferrous iron.

Using non-filtered samples may tend to overestimate acidity and metals concentrations. However, for mass balance determinations or long-term monitoring, the difference is usually not significant and the values are used as relative indicators and not absolute. When sampling for design parameters, it may be important to filter the cubitainer as well as the metals container. This is because acidity is determined from water in the cubitainer and any metals in the water sample will be digested prior to analysis and drive up the amount of acidity detected in the sample.

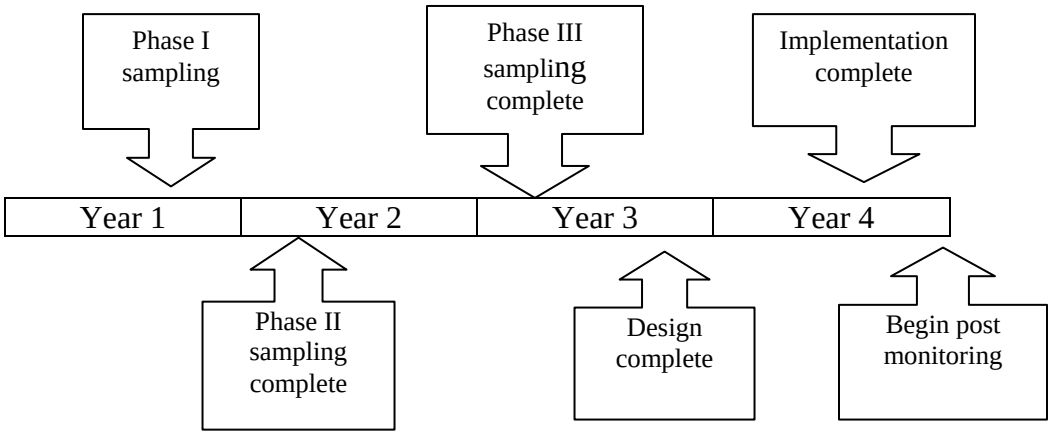


This graph shows that the difference between filtered and non-filtered iron along the mainstem of Monday Creek was insignificant.

Project Timing and Implementation

In general, AMDAT plans can take up to two years or more, depending on complexity, weather, funding, and other limiting factors. However, project implementation must also be planned for and timed according to available funding and other project constraints such as engineered designs, acquisitions of appropriate permits, contractor bidding, and the like. The schematic below is a conceptual planning drawing that provides a timeline for the process.

Figure 10. Project timing and implementation



Data Storage and Retrieval

All of the data should be entered into an electronic retrieval system. Such a system will be critical to the on-going assessment of data and may be a simple database or spreadsheet that provides for summary analysis and tabular displays. In addition to recording the actual data in this system it is important to capture the geographical coordinates of each sampling site. This will enable the data to be linked to an electronic mapping system (GIS) for further geographic analysis. Such systems are an essential component of a large watershed plan in order to evaluate the location of those areas where resources should be focused. Local protocol for GPS data is to use the NAD83 or GWS 84 for latitude – longitude.

Non-point Source Database Monitoring Project

The NPS Monitoring Project was created by the Voinovich School at Ohio University in partnership with the ODNR Division of Mineral Resources Management (ODNR-MRM) http://www.watersheddata.com/. As a result of the NPS Monitoring Project, an on-line reporting system has been created to track environmental changes in several Ohio coal region watersheds. This web site provides a repository of information relating to the water quality analyses, entry forms for AMD project information, downloadable reports, and ArcIMS data entry systems. Water quality and biology data can be viewed, entered, edited, mapped and downloaded. The Data entry systems are conformed for both water chemistry and biology. It contains a full slate of parameters, dissolved and total, site information, flow measurements, field parameters. The database does not evaluate the data. However, databases can yield site-specific data for manipulation in Microsoft Excel or other graphing software.

Credible Data

Credible data means scientifically valid chemical, physical, or biological water quality monitoring data concerning surface waters. Rules for credible data are established under section 6111.51 of the Ohio Revised Code. Four levels of proficiency exist and any water quality data collected for the AMDAT must achieve Level II at a minimum (OAC 3745.4). Training is available to attain proficiency of sampling protocols and field methods so that the data collection and interpretation of reproducible, scientifically defensible, and free from preconceived bias. Sampling supported by ODNR must be conducted by a qualified data collector (QDC) or agency personnel exempt fro QDC requirements.

DATA ANALYLSIS FOR PROBLEM IDENTIFICATION

The problem identification stage will focus the issues and help to maximize the resources available to develop a successful AMDAT plan. For this reason, the careful analysis of available monitoring data to identify patterns or trends and critical conditions is necessary to help determine technical approaches. Critical issues are identified by asking, "when, where, and under what conditions are problems evident?"

When reviewing existing data, one might ask

- How does the data vary with space and time?
- Does the data cover the area of interest for the AMDAT study or is more data required?
- Are the available stressors linked with impairments?
- Is the stream acidity and metals more pronounced during high flow or low flow?

High flow acidity may point to unreclaimed surface mines that flush acid and metals into streams in spring during the resurgence of precipitation events. Low flow acidity may indicate the presence of underground mines that serve as a reservoir continually discharging AMD which becomes more pronounced during base flow and when NOT diluted by surface precipitation.

If a certain stream segment has elevated acidity at low flow, than the solution may be to build a system that will store water to be slowly released into a treatment system during the dry season. On the other hand, if acidity may be problematic during spring rains and other precipitation events, then the solution may be a system that can turn on and off with rainfall.

The answers to these questions help to define many of the technical aspects of the AMDAT including what sources are quantified, what approaches can be used, and on what time and spatial scale the analysis should be conducted. A watershed study can include an entire watershed, multiple subwatersheds, or just impaired segments.

Important aspects in data analysis include

- Spatial analysis to identify variations and conditions and to understand the relations among impaired segments
- Temporal analysis to evaluate the timing of impairment and potential source loading
- Analysis of in-stream loads to identify potential sources of AMD
- Analysis of clean water sources for alkaline addition
- Critical conditions (critical conditions would severely limit biological community unless restoration would mitigate the problem. These could be higher or lower flows depending on the source of AMD)
- Analysis of acidity with and without manganese

The following are examples of graphed data representing a variety of conditions.

This graph below is a spatial analysis from headwaters to mouth showing decreasing pH and increasing net acidity. It profiles the mainstem of Monday Creek after the lime doser was installed in Jobs Hollow (headwaters).

Figure 11. Comparison of pH and net acidity along mainstem Monday Creek

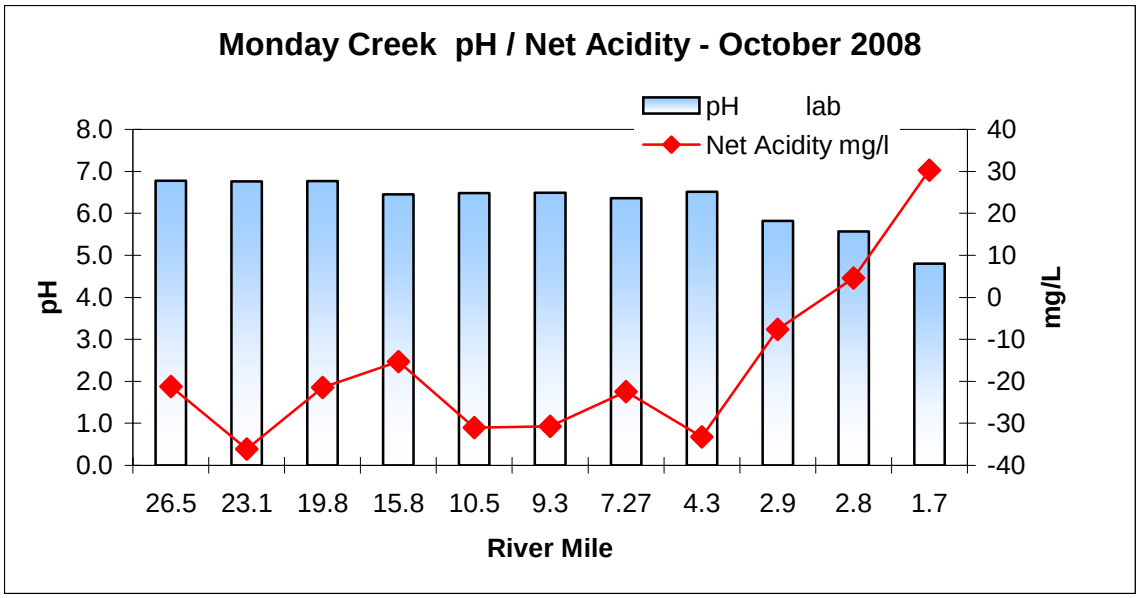
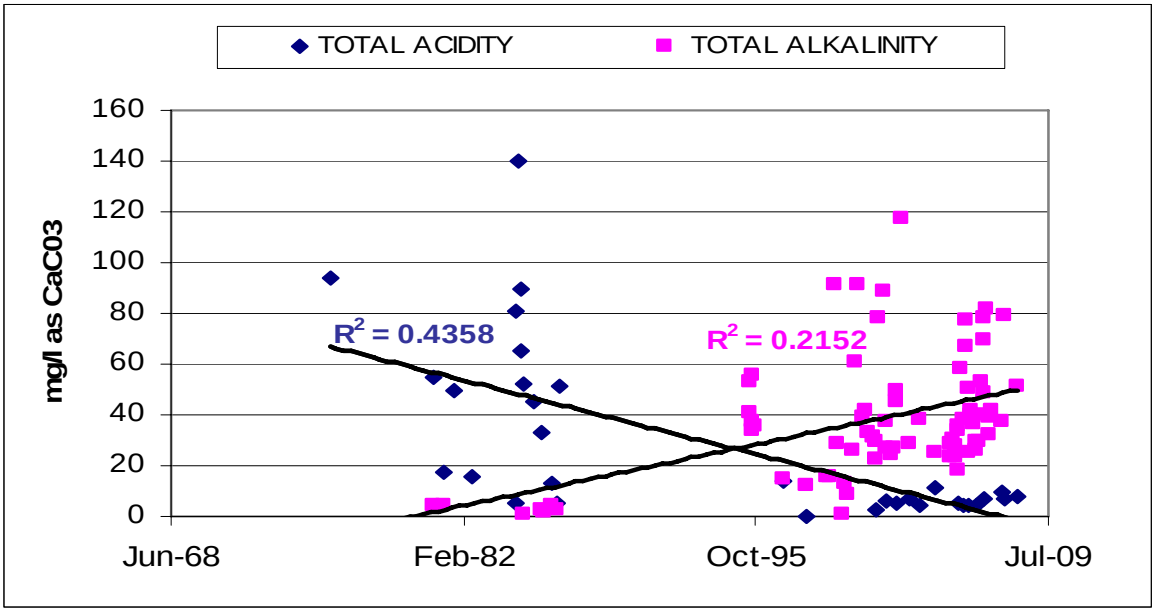


Figure 12. Regression analysis comparing acidity and alkalinity



The above graph is a scatter plot using a several data points at a single site over various dates. The trend lines suggest that acidity decreased in the dry season and conversely, alkalinity increases.

The graph below shows temporal analysis and regression curve. The pH is improving with time. It could represent pre- and post-treatment at a stretch of river in Little Raccoon Creek.

Figure 13. Regression and temporal analysis showing pH over time

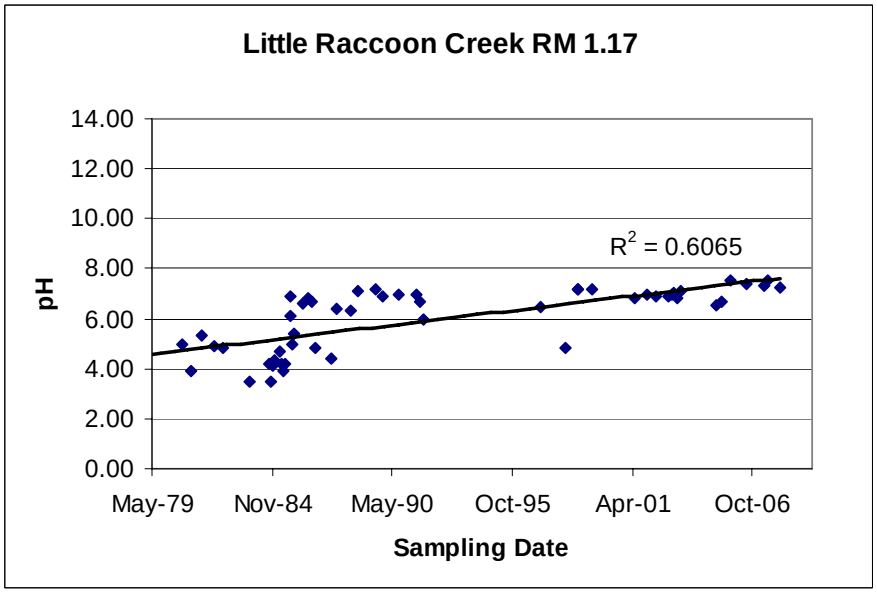
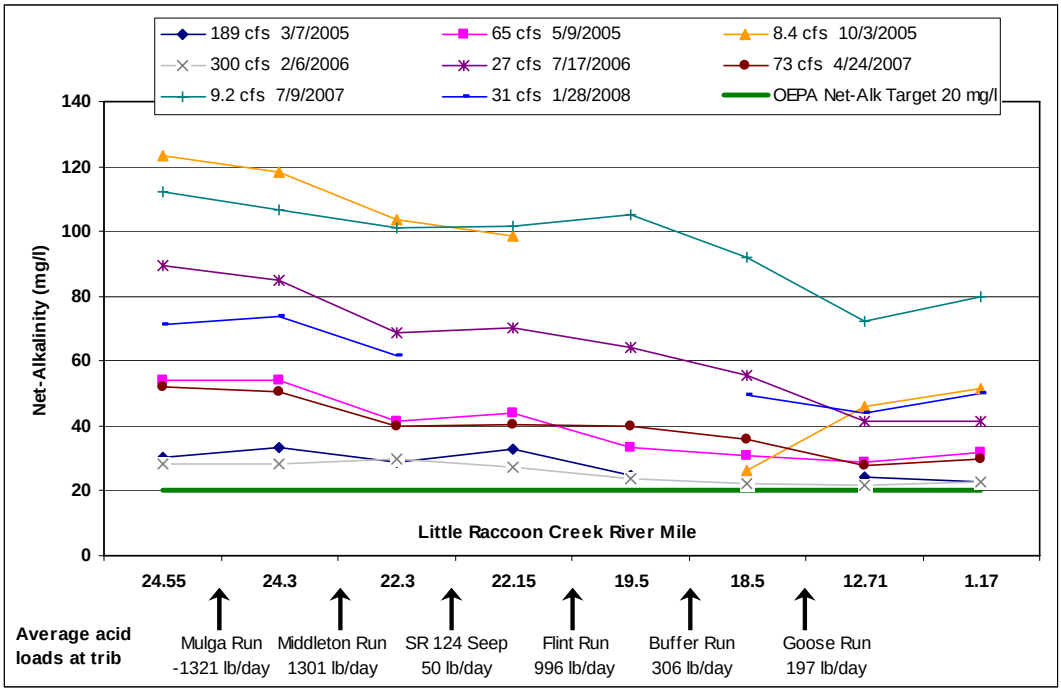
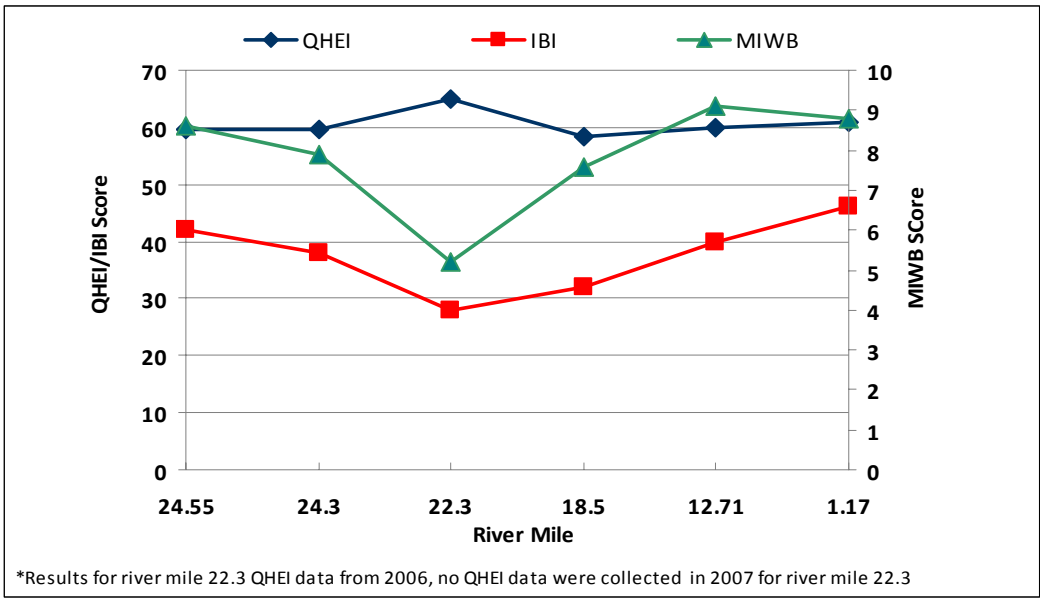


Figure 14. Alkalinity trends under various flow regimes from headwaters to mouth



Watershed characteristics vary from the headwaters to the mouth. In the above case, alkalinity decreases from the headwaters to the mouth. The X axis is labeled both with river mile and tributary input.

Figure 15. Biological indices along Hewett Fork



The above graph shows changes in biological indices from Hewett Fork headwaters to mouth.

Figure 16. Changes in flow at a single site on different dates

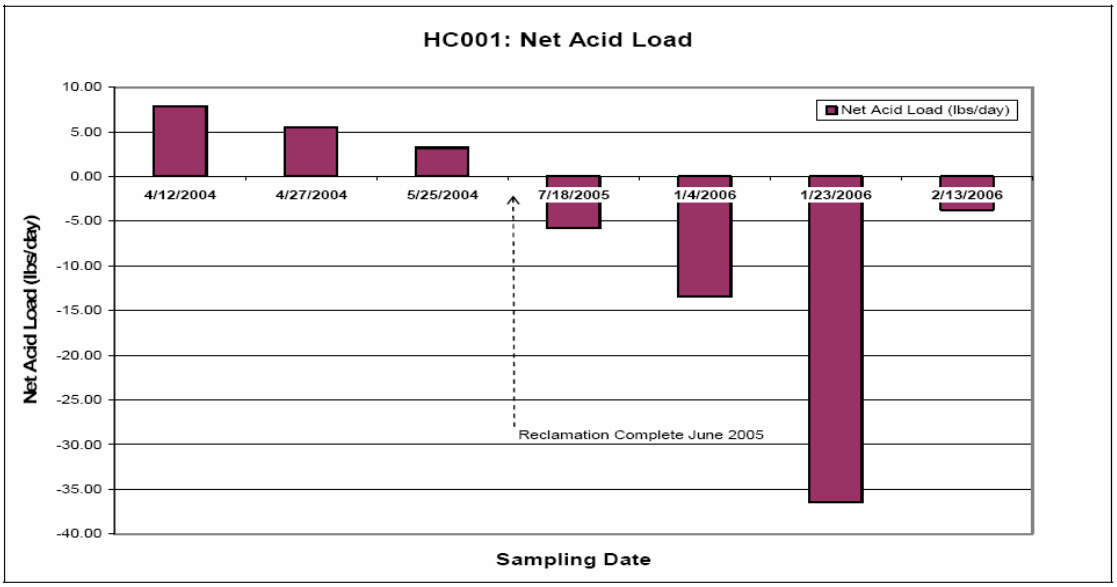
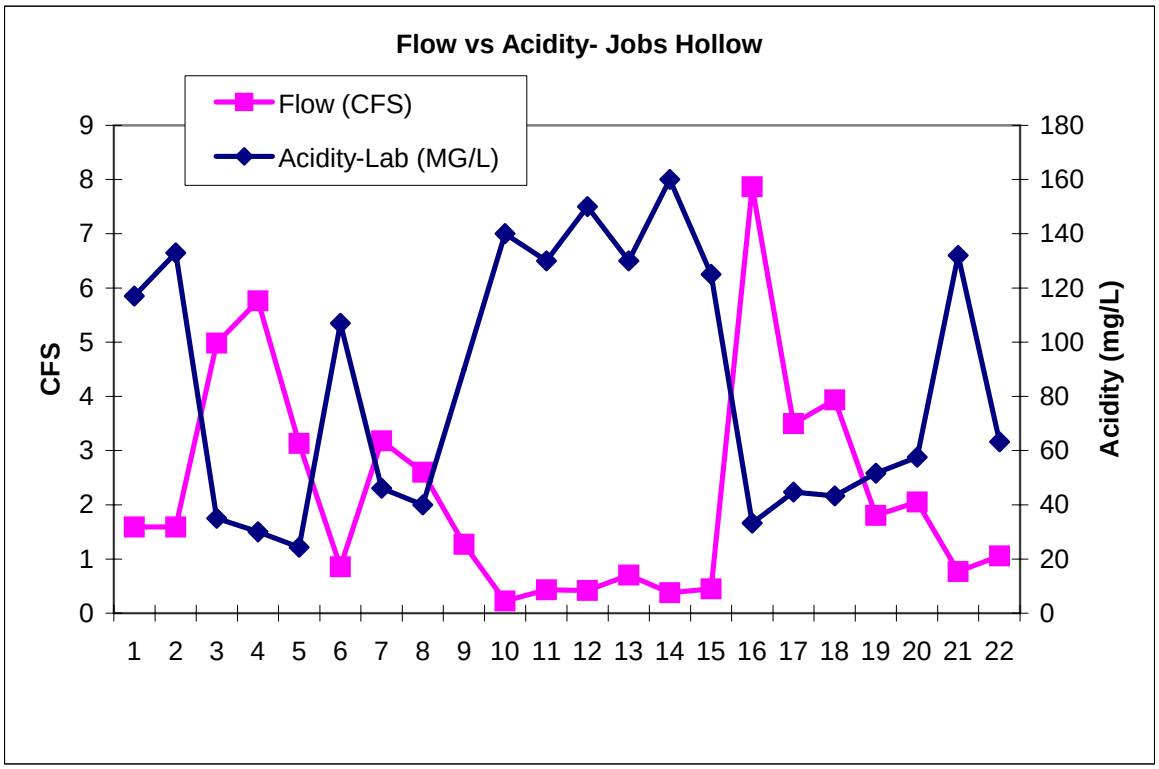


Figure 17. Flow and acidity are inversely proportional



This graph (above) shows 22 samples at a single site in Jobs Hollow, Monday Creek. As flows decrease, acidity increases.

Figure 18. Metal loads decrease while concentrations increase

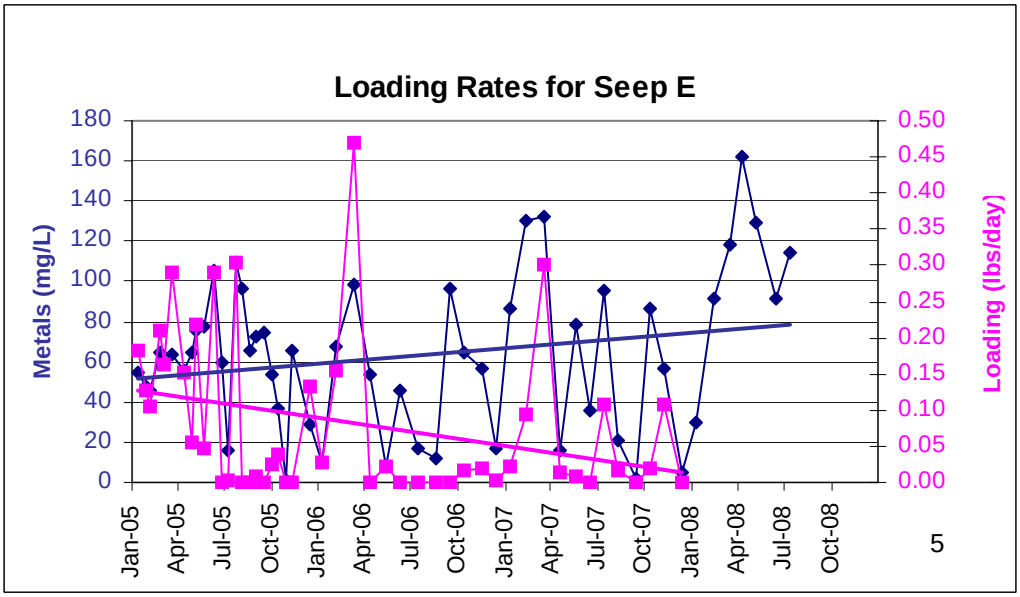
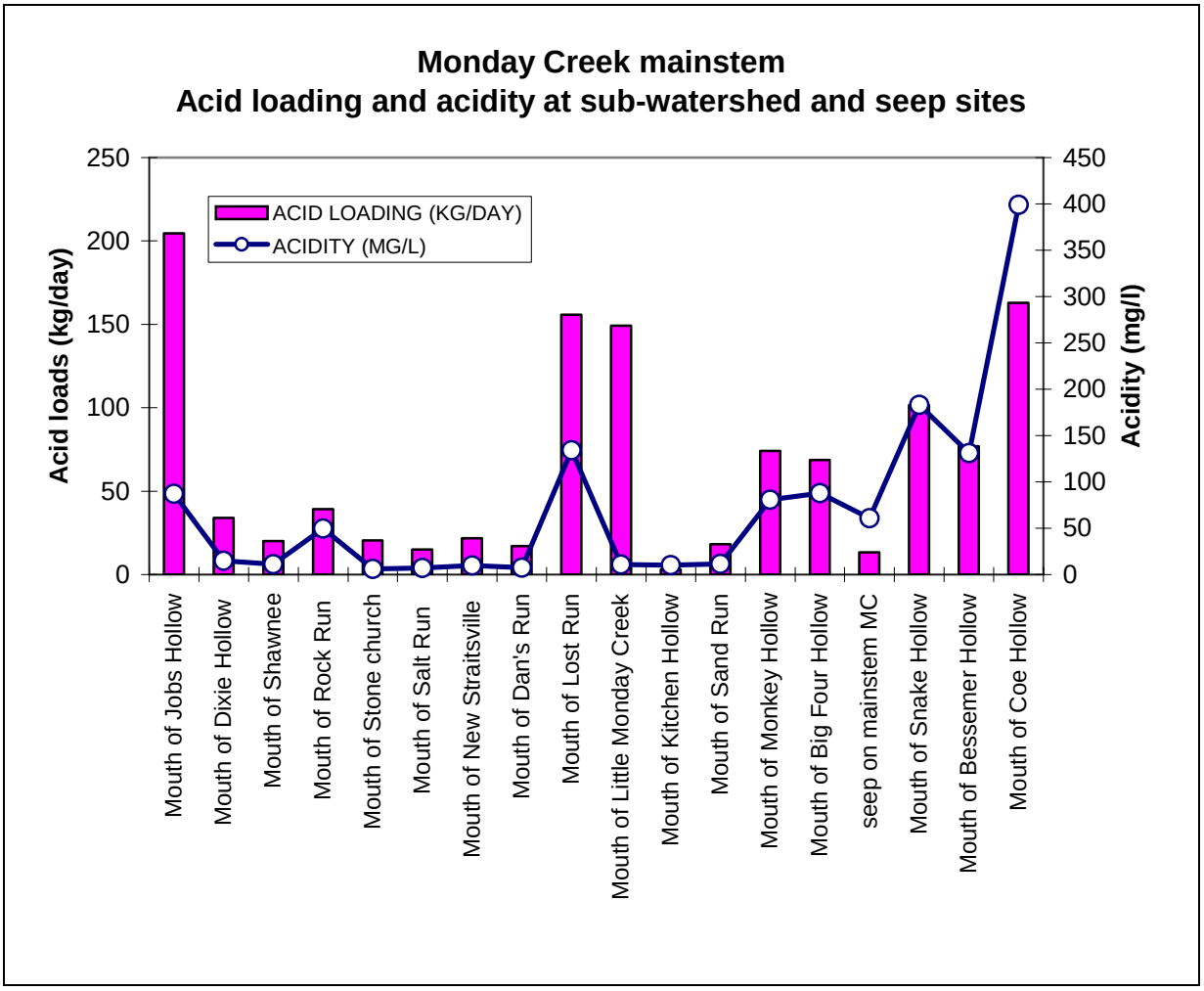
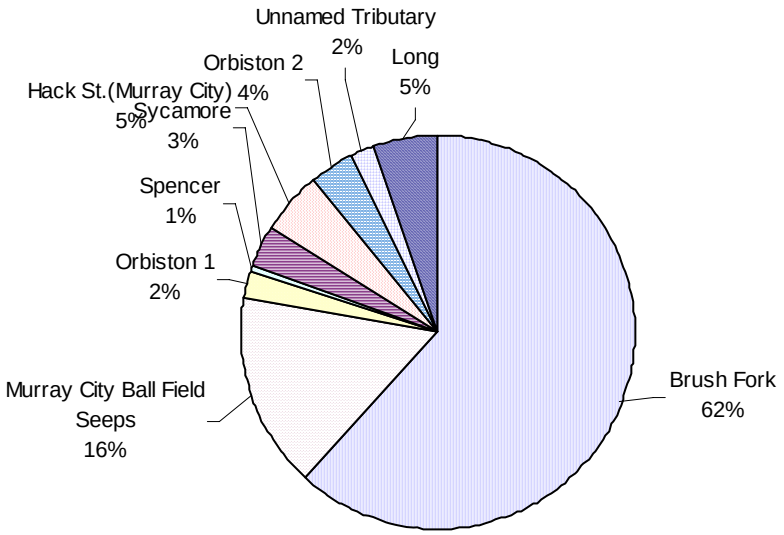


Figure 19. Comparing acid loading and acidity



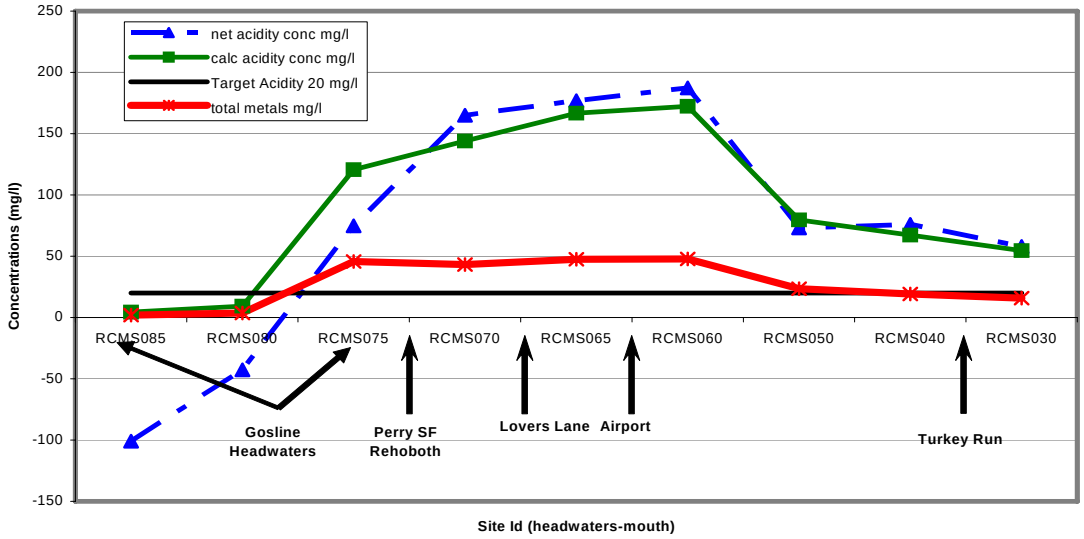
Above, tributaries are listed in order from headwaters to downstream. The concentration of acidity drastically increases at Coe Hollow. Based on this graph, where would treatment be located? (Answer: Jobs Hollow and Lost Run – initially).

Figure 20. Pie chart showing percent of loadings for each sub-basin



This graph (above) shows the result of a mass balance as percentage of acid loading into mainstem Snow Fork.

Figure 21. Rush Creek mainstem sites – Acidity and total metals concentrations



(Above) This graph combines the NET acidity (acidity – alkalinity), total metals, and calculated metals. Manganese concentration was very elevated in this watershed,

therefore, acidity was calculated leaving out the manganese, as the manganese is usually not considered for treatment, and yet, if left in, would drive up the costs of treatment.

LOCATING AND CHARACTERIZING SUBSIDENCE FEATURES

Abandoned underground mines can subside due to age, structural deterioration of the overburden, or erosion into the subsurface from streams. When this occurs, the void where the coal was removed becomes filled in with the overlying rock. The subsidence voids may create openings at the ground surface allowing surface water to enter. Entire streams can be consumed into a subsidence feature and emerge somewhere downgradient or even as inter-basin transfer as acid mine drainage. Correcting these problems not only eliminates acid mine drainage, but redirects fresh water back into the watershed.

Corrective actions will require knowledge of the following:

1. Measure subsidence feature width, height, depth.
2. Determine drainage area being captured by subsidence feature.
3. Estimate mean annual flow: 1 square mile of drainage area roughly equals 1 cfs.
4. Prioritize subsidence closure projects by the size of drainage area being captured (Question: How much surface water is being lost into the subsidence feature?)
5. Use underground mine maps to estimate the point of discharge for the water being captured using your knowledge of the down dip gradient of coal.
6. Measure flow at known mine opening sources and look for subsidence features up dip where water could be eliminated from entering the underground mine complex.
7. Look for subsidence features during leaf-off or in winter. Mark these locations with GPS.
8. Abatement projects for rerouting streams from abandoned deep mine openings or abandoned highwall pits should include upstream flow measurements and water quality data in addition to any associated down dip mine discharges.
9. Pay attention to flow regime
    - Does flow increase during the spring high flow?
    - Does flow dry up in the summer?
    - Does flow stay relatively constant year round?

Figure 22.

STREAM USE DESIGNATIONS

Standards created by the Ohio EPA exist in the form of "Designated Aquatic Life Uses". These standards are not chemical parameter specific, but instead use the biological integrity of the stream to classify the health of a stream segment. The contaminates that are affecting the biological health of the stream are then identified and targeted for restoration so that stream can achieve the highest "designated use" attainment possible. On the basis of IBI, IWB, ICI, and QHEI scores (defined later) in each study site are evaluated and assigned one of the following Ohio EPA stream-use designations:

Exceptional Warmwater Habitat (EWH) – These are waters capable of supporting and maintaining an exceptional or unusual community of warmwater aquatic organisms having a species composition, diversity, and functional organization particularly those that are highly intolerant and/or rare, threatened, endangered, or of special status. This use designation represents a protective goal for water resource management efforts.

Warmwater Habitat (WWH) – These are waters capable of supporting and maintaining a balanced, integrated, adaptive community of aquatic organisms and represent typical warmwater assemblages of aquatic organisms of Ohio streams. It is the principal restoration target for the majority of water resource management efforts in Ohio.

Modified Warmwater Habitat (MWH) – Applies to streams with extensive and irretrievable physical habitat modification, for which the biological criteria for warm water habitat are not attainable. The activities contributing to the modified warm water habitat designation have been sanctioned and permitted by State or Federal law. The waters are generally composed of species that are tolerant to low dissolved oxygen, silt, nutrient enrichment, and poor habitat quality. The category applies to dammed or channelized rivers, and can also be applied to streams affected by AMD.

Limited Resource Water – Acid Mine Drainage (LRW-AMD) – Typically, the drainage area for these streams are usually < 3 square miles. The surface waters may have sustained pH values below 4.1 S.U. or with intermittently acidic conditions combined with severe streambed siltation, and have a demonstrated biological performance below that of the modified warmwater habitat biological criteria.

ELEMENTS OF THE WATER SAMPLING PLAN

BIOLOGICAL MONITORING

The AMDAT plan shall contain specific objectives that are quantified in terms of measurable environmental benefit. The best approach for the evaluation of water resources that is sensitive to all forms of pollution is biological monitoring. Therefore, the methodology shall contain a measure of biological recovery. For instance, the measurable benefit may be stated as X reduction in acidity loading per day at the site and a resultant increase in biological index at a certain point downstream within a stated period of time. Multiple projects within a watershed may have a cumulative effect on improving the biologic recovery of the stream. Monitoring needs will be both short term and long term and both specific to the project site and on a more watershed-wide basis. The monitoring plan shall address how each specific project and how the specific project, when grouped together, contribute to biologic recovery. The cost of monitoring (data collection, data analysis, and reporting) shall be incorporated into the AMDAT plan.

A biological and water quality survey, or "bio-survey" is an interdisciplinary monitoring effort coordinated on a water body specific or watershed scale. This effort may involve a simple focus on one or two small streams, one or two principal stressors, and a handful of sampling sites or a much more complex effort including entire drainage basins, multiple and overlapping stressors, and many sites. These monitoring assessments are conducted to meet the following objectives: 1) determine the extent to which use designations are either attained or not attained and 2) determine if any changes in any ambient biological, chemical, or physical indicators have taken place over time. The next paragraphs introduce concepts related to biological well-being (MIwb) and Ohio's "use designations" of streams. Describing the causes and sources associated with impairments revealed by the biological criteria and linking this with pollution sources involves an interpretation of multiple lines of evidence including water chemistry, sediment data, habitat data, land use data, and point and non-point source water quality data.

In determining aquatic life uses, the Ohio EPA surveys fish and macro-invertebrate populations along with chemical and physical water quality parameters throughout a given watershed. The results from the bio-survey at each sampling station are used to calculate a metric score for both fish (IBI and MIwb) and macro-invertebrate (ICI) populations that indicates the biological integrity of that given stretch of a stream.

The Index of Biologic Integrity (IBI) metric is a measure of fish species diversity and species populations. This index gives a score which indicates how much a stream habitat is affected by pollutants, and which types of fish are present. Depending on the pollution tolerance of specific species, the IBI indicates which species are likely to be found and the level of fish diversity in the stream. The MIwb is a metric that incorporates four measures of fish communities: numbers of individuals, biomass, and the Shannon diversity index based on numbers and weight.

The Invertebrate Community Index (ICI) metric is based on measurements of macro-invertebrate communities living in a stream. Macro-invertebrate studies are important to assess because many insect taxa are known to be either pollution tolerant or intolerant. The presence of certain species indicates the general water quality of an area. This index gives indications about the amount of pollution stressing the stream environment.

A Qualitative Habitat Evaluation Index (QHEI), developed by the Ohio EPA, is also used to characterize physical habitat of the stream at each sampling station. Physical features that affect or are critical for fish and invertebrate communities are evaluated. Some of the features evaluated include type of substrate, amount and type of riparian cover, channel width, sinuosity, and erosion. QHEI scores over 60 are considered conducive to meeting WWH criteria although they are not used to determine the aquatic life designated use. (Ohio EPA, 2001)

Sediment chemistry standards do not exist for Ohio waterways. However, benchmark levels for sediment concentrations have been established in New York State to show when effects on biological communities occur (New York State Department of Environmental Conservation, Division of Fish and Wildlife, 1999). These benchmarks were established to show both low-level and severe-level impacts on stream biota.

Fig. 23. Biocriteria for streams in the Allegheny Plateau region

[Stream use designations requirements from Ohio Environmental Protection Agency, 2002a, and Ohio Environmental Protection Agency, 1997.]

Criteria	Exceptional Warmwater Habitat	Warmwater Habitat	Modified Warmwater Habitat	Limited Resource Water – AMD
Qualitative Habitat Evaluation Index	75	60	45	NA
Invertebrate Community Index	46	36	30	8
Index of Biotic Integrity	50[a]	44[a]	24	18
	48[b]	40[b]		
Index of Well Being	9.4[a]	8.4[a]	5.5[a]	4.0[a]
	9.6[b]	8.6[b]	5.4[b]	4.0[b]

[a] Wading sites

[b] Boat sites

Multimetric Aggregate Index (MAIS)

The Multimetric Aggregate Index (MAIS) was introduced to Ohio by Kelly Johnson, PhD (Ohio University) as a rapid assessment technique taught to watershed group members and students. Macroinvertebrates are identified to family by trained students/ volunteers or Dr. Johnson, and all are archived in the event that further taxonomic resolution or verification proves feasible at a later date. DMRM has been using a family-level aggregate multimetric index (MAIS) to assign a numerical score to each site. The MAIS was developed using an eco-region, reference site approach from data from six eco-regions in West Virginia, Virginia, Maryland, Pennsylvania, including the WAP, although proportionally fewer WAP sites were represented in the dataset. Thus, the current cut-off values for the four classification levels ("very good", "good", "fair" or "poor") may differ slightly for our ecoregion (but a study by the West Virginia DEP with a very similar index found no differences between biota in the WAP and neighboring Central Highlands ecoregion). However, the numerical values of the index (which range from 0 to 20) should provide a reasonable basis for year-to-year monitoring and local comparisons with unimpacted control sites. The MAIS is used in place of the more extensive and time-consuming methods of macroinvertebrate assessments established by Ohio EPA.

Biological Sampling Suggestions

Biological sampling points should be located immediately below the mixing point of the AMD source, at the mouth of the next stream, and at every five miles in between. Qualitative macroinvertebrate sampling to the family level should be done at all sampling points (OEPA may provide training if requested). Fish sampling should be conducted at all sample stations on perennial and interstitial streams. Fish shocking should be conducted in segments 150 meters long. On intermittent streams, salamander surveys should be used in addition to macroinvertebrate sampling. The qualitative habitat evaluation index (QHEI) form should be completed at all biological sampling points. The use of kick nets and/or rock cages will be adequate for most biological sampling on lessor order streams. Streams having an Index of Biotic Integrity (IBI) of 45 or more should be sampled by the OEPA, which may include quantitative as well as qualitative measurements.

Relating Biological Data to the AMDAT Assessment

Projects must be predicated on biological data and contribute towards improvements in water use designation (MAIS & IBI). Existing biological data may be readily available from the OEPA district offices in the form of a Total Maximum Daily Load (TMDL). If not, the biological assessment should be conducted concurrently with the water chemistry and loading assessment, and QHEIs when possible. Where stream water quality is found to decline to a pH less than 5.0, it can be assumed that the aquatic life is severely impacted by mine drainage. If the stream has a higher pH, then additional biological data should be collected. Such data may be gathered through a variety of sources (ODNR Division of Mineral Resources Management or Division of Wildlife, OEPA student interns and staffers, USGS, college students, consultants), but should be gathered using standard recognized protocols and should address macroinvertebrates as well as fish and

other organisms. At least one reference site should be located in or near the study area. A reference site exists where the influence of humans has not negatively impacted the biology and where water or pools exist year round. In establishing long-term goals for stream recovery the biological indicators present in these un-impacted streams will often be used as the ultimate gauge of success of the AMDAT plan. All assessed data should be entered into an electronic database (such as the Nonpoint Source Monitoring (NPS) project for Acid Mine Drainage at the Voinovich School at Ohio University), or spreadsheet, preferably in a format that is GIS compatible.

WATER CHEMISTRY SAMPLING

Characterizing the water quality of the watershed is a long term and on-going process. Included are long-term monitoring, project sampling for pre and post-construction, and mass balance sampling. The monitoring plan will be determined by the goals of your project. The AMDAT plan goals will be refined once the initial data and background information have been collected. A quality assurance project plan will help insure that the data collected meet the needs of the plan. Basic QA/QC (quality assurance / quality control) sampling and data elements include the concepts of precision, accuracy, representativeness, completeness, and comparability.

Long Term Monitoring (LTM)

Long-term monitoring data assess the mainstem baseline and track changes in baseline conditions over time. Any significant reclamation in the subwatershed or headwaters should reflect changes in water chemistry. Through reclamation activities, improvements in loadings of acidity, alkalinity, and metals are anticipated over time. The seasonal variability in concentrations vs. loadings should be assessed. These data are collected quarterly and in some circumstances, twice a year. LTM stations are set up on the mainstem just downstream from the tributaries. Long-term monitoring will provide a powerful tool with which to understand the watershed. The objectives of long-term monitoring include

- Delineation of watershed wide impacts of AMD sources provide a “snapshot” of the entire watershed for any given flow condition. It also provides an overview of the extent of impaired streams throughout the watershed as well as the resultant intermixing of streams.
- A measurable, highly visible environmental indicator of stream conditions based on aquatic organisms and human stream usage.
- A monitoring and evaluation tool to document initial chemical and biological conditions for comparison to post-AMD abatement.
- A comparison and prioritization of mainstem tributaries for treatment opportunities based on net acid / alkaline loading.
- Cumulative loading impacts.

- The opportunity to provide further educational benefits for students and volunteers who will be assisting in the collection of data.

Project Sampling

Project sampling assesses a discrete area for water chemistry and flows in order to determine the type and amount of treatment necessary to remediate the problem. Questions are answered such as how much acidity and metals are produced through seasonal variations and how much alkalinity will be necessary to treat the problem. How much sludge would be anticipated with certain treatment systems? It is desirable to have monthly samples (six to 12 months) both pre and post construction project. If flows cannot be measured in the field, they can be estimated based on drainage area size, (Techniques for Estimating Selected Streamflow Characteristics of Rural, Unregulated Streams in Ohio by Koltun and Whitehead, 2001).

Mass Balance Sampling

A loading mass balance should be an element of the AMDAT plan as well as for continued monitoring. The mass balance can show the extent to which changes have taken place after remediation projects have been constructed in the watershed. Refer to the earlier description of mass balance sampling described in the section of "Watershed Characterization, Source Assessment". Mass balance sampling requires a lot of pre-planning and coordination. Let the laboratory know ahead of time to expect many samples. Let field workers schedule ahead of time and perhaps have an alternative date saved in the event of bad weather.

Figure 24.

AMDAT Plan Review and Approval

Watershed groups are encouraged to develop their plans with input from DMRM and other agencies (USFS, OEPA, and OSM). Once the AMDAT plan is finalized, it should be submitted for approval to the Division of Mineral Resource Management. If possible, consider timing the AMDAT field work in conjunction with Ohio EPA's Total Maximum Daily Load (TMDL) assessments. This would aid in avoiding duplication of efforts.

AMDATs are designed to be dynamic documents; in other words, as conditions in the watershed change over time, the AMDAT should be updated or amended. Especially, once every five years, after projects have been constructed and water quality changes have occurred. Technological changes in treatment alternatives also cause changes in treatment selection. For example, initially, open limestone channels were identified as one of the treatments of choice, but through implementation throughout Ohio coalfields, they were determined to be generally ineffective. This is likely due to the lower gradient streams upon which they were installed as compared to those in West Virginia. In more recent years, dosers have become the preferred treatment, even though it is considered "active treatment". Many passive treatments have succumbed to premature failure, and required much re-working and ongoing maintenance. The next section addresses treatment selection in more detail.

TREATMENT SELECTION

The selection and design of the correct treatment system is based upon a complete evaluation of the physical, chemical, and biological processes. Projects must be predicated on biological data and contribute towards improvements in meeting the Ohio EPA's water use designation.

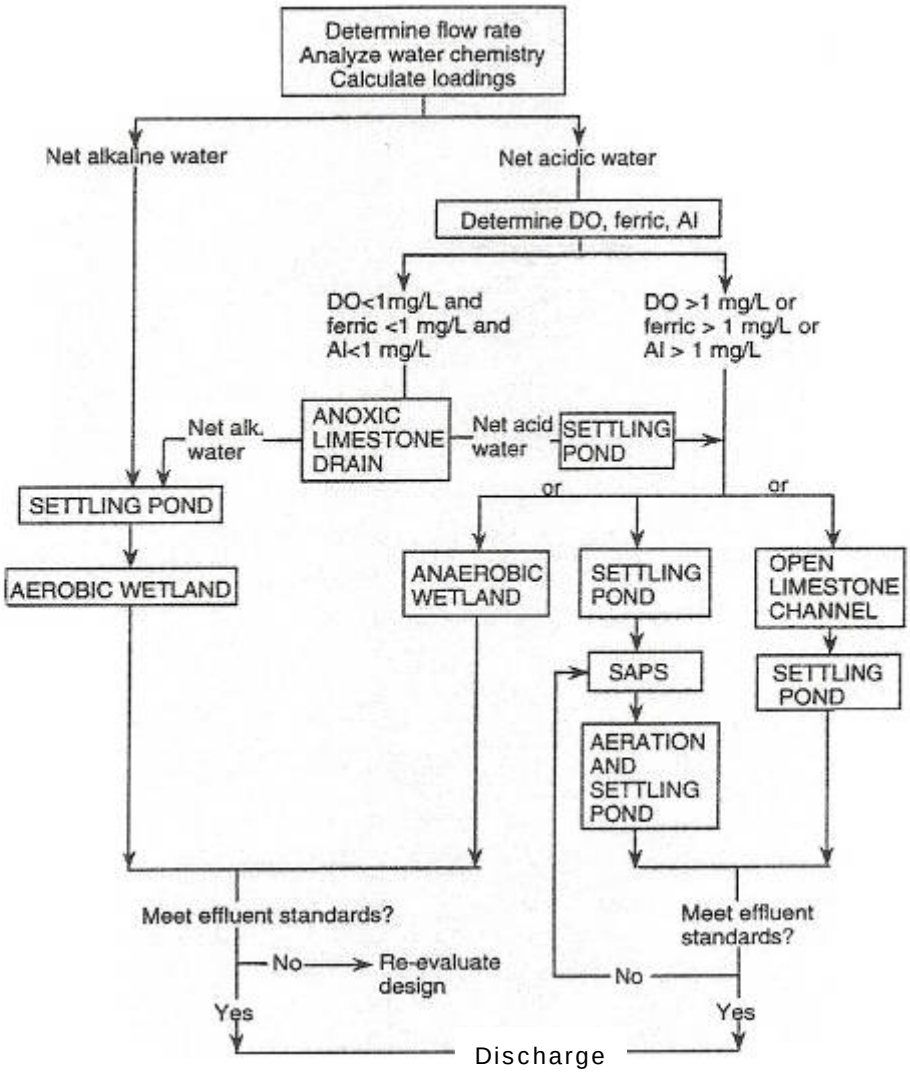
The individual sites for treatment are selected based on expected gains in both stream and aquatic organism quality relative to the treatment cost. An economic approach uses a dollars/ton/year in acid and/or metals reduction.

Passive treatment is most typically applied to the treatment of waters containing elevated acidity, iron and/or aluminum. Not figured into the decision tree are the applications of lime dosers, which are considered active treatment. These are typically applied in streams that are the recipient of multiple sources of AMD and as a way to treatment many stream miles. Expect a "sacrifice zone" for a mile or more downstream. For almost all treatment systems, it is necessary to conduct regular and sometimes frequent maintenance if the system is to operate effectively. Project designs should include an operation and maintenance plan. It is the Division's experience that tweaking of these systems will occur for the first year. And finally, for complex treatment, the phasing in of various systems over several years may be prudent.

A thorough discussion of treatment technologies is beyond the scope of this manual. However, several treatment decision trees and matrices are provided below.

Figure 25. The Carbondale Doser treats high-iron low-pH water from an underground mine without electricity. Approximately nine miles of Hewett Fork are treated with Calcium Oxide.

Figure 26. Decision tree for passive treatment



Anachronisms:
DO Dissolved oxygen
Al Aluminum
SAPS Successive Alkalinity Producing Systems

Modified after Hedin et al., 1994, with additions.

Figure 27. Design of passive treatment Systems

Treatment System	General Requirements	Construction	Design Factors	References
Aerobic wetland	Net alkaline water	Overland flow Cattails planted in substrate	• 10-20 g Fe/m^2/d • 0.5-1 g Mn/m^2/d	Hedin et al (1994)
Horizontal-flow Anaerobic wetland	Net acidic water, generally low flow rate	Horizontal flow above organic substrate	• 3.5 g acidity/m^2/d. • Hydraulic conductivity of substrate (generally 10^3-10^4 cm/sec) • Rate of sulfate reduction (~ 300 mmoles/m^3/day - see text) • Hydraulic loading	Hedin et al (1994) Wildeman et al (1993) Eger (1994)
Anoxic Limestone Drain (ALD)	Net acidic water DO, Fe^{+3}, Al <1.0 mg/L	Horizontal flow through buried limestone	• 15 hours contact time • 6 to 15 cm diam. limestone • Lifetime limestone consumption	Hedin and Watzlaf (1994)
Successive alkalinity producing systems (SAPS)	Net acidic water	vertical flow through an organic layer overlying a limestone bed	• 15-30 cm organic matter with adequate permeability • 15 hours contact time in limestone • Lifetime limestone consumption • 6 to 15 cm diam. limestone	

Skousen, et al. 1998

Software Technology

Computer software tools such as Office of Surface Mining's AMDTreat, or AMD Design can be useful for selection treatment options and costing them out. AMD Design (Paul Ziemkiewicz -1996, West Virginia Water Research Institute, West Virginia University) is an excel-based spreadsheet calculator that aids in designing treatment system size, retention time, predicts outputs of alkalinity, and other helpful calculations. AMDTreat determines project costs based on input of water chemistry and flow. However, the models are not a replacement for the user's knowledge of appropriate technologies and first-hand experience. Download AMDTreat from OSM's website (http://amd.osmre.gov/).

Several books and guidance documents are available to learn about the various treatment systems for acid mine drainage. The technologies are either passive treatment or active treatment and are primarily ways to introduce alkalinity into acidic water. Decision matrices and flow charts for the selection of appropriate treatment alternative are included in the section on Treatment Selection.

Figure 28. Project design matrix

Decision	***Site criteria***		***Treatment options***	***Residence time***	***Max. output***	***Cost***
Add alkalinity		Yes	Limestone Leach bed	11 hrs.	70 mg/L alkalinity	$50-$100 /ton/yr*
	Fresh water?	Yes	Steel Slag LB	1-3 hrs.	2,000 mg/L alk	$50-$100 /ton/yr*
		No	ALD	11 hrs.	~100 mg/L alk	$50-$300 /ton/yr*
		No	OLC	5-10 hrs.	50-95% acid load removal	$50-150 /ton/yr*
		No	Limestone leach bed	1.5 hrs. max	50% acid load removal	$50-$100 /ton/yr
		Yes	OLC	0.25 hrs.	oxidation	$40-150/ ft.
Oxidize?	Slope >10%	No	Aerobic wetland	1-2 hrs.	oxidation	$5000/ac.ft.
		Yes	OLC	4-6 hrs.	99% removal	$40-150/ ft.
Settle Flocs	Slope >10%	No	Aerobic wetland	35 to 80 days (500 tons Fe/ac/yr)	99% removal	$5000/ac.ft.
Wait six months, determine what's left	System meets expectations	Yes	Monitor every six months for 3 years			
		No	Return to Phase II			

provided by Paul Ziemkiewics

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USEPA: *The Volunteer Monitor's Guide to Quality Assurance Project Plans*, EPA 841-B-96-003. 1996. Dale Eicher, 614.644.2136
dale.eicher@epa.state.oh.us
Also see: http://www.epa.gov/QUALITY/qapps.html

USGS provides water sampling protocol on their web site: http://water.usgs.gov/owq (look under Techniques)

USGS Measurement of Stream Discharge by Wading (CD ROM)
By K Michael Nolan and R. Shields
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