Operation and Maintenence of Passive Acid Mine Drainage Treatment Systems

A Framework for Watershed Groups

Division of Water and Waste Management

Nonpoint Source Program

west virginia department of environmental protection

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Division of Water and Waste Management
Nonpoint Source Program

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About the Nonpoint Source Program

The mission of the Nonpoint Source Program in the West Virginia Department of Environmental Protection is to inspire and empower people to value and work for clean water. The Nonpoint Source Program coordinates multi-agency and non-government organizations efforts to address nonpoint pollution by:

- Providing assistance in the proper installation and maintenance of best management practices;
- Supporting citizen based watershed organizations;
- Supporting partners whose activities relate to nonpoint source pollution issues; and
- Restoring impaired watersheds with nonpoint source pollution abatement projects.

The Nonpoint Source Program administers funds authorized through section 319 of the Clean Water Act. If the state adds a waterbody to its list of impaired waterbodies, a Total Maximum Daily Load analysis indicates that adjusting water discharge permits cannot restore the stream, and a Watershed Based Plan for restoration of the stream has been approved by EPA, then the Nonpoint Source Program can make funds available for clean-up projects.

The Program's projects have addressed:

- Acid mine drainage from mines abandoned before 1977, when the Surface Mining Control and Reclamation Act was passed,
- Agricultural pollution, including sediment and manure,
- Sewage,
- Stormwater, and
- Streambank restoration.

The Nonpoint Source Program also supports citizens' groups that seek to monitor, restore, and educate residents about protecting and restoring water resources.

More information is available at the Program's website: http://www.dep.wv.gov/nonpoint

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Foreword

Fifteen years ago, those working on acid mine drainage (AMD) were pushing passive treatment with hopeful claims that projects would treat AMD for 20 years. Those claims were welcomed by those installing passive AMD projects because government programs support only construction, and no operation and maintenance.

Because of that optimism, many projects were built (http://www2.datashed.org/). Successes and failures have led to improvements in design of treatment measures, rules for selecting and sizing them, and methods to refurbish them when needed. Twenty year life spans are rare, but several projects have done well for five to seven years, lost efficacy, and been rejuvenated by some maintenance procedure. On the other hand, many projects never functioned as expected at all.

Watershed groups (WGs) and state environmental agencies have installed many effective *active* AMD treatment projects, but even though they seem more dependable, the lack of funding for the ongoing costs of active treatment means that WGs will continue to rely on passive treatment in most cases.

The purpose of this report is to encourage WGs to develop plans for the operation and maintenance (O&M) of all their projects and to gather resources to carry out those plans. Sections include institutional practices supporting O&M, O&M considerations through the project life cycle, common best management practices for AMD remediation and their maintenance needs, post construction inspection, monitoring, and operation, and post-construction major maintenance.

It will not be easy for WGs to plan and carry out thorough O&M plans because resources are scarce. Rising to the O&M challenge will require the hardest kinds of work WGs do. Individual leaders must draft plans, committees must refine them, and members must recruit volunteers and solicit contributions. This report suggests some things to try. As WGs plan, implement, and monitor projects, they will come up with many ideas and practices beyond this document.

Addressing the need for O&M at AMD remediation projects by saying “Citizens must try even harder!” is not entirely fair or realistic. Citizens should communicate with all levels of government to generate additional resources. Documentation gathered during O&M efforts will support that effort.

This report proposes a systematic framework for not giving up on AMD projects. It is a list of things to try when developing new projects, observing completed projects, or coming back to projects with problems. However, the most important message is very close to that from fifteen years ago: passive projects can restore AMD streams, but periodic maintenance will be needed. It may be difficult to find the resources, but watershed groups have done difficult things before.

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Cover photo: Friends of Deckers Creek volunteers remove a hay cover from a self-flushing limestone leachbed in preparation for a limestone stirring operation, which rejuvenated the leachbed.

Back cover photo: Friends of Deckers Creek Sandy Run AMD remediation project

Summary

Volunteers and watershed associations, as well as local, state, and federal agencies, are restoring streams and fisheries from pollution by acid mine drainage (AMD) that discharges from abandoned mines. These partners reduce pollution in streams by building AMD treatment projects. Due to the nature of the funding available, most AMD projects are passive and do not require regular inputs of additional acid neutralizing chemicals. The capacity of these passive projects to improve water quality frequently decreases over time, sometimes within months. Partners should make plans to get the most water quality improvement out of them by maintaining them and by repairing or replacing them when inspections or water quality monitoring show that it's necessary. A few government programs support construction of AMD remediation projects, but there are few resources for operating, maintaining, repairing, or replacing them.

Non-profit organizations, including watershed organizations, have the potential to overcome the lack of resources by securing donations of volunteer labor, in-kind resources, and funds to support their work. Good governance and focused effort by the watershed group, as well as supportive partners among state and federal agencies, are important for using resources as effectively as possible.

Operation and maintenance of a project should be kept in mind through the project's entire life cycle. A project will be easier to maintain if it is obviously important to the health of a stream and if the landowner is a fully-involved partner. All possible sources of information should be reviewed when developing the project. Engineers designing the project should be knowledgeable and experienced concerning AMD remediation. Construction must be consistent with plans and specifications. Any trouble spots during construction should be revisited during operation and maintenance.

A small number of techniques, known as best management practices, are usually used in AMD remediation. Each has a proper function, rules to determine how big it should be, and ways to assess performance. Each one also has one or more typical ways in which performance degrades and typical repairs that can be performed to rejuvenate them.

Once a project is built, a watershed group should keep projects safe, effective, neighborly, and tidy. Projects should be attractive so that additional landowners will be willing to host them.

A watershed group can perform needed maintenance either with volunteer labor and in-kind donations, or with funding from partner agencies.

Running a consistent, effective operation and maintenance plan will be difficult or near impossible without any fitting source of funding, but projects must be maintained if streams are to be restored. Any modifications to existing funding programs or new funding programs that support operation and maintenance of existing AMD remediation projects will help keep formerly polluted waters clean.

Summary 1: O&M, as well as AMD remediation, is up to watershed groups (WGs)

WGs conduct AMD remediation in a matrix of government laws or agencies, but it is their own commitment that makes the work happen. O&M is a central part of a WGs mission!

Set O&M goals for AMD projects, including:

- Projects should be safe
- Projects should effectively decrease pollutant loads.
- Projects should make landowners and neighbors proud.
- Project should be kept tidy.

Keep an inventory of and budget for O&M needs

- Regularly scheduled inspections, monitoring, and operation and repairs (Section 4)
- Additional repairs as needed (Section 5)

Resources for O&M

- Volunteers
- Community and small business support
- Grants
- Donations

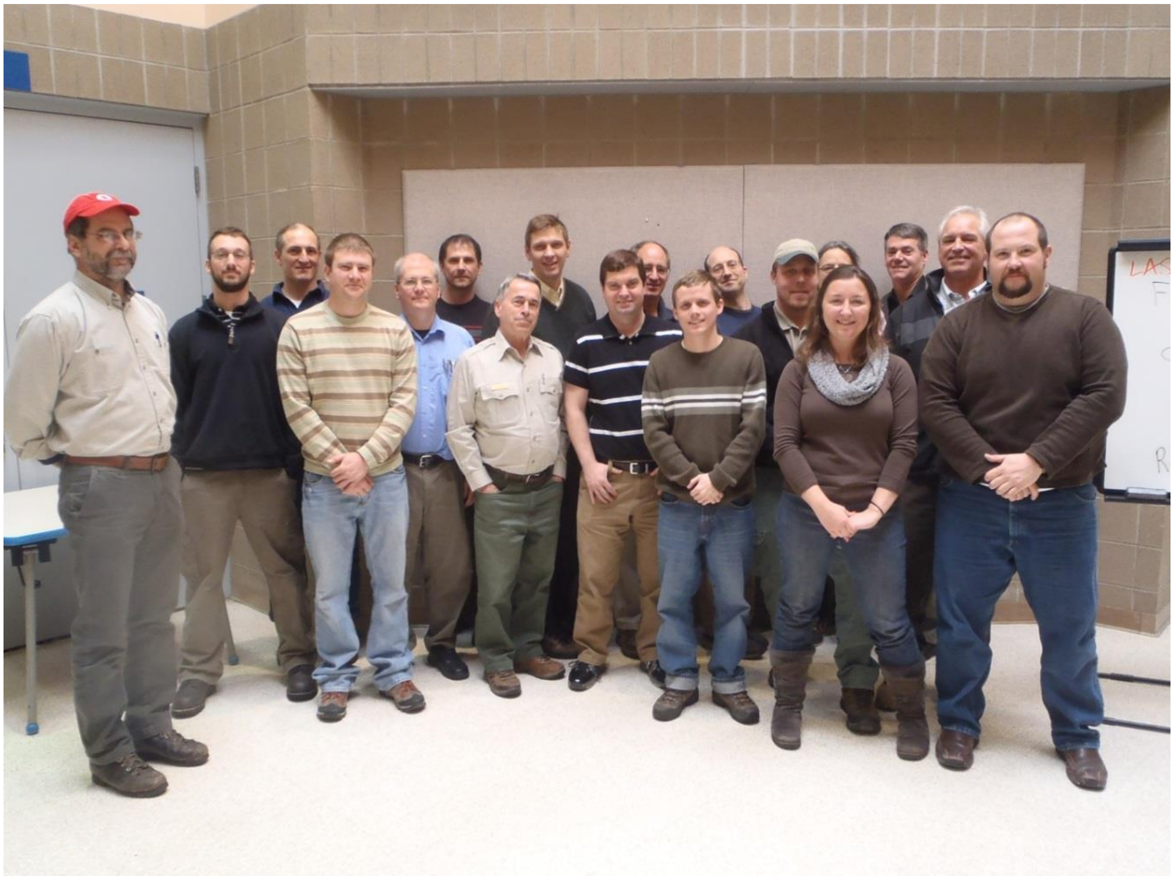
A. AMD remediation relies on NGOs and their resources

Acid mine drainage (AMD) is a solution of sulfuric acid and metals that forms when mining exposes pyrite to air and water. AMD pollutes streams in many areas where coal was mined before passage of the Surface Mining Control and Reclamation Act (SMCRA, 30 U.S.C. §1201 et seq.). These polluted streams, including at least 5,200 miles of streams in West Virginia, may have pH values or concentrations of aluminum, iron, or manganese that interfere with their designated uses (WVDEP, 2011)

Picture 1: Citizens clean up waterways, such as the Cheat River, to improve the economy and satisfy the law of the land, and because they like clean water.

Both the Clean Water Act (CWA, 33 U.S.C. §1251 et seq.) and SMCRA have the purpose of improving water quality that is damaged by mines abandoned before August 3, 1977. However, neither law forces any party to undertake remediation projects. Both laws provide resources for those clean-ups, but because no one is compelled to perform remediation, the work is usually left to non-governmental organizations, especially watershed groups (WGs). Both laws, however, provide support for remediation. Under CWA §319, EPA can fund state efforts to clean up nonpoint source pollution (including AMD from abandoned mines), and states can enter into agreements with other entities, such as non-profit WGs, to carry out the work. Similarly, SMCRA can fund non-profit organizations undertaking water remediation through OSM's Watershed Cooperative Agreement Program (WCAP). Both funding programs allow work periods of only a few years, the time it should take to construct a project. Neither supports operation and maintenance (O&M).

O&M activities and nonprofit watershed associations



Picture 2: The River of Promise group includes watershed group activists, state and federal agency personnel, experts and researchers from academia, engineers, and others. The group has collaborated to install more than a dozen water remediation projects for the Cheat River.

A. Organizational governance

Environmental laws do not compel the state or the nation to clean up any streams impaired by nonpoint source pollution, but a desire for clean water compels citizens to undertake such clean-ups. Citizens usually do this by forming watershed groups (WGs) that are non-profit corporations. Non-profit status gives the organization a way to raise funds, hire staff, and purchase items without paying some taxes. Incorporating and organizing allows the people in the group to divide labor and do more work.

Working through CWA and SMCRA to fund and carry out water remediation projects requires a number of skills from WGs. They must be able to

- Hold meetings with focused discussion, make decisions, and keep records of those decisions,
- Adopt clear rules for governance,

- Delegate work to individuals or committees who then carry out their assignments,
- Satisfy all laws concerning finances and taxes,
- Satisfy all requirements given by funding agencies,
- Budget and correctly account for funds,
- Identify and obtain any permits their work may require,
- Hire and hold accountable contractors to carry out work that volunteers cannot perform, and
- Establish communication with town councils, county commissions, the press, and the community.

It takes time for any group of people to attain such organization. If a group must develop so many skills to install AMD treatment projects with substantial support from government agencies, the group must run even more efficiently if it is going to carry out an O&M program largely without the financial support of those agencies. WGs should use every resource they can find to make their own operations more efficient. River Network (RiverNetwork.org) has a number of resources for WGs, including “Building Better Boards,” “Governance of Charitable Organizations and Related Topics,” “Leading and Communicating,” and many others.

Every aspect of the WG must accommodate the need to carry out O&M. O&M should be

- Consistent with the mission statement,
- Explicitly included in a strategic vision statement,
- Reviewed regularly by the Board of Directors,
- Allocated resources in the budget,
- Performed by staff, contractors, or volunteers,
- A target for fundraising,
- A reason for outreach to potential volunteers, supportive businesses, and major donors.

1. Mission statement

Restoring streams is usually a fundamental part of the mission of WGs. Some WGs undertake to manage water remediation projects themselves by seeking funding, hiring engineering and construction contractors, and overseeing the entire process. Some choose to restore streams by advocating that government agencies build remediation projects. Regardless, streams cannot be restored unless someone takes responsibility for making sure that remediation projects work. An organization that manages its own remediation projects will probably choose to take on the O&M role. If a WG works primarily through advocacy, it must make sure that whoever carries out the remediation project operates and maintains it so that it continues to improve water quality. In either case, O&M of AMD remediation projects must be an acknowledged part of the mission.

2. Strategic vision statement

Some organizations adopt strategic vision statements, which give more precise guidance for day-to-day decisions than a broad mission statement. Strategic vision statements give an opportunity for the Board of Directors to agree on particular approaches to achieving the mission, such as what an organization does day-to-day, how big it might get, and so on. A strategic vision statement that includes O&M might state:

> *As the organization installs more AMD remediation projects, the need for O&M will increase. It is likely that in five years, raising funds for and doing O&M will account for a large portion of staff, volunteer, and fundraising effort of the organization.*

3. Board of Directors

The Board of Directors is the steward of the mission. They may carry out the WGs work as volunteers, or they may hire and oversee paid staff. The Board is ultimately responsible for O&M of AMD remediation projects. It should set goals for O&M, inventory the O&M needs, allocate available resources to meet those needs, and plan for gathering additional resources for unmet needs. River Network provides several resources to help Boards assess their own strengths and weaknesses and improve their effectiveness (http://www.rivernetwork.org/category/resource-library/organizational-development).

Setting goals—Most O&M programs will share four basic goals:

- Projects should be safe. They should not threaten neighboring properties (e.g., because earthen berm holding water back may fail). They should not be dangerous to people who enter the site.
- Projects should achieve the water remediation goals set for which they were designed.
- Projects should be viewed as neighborhood assets. Neighbors should be proud that the projects are there, both for the improvement in water quality, and for how they look. They should not detract value from neighboring properties.
- Because projects should be kept in a safe condition, should look good, and should not turn off neighbors, projects should look cared for and tidy.

Assessing O&M needs—it is difficult to predict what any given site will need in a year. The following categories, which are discussed further in the rest of this document, must be considered:

- Inspection, monitoring and operation (IMO) trips—regular visits to assess site condition and water quality remediation performance and to perform any adjustments needed to keep the project in good condition. A reasonable baseline is four IMO trips per year. Additional time for preparation and recording observations, measurements, and operations must also be included.
- Contacting neighbors—calls to identify any problems that might be occurring on the site, and to confirm that they still see the project as a source of pride.

- Rainy-day inspection—one purpose of normal inspection is to determine whether earthworks are holding up or eroding. Observing a site during or immediately after a heavy rain will provide more evidence than dry-weather visits. One such trip a year is prudent.

- Landscaping—to keep a site looking cared for, one or two landscaping trips might be needed each year, in which staff and volunteers remove dead branches or other debris, cut vegetation where it is interfering with any goals, and keep it looking good.

- Other site work—from time to time, staff and volunteers may make small repairs to the site, for example, by digging shallow French Drains to manage surface water at the site. One such trip each year might be needed.

- Addition of materials or minor repair requiring heavy equipment—some operations can be done quickly with a small amount of heavy equipment, but not so much that hiring an operator will require bids and elaborate procurement procedures. Hopefully, a project will not require this more than once every five years or so.

- Major repair—many projects will eventually require partial or complete replacement, and may require all the steps—proposals, permits, engineers, bids—that went into the original construction. One hopes that such measures will not be needed more than once every fifteen to twenty years.

In summary, a typical project, therefore, might require, five days of staff time for IMO trips (including preparation and data recording), three days of staff time with volunteer groups for landscaping and minor repairs, and, ideally, a contribution to a contingency fund for minor repair. Major repairs will most likely rely on funding through programs similar to those which funded the original construction.

Allocating resources—in an organization with no staff, one Board member might take responsibility for O&M needs. If there is staff, it will probably become a staff responsibility. The responsible person will probably soon determine that the resources of the organization do not meet the O&M need. Fundraising, volunteer recruitment, and outreach to businesses might fill in some of the resource gap.

B. Staff

If the WG has staff, the Board will most likely charge them to carry out the O&M goals by inventorying and prioritizing O&M needs, assessing what can be accomplished using currently available resources, gathering additional resources, and finally, performing the needed tasks.

C. Volunteers

Volunteers can play a vital role in O&M. Volunteers can participate in or even direct many O&M activities. The following general advice about volunteers can apply to volunteers for O&M:

- Treat volunteers as professionals: begin and end activities on time; prepare so they do not have to stand around while they are there to work.
- Make sure tasks are clear, and there is instruction and support for any complicated parts.
- Recognize and thank volunteers in newsletters, in the newspaper, and at the organization's public events, as well as in person.
- Connect the day's work and the day's accomplishments to the central mission of the organization (which the volunteers probably support).
- Give them a voice in the project (they may have volunteered because they have applicable skills and experience).
- Keep track of volunteers' activities. With experience, they gain skills which they can teach to newer volunteers. Volunteer hours are also a crucial resource for matching grants or other contributions.
- Feed them! Food nourishes camaraderie.
- Educate them! Give them as much information as they want to absorb. They might have the next great idea.

Conducting O&M with a group of volunteers, who get to know each other and work together repeatedly, builds teams and friendships. Volunteers often cite meeting people and making friends as a main reason volunteering is satisfying. Those who have a positive experience volunteering are more likely to contribute more to the organization, including money, time, and leadership.

D. Fundraising

Include O&M among the items that you explicitly raise funds for, even though raising funds for O&M is not easy. Nevertheless, set goals for O&M fundraising, and make O&M a specific target of a particular fundraising event.

E. Communicate with local landscaping companies

Businesses are often most comfortable making in-kind donations of the service that the business offers. As you are building your volunteer base and your business membership, reach out to local landscaping contractors. Let them know what your needs will be. Keep a list of such contractors and make sure they have an opportunity to bid on any large construction projects that you might have. But be careful to prevent the appearance of a conflict of interest. A company can never receive a project because of its gifts to the organization. Check with funding agencies about any conflict of interest concerns regarding a contractor who has donated services to you in the past.

F. Learn, attend conferences, contact the experts

The field of AMD remediation is changing. Widen your horizons. Read. Allocate resources that encourage staff or volunteers to attend conferences where AMD remediation using passive treatment is discussed, such as

- The West Virginia Mine Drainage Task Force Symposium, held during the last week of March in Morgantown, WV. See http://wvmdtaskforce.com/.

- The Pennsylvania Abandoned Mine Reclamation conference, held sometime during the summer somewhere in Pennsylvania. Find this conference through the Western Pennsylvania Coalition for Abandoned Mine Reclamation (www.WPCAMR.org) or the Eastern Pennsylvania coalition for Abandoned Mine Reclamation (www.EPCAMR.org).

G. Educate all levels of government

The need to operate and maintain AMD remediation projects may exceed the capacity of WGs, and they should ask for and receive help from every level of government. Make sure the governments of towns, cities, or counties that contain or are downstream from AMD projects know what the needs are. Request use of any heavy equipment they may own from them when it is needed! Enlist their engineers for expertise.

Summary 2: O&M through the project life cycle

Identify a good project:

- Partners are more likely to support a project that is crucial for restoring substantial lengths of an accessible stream. NPS funds target removing pollutant loads from subwatersheds (SWSs).

Landowner cooperation:

- Landowners should share commitment to the mission.
- Landowner must tolerate all levels of O&M (routine trips, landscaping groups, minor repairs, possible replacement).
- Landowner must accommodate O&M schedule.
- Landowner must allow use of roads or driveways to site.
- Landowner must be satisfied with protection from liability for those involved in O&M.
- Landowner and neighbors may have knowledge about the site.

Site and source characterization

Summary 2 continued

- Make many load measurements to estimate average load and maximum flow.
- Observe site for problems (intermittent springs, wet spots).

Good engineering:

- Make sure engineer is experienced and knowledgeable.
- Review engineer's rationale for treatment method and size of the project.
- What size project does the load require?
- Is the engineer experienced in siting and designing such a project?
- Engineer should prepare an O&M manual for the project.
- Design should make for easy monitoring.
- Engineer or Contractor should provide an as-built drawing of the project.
- Protect treatment components from sediment.

Construction:

- Note trouble spots that appear during construction such as soil slips, ephemeral springs, and muddy areas.

O&M through the project life cycle

Projects take a long time to plan and build. Between initial identification of an AMD source and completion of a project there may be many years. It is important to think ahead to the O&M phase of the project from the very earliest part of project development.

Typical stages for an AMD remediation project include identifying the AMD source, meeting landowners and assessing the possibility of developing a project, characterizing the AMD to determine what kind of project to build, quantifying the AMD load and gathering site information, hammering out the design (with landowner, engineers, and funding agencies), and constructing the project. Section IV discusses the phase after construction, when O&M is the central activity.

A. Design and initiate a comprehensive monitoring plan

Identifying the AMD source that will be the target of the project requires water quality monitoring. Once the project is complete, demonstrating that it is meeting its water quality goals will require more monitoring. Comparisons of before- and after-construction data will make more sense the more consistent the monitoring is. One of the first steps in a project is developing a good monitoring plan. Before construction, water quality monitoring has a number of purposes:

- Identify a treatable source of AMD
- Demonstrate that the AMD source has a substantial negative impact on the stream

- Determine the quality of the pollution to determine proper pollution control measures
- Determine the quantity of the pollution to determine the size of the necessary pollution control measures.

After construction, water quality monitoring still has more than one purpose:

- Determine whether the constructed measures are indeed decreasing pollution loads
- Get people to the site to make sure it continues to operate safely and effectively.

To accomplish all the goals, three different kinds of monitoring locations must be identified. First, the decrease in the pollutant load should be measured in a downstream location that will be the same before and after construction, so that the measurements are as comparable as possible. Second, the quality and quantity of AMD must be monitored at the location where it will be treated, most likely right at the source or sources. Sources must be monitored not only to choose the kind and size of the treatment project, but also to determine whether changes in performance of the project are the result of changes in the project or changes in the input.

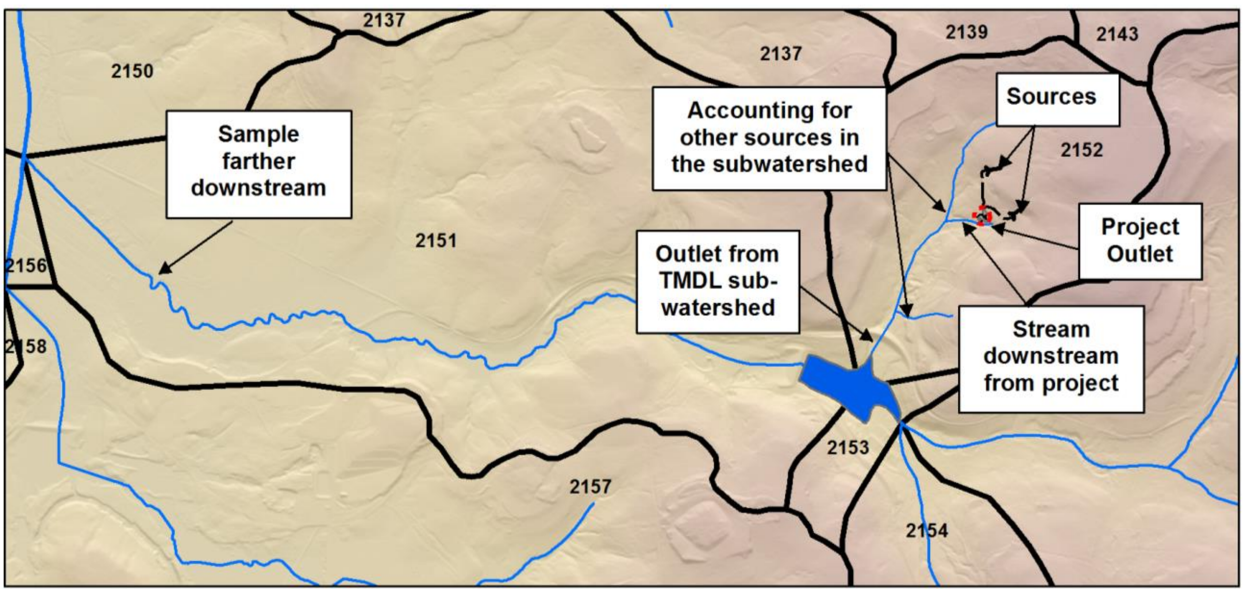


Figure 1: Typical monitoring locations to consider for a comprehensive monitoring plan.

The third set of monitoring locations should be selected to assess the impact of the project on the watershed as a whole. For the sake of the Nonpoint Source program, the watershed in question should be the subwatershed (SWS) for which a Total Maximum Daily Load was calculated. If additional resources for monitoring are available, they can be used to demonstrate effects even farther downstream, or to make sure the change in the target SWS was not caused by changes in upstream SWSs.

As important as where to monitor are what, how, and how often to monitor.

<u>What</u>: Measurements taken should include flow, pH and alkalinity, dissolved aluminum, dissolved iron, and dissolved manganese. These measurements together supply the data for a "calculated" acidity load (e.g. Kirby and Cravotta, 2005) as well as loads of the dissolved metals. Water quality standards for iron and manganese in West Virginia are based on total, rather than dissolved loads, but concentrations of the dissolved metals will demonstrate how much acidity has been reduced, which is the key to removing the metals. Many labs offer a direct, titrated, measurement of hot acidity which should be very close to the calculated value. However, labs commonly report erroneous hot acidities, possibly because of slow response of pH probes connected to auto-titrators. If resources allow, other measurements of interest include benthic macroinvertebrate communities or other biological indicators.

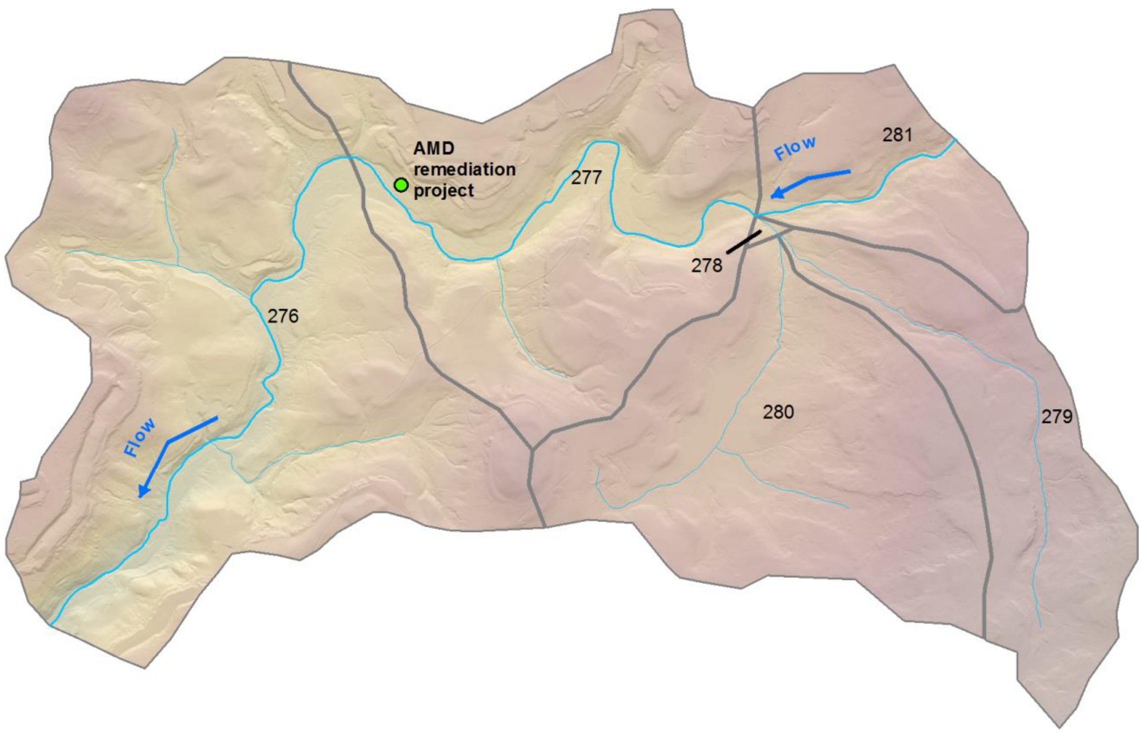


Figure 2: To determine the effect of the AMD remediation project, AMD loads at the outlet from SWS 277 into SWS 276 should be measured, and also the loads at the outlets from SWS 278 and 281 (or SWS 279, 280, and 281).

<u>How</u>: Chemical measurements should follow standard methods. In very small streams (<30 gpm) the assumptions behind flow meter measurements (especially that flow in the water column reaches an average rate six-tenths of the distance from the surface to the streambed) are often violated because of obstructions in the stream or an uneven streambed. If possible, stations for bucket and stopwatch readings should be established for monitoring small flows. Installing a flow pipe can enable flow measurements that are speedier and more accurate than those made with a flowmeter. V-notched or rectangular weirs can also accelerate flow

measurements, but can often be blocked with debris, which interferes with the relationship between water height and flow.

How often: Quarterly monitoring of sources, the system-out point, and the SWS outlet is ambitious yet reasonable. If monitoring occurs each quarter, flows and water quality characteristics during high flow and low flow conditions will probably be seen. The application for OSM-WCAP funding requires twelve monitoring visits. During the load determination phase, monthly sampling will provide enough data in a single year.

Monitoring information, both pre- and post-construction, is useful for outreach as well as for justifying a project to funding agencies. Comparing the load at the target AMD source to the load at the outlet from that project's SWS gives an estimate of the importance of the AMD source. Volunteers and donors, as well as funding agencies, are more likely to support a project that will have a profound effect on the SWS than one that will have a small effect.

Figure 3: Left: Buckhannon River Watershed Association installed a flow pipe to measure flow at this seep; Right: soil and rocks are used to pool AMD so that it flows through the flow pipe

A. *Contact with the landowner*

Landowners where construction takes place are partners in the effort to restore streams, and their input should be welcome at any time. WGs should explain how they will operate and maintain projects to the landowners. WGs and the landowner should develop and sign a Right-of-Entry agreement that protects both parties. Points of discussion and landowner concerns that should be addressed might include:

- How often will the WG enter the project? Does the landowner understand the full range of activities for which a WG might enter the site (including a regular monitoring routine, rainy-day visits, volunteer groups for landscaping, minor repair, tours by agency personnel, and replacement)? If a landowner values the project site for peace and quiet, or for hunting, WG visits could cause conflicts.

- What notification does the landowner need before the WG visits? None? A phone call the day before? A letter?
- How will the WG access the site? Does the landowner wish to restrict one access so that the WG must find or build a second road?
- Will the landowner allow you to use volunteer groups, or even youth groups, to conduct O&M? Will the landowner be satisfied with any liability waiver you intend to use?

B. Characterizing and quantifying the AMD load

If preliminary assessment of the AMD and discussions with landowners indicate that the project might proceed, the WG will probably begin a roughly one-year monitoring program to get a better estimate of the character and load of the AMD from the site. A set of twelve measurements of the AMD load is recommended for the OSM WCAP application, for example (http://www.osmre.gov/lrg/fam/6-200.pdf part 6-200-40). During this period, careful observations at the site may lead to design decisions that greatly reduce O&M problems later.

Which AMD best management practice (BMP) to use is one of the most important decisions for the project and for its long-term maintenance? A BMP that is well suited to the kind of water being treated will last much longer than an ill-suited BMP, and will be less likely to require replacement after a short time. The different BMPs and the water they are suitable for treating is described in Section III, which also describes rules for deciding how large a project is needed based on the load of AMD being discharged. Crucial measurements include flow, pH, dissolved oxygen, alkalinity, dissolved aluminum, dissolved iron, dissolved manganese, and ferrous iron.

While visiting the site, it is useful to note additional springs and wet areas during the wet season. These springs will have to be managed in the final design, either by diverting relatively unpolluted water off site in a way that doesn't erode the earthworks, or by diverting polluted water into the treatment system. During and after construction, springs can cause soil to erode into waterways or into treatment components, or contribute to soil slips that may destabilize slopes, or push pond liners away from pit walls, decreasing the pit's volume and the residence time of AMD passing through it. Walk upstream to determine if there are existing sediment sources, or likely sources, if more building or development is about to happen.

During this period, the WG should also gather other information that may help the engineer plan a good project and minimize O&M issues. Important sources include the landowners, and neighbors who worked in the mine before it was abandoned or who have been visiting the land for decades. If an agency, such as the WVDEP Office of Abandoned Mine Lands and Reclamation, has worked on a site, then the WG should secure copies of their designs and site assessments and pass those onto the engineer designing the WG project.

Figure 4: The liner in lined ponds may be pushed away from the soil by ground water underneath the liner, decreasing the volume and retention time in the pond.

C. Good engineering

The best way to minimize O&M and avoid large replacement projects is to build an excellent project in the first place. To build such a project, a WG will seek the help of an engineer with extensive experience in AMD remediation. The engineer will make good major decisions about the project, will provide information to the WG about its operation and maintenance, and will design the project so that inspection, monitoring, and operation are possible.

1. The right thing in the right place

One of the most important decisions in design is what best management practice (BMP) to build, and how big it should be. Many sources present the basics of selecting AMD treatment technologies. A good engineer will probably select and size a BMP according to guidance similar to that in Section III. The WG should review the engineer's choices in light of the guidance, and the engineer should give a rationale for any deviation from the guidance.

2. Documents

An engineer can support O&M with several documents as part of the design process. While selecting which engineer to hire for the project, the WG should indicate which of these documents the engineer will be required to produce.

In a decision rationale, the engineer records the factors that influenced the decision about which BMP to use, and how large to build it. If a project then fails to perform as well or as long as expected, a review of the design rationale may identify mistaken assumptions or incomplete knowledge that must be corrected before the next project.

The WG might require an O&M manual. The manual should describe how to monitor the project's performance, how to diagnose the cause of any decline in performance, and how to fix any problems that are likely to arise. The manual will describe what measurements to take and a number of maintenance procedures to perform. The manual will also indicate what measured results should trigger what maintenance activities.

The engineer should provide, or require the contractor to provide, an as-built diagram of the project, so that, if any part of it needs to be dug up, every buried item can be located and avoided or found and replaced, as needed. The manual should include a small, but detailed, map of the project for use in inspection and monitoring trips, as well as a checklist and data sheet for monitoring trips.

3. Details

The engineer can make O&M easier by including in the design certain details that will make monitoring, operation, and maintenance easier.

Monitoring—it should be easy to measure flow at places where monitoring is likely to take place. If at all possible, water should drop out of a pipe high enough that a bucket can be placed under it. A variety of configurations make it virtually impossible to measure flows (**Figure 4**).

In some cases, AMD may flow from a sealed portal directly into a BMP without going above ground. In such cases, a well can be installed so that the AMD flowing into the BMP can be sampled. Such a well can be sealed so that oxygen does not get in during normal operation.

Decreased permeability may raise the water in certain BMPs. A staff guage can be used to measure changes in water level. Changes in water level can also easily be seen in a limestone leachbed with an uneven surface. Small changes in the level of the water can cause the edge of the water to migrate a large distance.

Operation—A clear O&M manual is the most important aid to operation. It must indicate when valves must be turned, how often beds should be flushed or ponds drained and dredged, and what chemical and physical indicators call for action.

Maintenance—An engineer may be able to anticipate events that can shorten the effective lifespan of a project. For example, heavy storms might disturb the compost layer of an AVFW, or sweep debris into an AVFW, leachbed, or settling pond. High flows may force water through AVFW's so quickly that the compost fails to remove the oxygen from the water, and the limestone portion of the AVFW bcomes aerobic. Such high flows through BMPs can be prevented with a structure that will divert flows greater than a certain amount into a bypass channel. The channel may also be useful if the entire flow of AMD must be diverted from the BMP for maintenance.

Additional practices can prepare for times when maintenance is needed. For example, an engineer might treat AMD with two similar BMPs but arrange piping so that either one can be bypassed. While the bypassed bed is being maintained, the other bed can continue to treat AMD.

Figure 5: BMPs where flow is difficult to measure, including pipes discharging water through multiple perforations; a drop inlet from a channel, a pipe into a grouted channel with no lip beneath the pipe, an inlet pipe submerged beneath the surface of a pond, a transition from a bat gate to an open limestone channel.

Most erosion and sedimentation (E&S) plans are developed to prevent sediment from washing off the site and into nearby streams. E&S plans should also protect any channels and ponds that will be treating AMD.

The design should not impede equipment access to treatment components where O&M will be needed.

The engineer should provide, or require the contractor to provide, an as-built drawing to support O&M as well as repairs or replacement.

D. Construction

During construction, make every effort to make sure the engineer's plans are followed. Frequent visits to the project during construction are important for maintaining good communication with the contractor.

Identify places that may become issues during the O&M phase, for example, a place where an unexpected spring developed during excavation, or a repaired slip on a slope.

Surprises occur during construction of AMD BMPs. Most commonly, a spring will develop in what should be a smooth, vegetated slope. A source of water where it is not expected may have a number of unwelcome effects, including eroding earthworks and flooding flat areas. In one project, such a spring apparently flooded a soil cap over porous media and compressed it until it was no longer porous enough to conduct the AMD it was to treat.

Trouble spots encountered during construction should be added to a list of points to inspect for the later, inspection, monitoring and operation phase of the project.

Figure 6: A spring forming during construction on a smoothed and re-vegetated slope.

Summary 3: Purpose, sizing rule, and O&M concerns for individual AMD treatment methods

Several different BMPs are commonly used to treat acid mine drainage

- Aerobic Ponds
- Anoxic Limestone Drains
- Anaerobic Vertical Flow Wetland
- Drainable Limestone Leachbed
- Steel Slag Leachbed

Each BMP has a general rule for determining the size of the BMP according to water quality and quantity.

Specific parameters are generally used to evaluate the performance of the various BMPs.

There are common ways for each BMP to fail, and common ways to revive them.

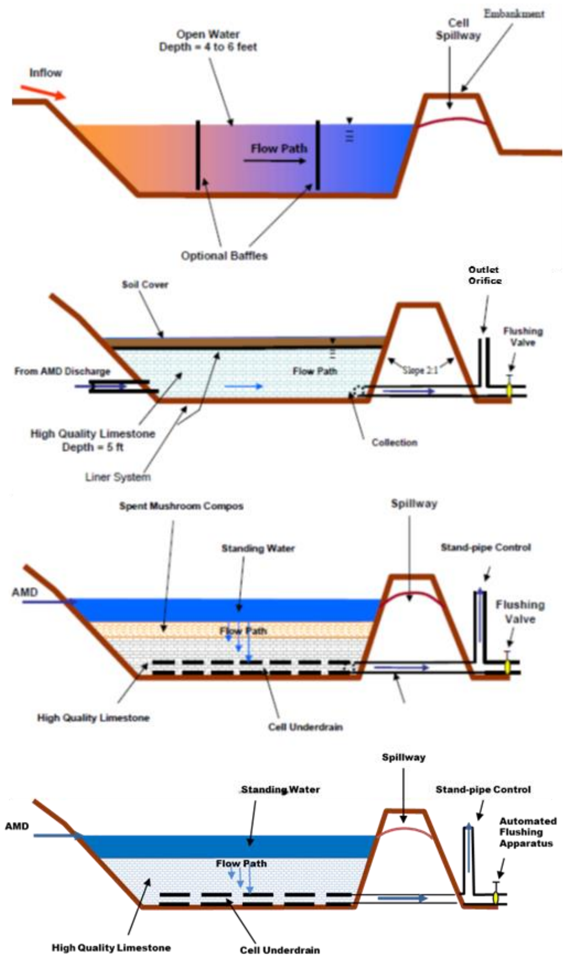


Figure 7: Common passive BMPs for AMD treatment (EADS-DG, 2006)

Anaerobic wetlands consist of ponds where iron oxidizes and iron oxide settles.

Anoxic limestone drains consist of limestone beds covered with a liner and then with a layer of soil. Oxygen is excluded and limestone dissolves to neutralize acid.

Anaerobic vertical flow wetlands consist of limestone beds with a layer of organic matter on top. The organic matter removes oxygen and reduces iron. Limestone dissolves and neutralizes acid. The water re-aerates and precipitates iron in a settling pond downstream.

Flushing limestone leachbed consists of limestone-filled pond that may be flushed periodically (not from EADS-DG, 2006).

Particular BMPs

Best management practice (BMP) is a term often used for a feature controlling agricultural runoff. AMD from abandoned mines is similar to agricultural pollutants in that it is nonpoint source pollution. The CWA calls for controlling nonpoint source pollution by supporting landowners who work to minimize it, rather than by issuing discharge permits through the National Pollution Discharge Elimination System. Therefore, methods of controlling AMD are often called BMPs.

Certain kinds of AMD require particular BMPs, and there are some guidelines about how big these BMPs should be. Each of these kinds of BMPs also has one or more things that typically go wrong, and a number of possibilities for how its function can be restored.

The decision about what BMP to use is usually made with a flow chart similar to that in Figure 8. The first determination is whether alkalinity present as bicarbonate in the AMD exceeds the acidity contributed by H^+, dissolved aluminum, iron, and manganese. If it is, the AMD can be treated by allowing it to aerate in relatively slow ponds or wetlands. Oxygen diffuses into the solution, and reduced ferrous iron oxidizes to ferric iron and precipitates out of solution.

If the AMD is truly acidic and does not contain more alkalinity than acidic components, alkalinity must be added to it. In most cases this is done by placing it in contact with limestone. If the AMD contains little aluminum, little oxidized iron, and little oxygen that might promote iron oxidation, it can be treated using an anoxic limestone drain (ALD). If it contains iron in the oxidized, or ferric, form, the AMD should be reduced before it is brought in contact with limestone. In an anaerobic vertical flow wetland (AVFW), oxygen is stripped from AMD by allowing it to interact with organic matter, such as compost, either before it is exposed to limestone or at the same time. In the absence of oxygen, organisms reduce the ferric iron to ferrous iron, which does not armor the limestone with a crust.

If there are large concentrations of aluminum, an AVFW may become clogged with precipitates as the aluminum drops out of solution. Al-rich AMD can be treated with an AVFW, but major maintenance will have to be planned. Such AMD may also be treated with a limestone leachbed, especially one designed to be flushed regularly. Completely draining leachbeds flushes out some of the precipitated metals and allows them to treat AMD longer. High metal concentrations will eventually clog a leachbed even with flushing. At that time, they may be rejuvenated by cleaning the stone. Flushed limestone leachbeds offer a balance of good effectiveness with moderate major maintenance.

Steel slag leachbeds, not included in charge unpolluted water with alkalinity. The “fresh” water should be low in divalent metals, such as calcium and magnesium, as well as in trivalent metals, such as iron and aluminum. Downstream, the alkaline water is mixed with AMD to neutralize its acidity. Precipitates are collected in one or more settling ponds.

A. Settling ponds and aerobic wetlands

Settling ponds and aerobic wetlands are used to treat alkaline mine drainage, in which the concentration of bicarbonate in the drainage exceeds the acidity contributions of hydrogen ion and dissolved metals. Such water usually contains dissolved iron in the ferrous form (Fe^{2+}) and manganese in the manganous (Mn^{2+}) form. At circumneutral pH values, ferrous ion will oxidize reasonably quickly, and iron hydroxide will form and precipitate to the bottom of a settling pond. Other BMPs, such as anoxic limestone drains and anaerobic vertical flow wetlands, are designed to add bicarbonate to acidic AMD, and project designs often place settling ponds immediately after them. Settling ponds can also protect BMPs downstream by allowing sediment to settle rather than entering and clogging the BMP.

In alkaline mine drainage, oxidation and settling typically remove approximately 20 g of iron per square meter per day (EADS-DG, 2006; Hedin Environmental, 2007).

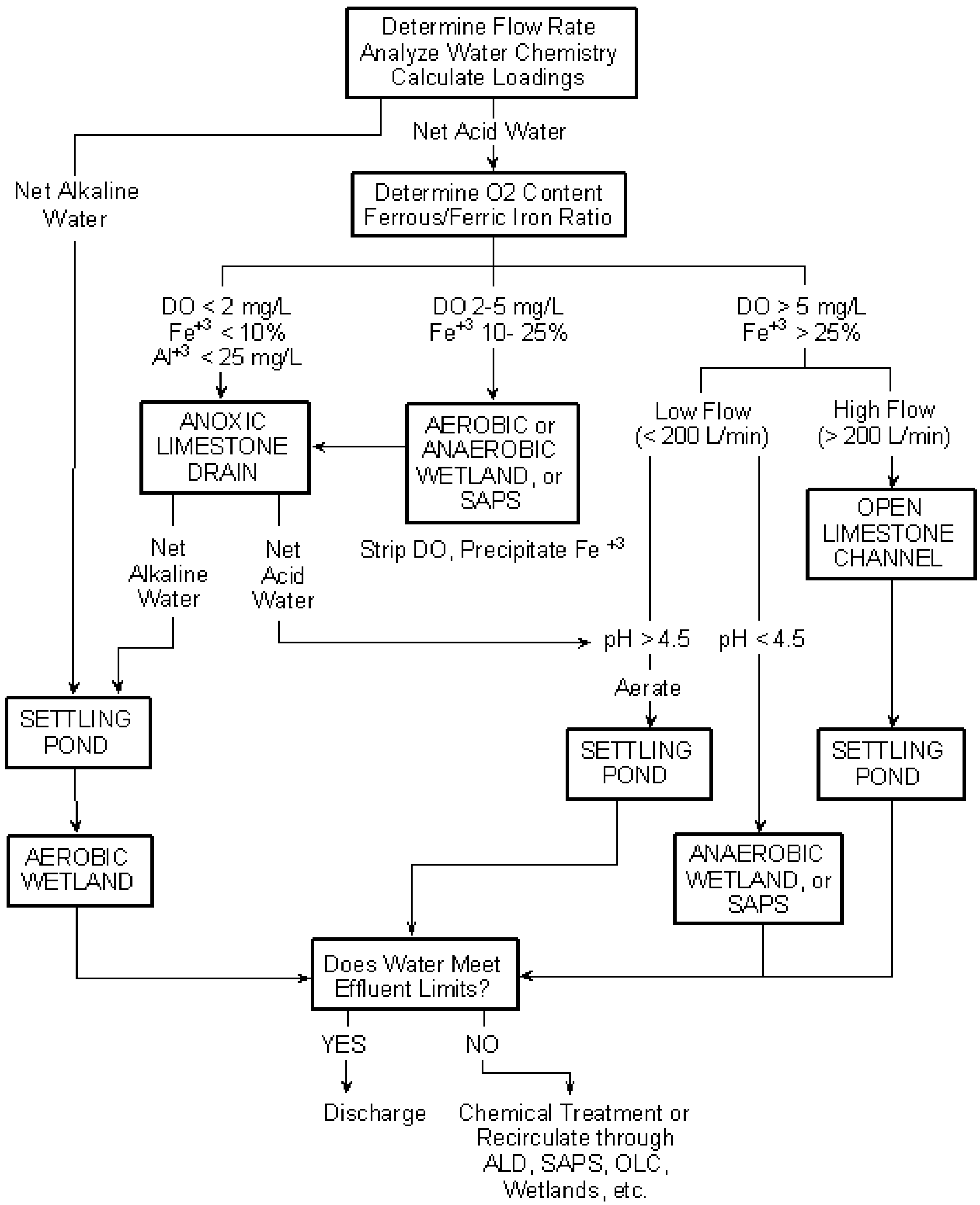


Figure 8: Decision tree for identifying effective BMPs for AMD under different circumstances (from Skousen, 1998).

The iron hydroxide sludge or sediment that precipitates occupies space and reduces the volume of the settling pond. If it is not occasionally removed, then the residence time in the pond may not be long enough for iron to precipitate out of solution. In addition, iron that has precipitated may be swept out of the pond and into downstream aquatic ecosystems or other BMPs.

Iron hydroxide sludge is usually pumped out of settling ponds. It can be pumped to unlined pits, from where the water in the material escapes into the soil, or into fabric bags which retain the solids but not the water. Dried sludge is sometimes landfilled on site. If enough water escapes that it reaches a solids content of 10%, and if it does not violate a toxic characteristic leaching procedure test, it can be transported to a landfill. Pure sludges dominated by hydroxides of a single metal may be marketable as pigments for paints or ceramics (e.g., Hedin, 2002).

Hedin (2008) described a passive treatment system for The Marchand Mine in Pennsylvania, and anticipated that sludge will need to be removed every 5-7 years. NRCS (2003) recommended that sludge be removed from settling ponds whenever it occupies one-half or more of the ponds volume. BioMost, Inc. (2007), wrote "General O&M Site Inspection Instructions," which recommend that sludge removal be considered if water is flowing over the sides of a settling pond. Skelly & Loy (2011) called for removal of sludge whenever it is more than 1 foot in depth anywhere in a settling pond.

B. Anoxic limestone drains (ALDs)

ALDs consist of beds of limestone, which are covered with a layer of geotextile or impervious liner, and then covered with a layer of soil. They are used to treat AMD that has no dissolved oxygen, iron in the ferric form, nor dissolved aluminum. Oxygen would cause the iron to oxidize to the ferric form, coat the limestone, and reduce the rate at which it dissolves and neutralizes acid. Ferric iron will precipitate and coat the limestone, and aluminum will precipitate and clog the spaces between the limestone rocks, reducing the amount of contact time with the limestone, and possibly diverting AMD from large portions of the limestone bed (Wolfe et al., 2010).

ALDs are sized so that they are large enough that AMD will have at least 16 hours of contact with the limestone. After that size is reached, an additional amount of limestone is added to make sure that there will be enough stone to last through the expected lifespan of the project, usually 20 years.

The mark of a malfunctioning ALD is a decrease in the alkalinity of the effluent. Such a decrease may indicate that the pore space in the limestone bed has become filled with metal precipitates and the AMD does not actually remain in contact with the limestone for as long as it should (EADS-DG, 2006). In addition, ALDS may start to leak as AMD can no longer move through them (EADS-DG, 2006).

ALDs are difficult to repair. EADS-DG (2006) evaluated a number of projects that included ALDs and suggested that they should be replaced with up-flow limestone leachbeds and should not be maintained or replaced with a new ALD.

C. Anaerobic Vertical Flow Wetlands

AVFWs consist of limestone leachbeds covered with a layer of organic matter, such as spent mushroom compost. The purpose of the compost is to consume oxygen. When bacteria in the compost run out of oxygen, they can use other chemicals, such as ferric iron or sulfate as oxidants. Ferric iron becomes ferrous iron, which does not form a crust over limestone. Sulfate turns to sulfide, producing bicarbonate in the process. While many AVFWs treat AMD effectively, many fail to maintain treatment for the expected design life.

AVFWs are commonly used for AMD that is inappropriate for settling ponds or ALDs. The organic matter cap prevents iron from interfering with flow through and interaction with the limestone layer, but aluminum will still precipitate when it encounters higher pH levels. Rose (2004) associated concentrations of Al in excess of 20 mg/L with a gradual decrease in the effectiveness of AVFWs. Better performing AVFWs contained limestone sand mixed in with the compost layer, or they consisted of a single bed of compost mixed with limestone (Rose, 2004).

Not all AVFWs that cease to treat AMD have been carefully studied, but there seems to be three ways that they go bad (Rose, 2004). A layer of iron hydroxide may precipitate on top of the compost layer and block water from moving through the system evenly. Amorphous aluminum hydroxides or hydroxysulfates may form and clog the limestone layer. Finally, the compost layer may be unevenly spread, or its demand for oxygen may decrease, so that water passing through it is no longer anaerobic enough to prevent iron from armoring the limestone.

One approach to the problem of metal hydroxide sludge clogging the limestone bed is installation of a piping system in the regions of the limestone bed where aluminum is expected to precipitate. When the system either discharges water with declining alkalinity, or an increase in the water level in the AVFW suggests that the hydraulic conductivity is decreasing, a valve is opened and water is flushed through the piping system. Kepler and McCleary (1997) report that this "Aluminator" system maintains the efficacy of AVFWs. However, Hedin et al. (2010) found a flushing system in an AVFW to be "ineffective and unnecessary." Watzlaf et al. (2002) calculated that less than 5% of accumulated Al is removed by flushing.

Other O&M activities to keep AVFWs operational require some amount of heavy equipment, such as removal of iron hydroxide from the top of the compost bed, replacement of compost that is not depleting oxygen quickly enough, and replacement of limestone that has become clogged with sludge. Hedin et al. (2010) estimate for the Anna S. system that the compost layer will need to be replaced at approximately 11 year intervals.

D. *Self-Flushing Limestone leach beds*

Limestone leachbeds are ponds filled or partially filled with limestone, which dissolves when in contact with water, especially if it is acidic. Such ponds are used to treat net acidic water. As an acidic solution containing dissolved metals is neutralized, the dissolved metals precipitate out of solution as hydroxides. The metal hydroxides can decrease the rate at which the limestone dissolves in two ways. First, as the iron precipitates it can form a crust of iron hydroxide that decreases dissolution. Second, the hydroxide material may form in the interstitial spaces and prevent the AMD from flowing through the leachbed uniformly. In such cases, AMD may flow through part of the leachbed very quickly, without sufficient time for limestone dissolution to neutralize all the acid. AMD may not flow through other parts of the leachbed at all, so that alkalinity generated there does not come out, mix with, and treat the acid load of the entire flow.

Flushing a limestone leach bed prolongs its efficacy. Self-flushing limestone leach beds are designed with drains that can be opened automatically according to a timer, or that discharge automatically whenever they become full. Wolfe et al. (2010) found that draining the leachbed completely once each week was an effective schedule for maintaining neutralization.

Wolfe et al. (2010) found that flushing removed soft, amorphous hydroxide sludge from interstitial spaces in the leachbed, but does not remove the iron hydroxide crust from the surfaces of the rocks.

Even with flushing limestone leachbeds will eventually clog, but they can be rejuvenated. The crust can be removed by reworking the stone itself as water is running over it. Because there may be hundreds or thousands of tons of limestone in a leachbed, heavy equipment will be needed to rework the stone. Nevertheless, other personnel, possibly volunteers, can use a pump with a nozzle to keep water moving over the stone to remove scale that comes off.

Limestone leachbeds can get clogged with sediment. During and after construction, it is important that erosion and sediment is carefully controlled on any slopes adjacent to the leachbed.

E. Steel Slag Beds

When AMD contains acidity and high concentrations of ferric iron and aluminum, there is no good option for a BMP in which AMD can be treated directly. If there is unpolluted water available on site, the unpolluted water can be routed through a steel slag leachbed where it is charged with excess alkalinity. The alkaline water is then mixed with AMD neutralizing its acidity and causing the dissolved metals to precipitate out of solution.

Steel slag leachbeds are commonly designed to have a residence time of four hours (Kruse et al., 2012). If more water is routed through the steel slag leachbed, more acidity can be neutralized. The size of the steel slag leachbed is usually set by the constraints of the site and the availability of unpolluted water, rather than the desired alkalinity generation.

Three problems have been reported for steel slag leachbeds.

Inadequate supply of unpolluted water—some steel slag leachbeds have been installed but were found to go dry during the summer. This problem has been addressed by building ponds upstream from the steel slag leachbeds. The ponds store water during wetter seasons and release it slowly to the steel slag leachbed during the drier seasons.

Formation of concrete—when steel slag is exposed to the atmosphere, the alkalinity in the steel slag and the carbon dioxide in the atmosphere join to form calcite, which precipitates as a concrete-like layer at the surface of the slag. Concrete formation can be slowed by submerging the steel slag under at least one foot of water, through which carbon dioxide diffuses slowly. If the concrete layer does form, it can be broken up either with hand tools or with heavy equipment. This process will have to be repeated regularly.

Decrease in alkalinity generation—users of steel slag leachbeds report decreases in the concentration of alkalinity discharging from steel slag leachbeds. Slag will have to be reworked or replaced at intervals.

F. Other BMPs

1. Open limestone channels (OLCs)

Erosion-resistant channels, in which the sides are protected either by stone rip-rap or are grouted with concrete are crucial in many projects for controlling where water flows. Without the channel, AMD or surface runoff during storms could run down slopes eroding topsoil, weakening the vegetation, and eventually causing gullies and exposing acid forming material to air and water. Using limestone to protect the sides of the channel provides a small amount of acid neutralization. OLCs and grouted channels sometimes neutralize a great deal of acidity either through limestone dissolution or through low-pH iron oxidation followed by deposition of acidic minerals in the channel.

Channels can collect debris, which may form a dam and divert water over the side. If the diversion of water has not eroded the side of the channel badly, the problem can be solved by removing the debris. Removing the debris quickly should prevent severe erosion.

OLCs and grouted channels should be inspected and debris removed regularly. Additional inspections should take place following extremely large storms.

2. Diversion well

Diversion wells are containers where the power of flowing water is used to suspend limestone particles and swirl them around so that they bang against each other and break up and dissolve faster. Diversion wells require ongoing inputs of new limestone, so they are rarely used in projects supported by §319 or OSM-WCAP funding.

Limestone in diversion wells can settle in some corner of the container where the flow is slowest. Containers are usually designed to be round to minimize slow areas. If the material is no longer swirling, it may have to be cleaned out. Swirling will be more dependable if flow can be increased or the limestone particle size can be decreased.

3. Dosers

Water-powered lime-addition devices, including the AquaFix, where moving water turns a waterwheel that drives an auger that dispenses lime from a hopper, and the Lime Doser Consultants doser, which uses the force of a five-gallon tipping bucket to dispense the lime. Both devices require many forms of O&M and are forms of active treatment. Only a few notes are within the scope of this document.

- The cost of the lime is a recurring, perpetual cost, and cannot be covered with funds from the Nonpoint Source Program or OSM's WCAP.
- The devices have a number of ways of malfunctioning, and require visits one or two times per week.
- Malfunctions include (but are not limited to) bridging—the lime material clumps and does not flow through the dispenser and freezing.
- Neutralization produces sludge which must be removed somehow, another perpetually recurring task.
- Both the sludge and the large metal silo may cause a neighborhood to get an industrial appearance, which neighbors may object to.
- It is difficult to get the lime to completely mix with the AMD. A large proportion of the sludge that must be disposed may be unreacted lime.

Summary 4: The operation and maintenance phase of a project

On a regular schedule, determine whether the project's goals are being met by

- Inspecting project to make sure it is safe and holding together
- Monitoring project to make sure it is treating water
- Operating project to keep it working in optimum condition

Inspect project on a rainy day to evaluate erosion.

Contact landowners and neighbors to maintain community pride, and provide more information.

Publicize condition and effectiveness of project, as well as work days.

Picture 3: Brian Carlson monitors the discharge from a completed AMD remediation project. The drop beneath the culvert allows for measurement of flow with a bucket and stopwatch.

The O&M Phase

Once construction of the project is complete, the WG should engage in well-deserved celebration. Then the WG should start the O&M phase of the project. In this phase, the WG makes sure the project is meeting the goals that were set for it. The project remains safe for those accessing it or living near it. The project treats AMD and removes pollutant loads. The project provides a steady stream of water quality information to be used in any needed project reports. Finally, the functioning project is a source of pride for the landowner and neighbors as it builds partnerships in the community. The project should be kept in a tidy condition that communicates to all that acid mine drainage can be treated effectively, and that the WG is a good neighbor to work with.

The O&M phase has three major components: inspection, monitoring and operation (IMO) trips, communications with landowners and neighbors, and outreach to the community.

A. Inspection, Monitoring, and Operation (IMO)

The WG makes regular IMO trips to the site to make sure it is staying in good shape, that it is treating water, and that any needed activities get done. These trips include:

Inspection—the WG must inspect projects for safety and for maintenance needs. A project can become a hazard to visitors or to neighboring properties and such hazards should be eliminated immediately. But the purpose of inspections is also to determine whether the project, which is usually made of earthworks, is holding together, or whether the forces of nature, especially erosion and vegetation changes, are degrading the site. Inspection is a group of thorough observations of all parts of the project.


Figure 9: Inspection issues: note any logs that have fallen into any part of the project and clean them out. Note any evidence that water has flowed over an emergency spillway and maintain the project so that water flows through expected pipes and channels.


Figure 10: Inspection issues: note construction debris (such as discarded culverts) and remove it. Note any erosion of channels for AMD.

Monitoring—Monitoring includes measuring water chemistry and flow to determine whether the project is removing the pollution loads for which it was designed, and whether the individual components of the system are performing adequately. Monitoring consists of the same sort of activities that took place while the AMD was being characterized and its load quantified.

Operation—Operation of an AMD remediation project consists of activities that keep the project in good working order. Typical operations include opening valves to flush limestone beds or adjusting valves to achieve an ideal mix of unpolluted water and AMD.

Incidental maintenance—Observations during some IMO trips will reveal small problems that might be solved during the next IMO trip. For example, galvanized steel screens were placed around inlet level controls in the Valley Point #12 project. These quickly dissolved in the AMD. They were replaced with a plastic mesh during a later IMO trip.

Figure 11: Inspection issues: channels may clog or back up, flooding adjacent ground. Drainpipes clog.

Figure 12: Inspection issue: iron precipitates accumulate in settling ponds or on top of anaerobic vertical flow wetlands, and must be removed.

Figure 13: Operation: Adjust the mixture of water from an AMD source with water from a steel slag leachbed to optimize settling in an aerobic pond.

1. Frequency

Quarterly visits provide information about a project in every season and in a variety of flow conditions. On the other hand, many things can occur in a three month period that can affect the performance or life span of a project, including heavy storms, dry periods, tree falls, and human visits. More frequent trips will provide additional information about whether the project is meeting its goals, but may divert resources from other crucial WG activities. EADS-DG (2006) recommends that AVFWs, ALDs, and aerobic ponds or wetlands need to be evaluated just once each year.

Investigations into operations (to determine a good level for stop logs or an optimum frequency for flushing, for example) will require their own schedule. For example, to determine how much flushing a limestone leachbed improves the BMPs performance, it might be necessary to visit it and determine loads three or more days in a row before flushing and then again three or more days in a row several days after flushing, once the leachbed has filled and is once again discharging at a steady state.

Figure 14: Operation: Flushing a limestone leachbed should wash metal hydroxide sludge out of the AMD treatment component.

2. Planning

Planning

Because there are many goals for each IMO visit to a site (water treatment, site condition, neighborliness), IMO trips are complex and require thorough preparation. Planning for IMO trips should produce three documents: a site diagram, a to-do list for each visit, and a form for recording data and observations. Obtain a site diagram that will fit on a single page, either from the engineer who designed the project, or by using documents exchanged during design, or just by drawing it.

Start a to-do list. If possible, set up a numbered outline on a computer that will renumber items as other items are added in between items that were added earlier.

The components of the water treatment system are the skeleton of the project. List all the components through which water flows in reverse order (from the downstream end to the upstream end). Working upstream will prevent any actions from affecting subsequent measurements on the same trip. For example, if the AMD discharges from a sealed portal, passes through an open limestone channel into an anaerobic vertical flow wetland, and then into a settling pond, the outline would appear:

1. Settling pond
2. AVFW
3. OLC
4. Sealed portal

Then, add stations for the sake of site inspection. Include an item for the access road, and an item for a station with a good overview of the entire project. Include stations where re-vegetated areas can be seen. Include stations where any surprises during construction occurred, such as soil slips. At this point, the outline may appear:

1. Access road
2. Overview
3. Settling pond
4. AVFW
5. Soil slip
6. OLC
7. Re-vegetation site
8. Sealed portal

Then under each item (at a lower outline level), write observations or measurements that must be made. Table 1 lists typical questions for different AMD treatment or landscape components. The list of things that can go wrong at an AMD project is probably not limited by imagination. Figure 15 mentions a number of conditions worth observing for a variety of typical components and BMPs of AMD projects. An accompanying data sheet might appear as in Figure 16.

General O&M Site Inspection Instructions
Comprehensive Operation & Maintenance Plan

March 2007
Stream Restoration Inc. & BioMost, Inc.

GENERAL O&M SITE INSPECTION INSTRUCTIONS

The following general instructions are meant to provide a one page supplement to the O&M manual for inspectors to take in the field and be used as a guide in conjunction with the individualized inspection sheets.

For each Passive System Component do the following if applicable:

1. Enter effluent pH, temperature, alkalinity, flow and other field data as applicable in water monitoring section.
2. If water samples were collected for lab analysis, enter bottle numbers in water monitoring section.
3. Check the outlet spillway for stability, erosion rills, debris, and significant siltation.
4. If present, check the effluent pipe condition. Is the pipe in good condition? Is the pipe crushed, broken, leaking, or plugged?
5. Was the pipe cleaned out? Does the pipe need to be cleaned out?
6. Is all water going through the effluent pipe or over the appropriate spillway?
7. Check all valves to insure full operation and no leaking? Do any valves need to be replaced?
8. If an inline water control structure is present: Were (Do) any stoplogs (need to be) added or removed? Were stoplogs cleaned and greased?
9. Is the access deck to the inline control structure in good condition? Is the deck damaged or rotting? Does the deck need repaired or replaced?
10. If present, check the condition of the emergency spillway for erosion rills, debris, and significant siltation.
11. Check the berm of the pond for slumping, erosion rills, tension cracks, vegetation. Is there evidence of water overtopping the berm?
12. Is there evidence of damage by wildlife such as muskrats burrowing into berms? Is there a need to conduct trapping?
13. Does sludge need to be removed? (If water is overtopping the berm or is about to over top the berm, sludge may need to be removed.)
14. Note any maintenance that was conducted. Note any maintenance that is needed and mark on schematic.

Anoxic Limestone Drains (ALDs)
1. Are there significant slumping or "subsidence-like" features where the ALD is located?
2. Is there water seeping out from the ALD indicating the ALD may be plugging?

Collection Channels, Diversion Channels, Open Limestone Channels (OLCs), Oxidation & Precipitation Channels (OPCs)
1. Check the channel for stability, erosion rills, debris/obstructions, and significant siltation. Does the channel need to be cleaned out?
2. Is there any evidence that water has overtopped the channel? Does the channel need to be repaired or replaced?

Culverts
1. Check to see if the culvert is crushed, plugged, damaged? Does the culvert need to be cleaned out, repaired, or replaced?
2. Is the culvert able to handle all of the water? Is there evidence of water flowing over or around the culvert?

Diversion Well
1. Does limestone or other treatment media need to be added? Does limestone or other treatment media need to be ordered & delivered?
2. Is the inlet clear of debris?

Forebays, Ponds, Settling Basins/Settling Ponds
1. Does the pond appear to be short-circuiting? Determine with use of a dye-test or by water quality data. If so, a baffle may need to be installed.
2. Is the baffle functioning properly? Is the baffle in the proper position? Does the baffle need to be weighted down? Does the baffle need reset?

Horizontal Flow Limestone Beds (HFLBs), Manganese Oxidizing Beds (MOBs), Sloped Limestone Beds (SLBs)
1. Is the water flowing above the top of the stone indicating the treatment media or piping may be plugging? Does the media need to be stirred?
2. Is there excessive vegetation growing in the treatment media that needs to be removed?

Vertical Flow Ponds (VFPs), Vertical Flow Wetlands (VFWs), Successive Alkalinity Producing Systems (SAPS)
1. Does the water level appear to be increasing in the pond?
2. Was the component flushed? Does the component need to be flushed or backflushed?
3. Does the treatment media need to be stirred and/or mixed?

Weirs & Flumes
1. Does the weir or flume need to be cleaned out? Clean the debris, sediment, and sludge and allow to equilibrate before measuring flow.
2. Check to make sure the weir or flume is stable and is level both horizontally and vertically. Does the weir or flume need to be reset?
3. Does the weir or flume need to be repaired or replaced?

Wetlands
1. Does the wetland appear to be short-circuiting or channelizing? If so, were haybales placed? Do haybales need to be placed?
2. Is the wetland well vegetated with wetland plants? If not what is the cause (water level to high, muskrats, water quality, etc)?
3. Are there invasive species in the wetlands?

Figure 15: Inspection guidelines by Biomost (2007)

Table 1: Example monitoring to-do sheet

1. Access road
   1.1 Erosion ruts? Stone coverage? Holes?
2. Overview
   2.1 Items that will not be covered under stations, below
3. Settling ponds
   3.1 Is flow short circuiting?
   3.2 Is pond filling with sludge? How deep is the sludge surface?
   3.3 Water quality and quantity measurement (Flow, Eh, pH, conductivity, temperature DO, sample for acidity, alkalinity, dissolved metals, sulfate)
   3.4 What is the elevation of the highest stop log? Did you change it?
4. AVFW
   4.1 Water quality and quantity measurement (Flow, Eh, pH, conductivity, temperature, DO, sample for acidity, alkalinity, dissolved metals, sulfate)
   4.2 Test flushing apparatus
5. Soil slip
   5.1 Does slip remain repaired? Is it starting again?
   5.2 What is the condition of the vegetation?
6. OLC
   6.1 Check for stability, erosion rills, debris/obstructions, in-growth of vegetation, and siltation. Does it need to be cleaned out?
   6.2 Is water escaping over the edge out of the channel?
7. Re-vegetation site
   7.1 Evaluate whether the vegetation is growing in adequately, and if it is thick enough to hold the soil.
8. Sealed portals
   8.1 Measure water quality.
   8.2 If there are two pipes, are they flowing equally, or are any blocked?
   8.3 Is there any evidence of leakage around the seal?
   8.4 What are the vegetation conditions?

1. Condition of access road

2. Describe any issues that can be seen from a distance

3. Settling pond

Condition: ☐short circuiting? ☐ Filled with sludge?
Sludge depth below surface______ in. cm. (circle units)

Outlet water quality: pH______; Temp ______°C; Specific conductance ____________

Dissolved oxygen _____ mg/L; Alkalinity __________mg CaCO3/L

Flow ________ gpm L/s (circle unit) Method ________________

Sample taken? ☐ Unpreserved ☐ Filtered and acidified

☐Acidified ☐HCl preserved

Notes:

Elevation of top stoplog: __________ in. cm. (circle unit)

4. AVFW

Condition: ☐short circuiting? ☐ Filled with sludge? ☐ Debris? (Describe) ☐ Smell?
Water level______ in. cm. (circle units)
Outlet water quality: pH______; Temp ______°C; Specific conductance ____________

Dissolved oxygen _____ mg/L; Alkalinity __________mg CaCO3/L

Flow ________ gpm L/s (circle unit) Method ________________

Sample taken? ☐ Unpreserved ☐ Filtered and acidified

☐Acidified ☐HCl preserved

Notes:

Operation: ☐ Flushed? How long? ___________________________
Describe flush water:_______________________________________

5. Soil slip

Is it active?

Vegetation: % Cover ____________ Health: ________________

6. OLC

Describe stability, erosion rills, debris/obstructions, in-growth of vegetation, and siltation. Does it need to be cleaned out?

Water escaping?

7. Revegetation site

Vegetation: % Cover ____________ Health: ________________

8. Sealed portal

☐ Equal flow in pipes? ☐ Leakage? (describe)
Outlet water quality: pH______; Temp ______°C; Specific conductance ____________

Dissolved oxygen _____ mg/L; Alkalinity __________mg CaCO3/L

Flow ________ gpm L/s (circle unit) Method ________________

Sample taken? ☐ Unpreserved ☐ Filtered and acidified

☐Acidified ☐HCl preserved

Notes:

Figure 16: Data sheet for IMO trip to an AMD project

3. Landowner and neighbor contact

Figure 17: Friends of Cheat personnel discussing a project with landowner

WGs work with other stakeholders in the watershed—landowners, businesses, local governments—to restore streams. A strong, well-organized O&M program is an asset, and should be used to strengthen the WG's connection to the community.

Landowners and neighbors that are proud of the local effort to restore streams will be an asset when trying to enlist other landowners and neighbors for future projects. The best way to make sure the landowner and neighbors are proud of their local stream-restoration effort is to ask them. Communicating with them is also an opportunity to learn if anything is happening on the site when WG personnel cannot visit. Questions to ask include:

- Are you worried about the project in any way?
- Do you see people visiting the project? Who? When?
- Do you see animals visiting the project?
- What is your impression of what it is doing to the water?
- Has anyone asked you about the project?

B. Outreach

Quarterly IMO trips, as well as contact with landowners and neighbors, also provide information to share with the community. Items that might justify press releases include good water quality results (e.g., "The watershed project was built to treat acid mine drainage with a pH of 2.8, but the water discharging from the site now has a pH of 8. The water quality improvement can be tracked all the way to the receiving stream, where the pH has improved from 5 to 7) or upcoming work days.

Summary 5: Beyond the IMO Phase

What to do if a project is not meeting its goals for

- Safety
- Effectiveness
- Neighborliness
- Tidiness

Options:

- Nothing: Not preferred.
  - WGs usually agree to maintain the project in both NPS and WCAP proposals.
  - NPS and WCAP funding is to solve the problem permanently.
  - Giving up is not the WG's mission.

- Act with one or more of the following sets of resources
  - Volunteer labor, in-kind materials, funding from donations
  - Another round of 319 grants
  - Other grants

Some projects/examples

- Rebuild
- French Drain
- Vegetation management

Beyond the IMO phase

For one reason or another, a project may not meet its goals. Either it has become unsafe to visit or is posing some kind of threat to neighboring properties, or it is not improving polluted water as well as it should, or neighbors have some complaint about it, or it just appears untidy. What can a WG with very few savings or other resources do?

If there is any safety issue at all, then something must be done. The WG should enlist every possible resource, including representatives of state and federal agencies to eliminate any threats to visitors to or neighbors of the project. They may have to use any uncommitted funds they have in savings. It is crucial that projects remain safe.

When a project is not eliminating pollutant loads as well as it should, or has become untidy, a WG may be tempted to do nothing. Reasons to delay solving the problems include the lack of resources, or a possibility that the WG will increase its capacity to act at some future time, for example, when increased funding supports additional staff.

However, WGs should resist this temptation for several reasons. First, they promised! In the cooperative agreements that WGs usually sign with funders, the WG agrees to be responsible for the operation and maintenance of a project. Failure to restore the project's efficacy can tarnish the reputation of the WG, which may be seen as wasting public funds and private donations, or as too lazy to take care of what it builds.

Picture 4: Friends of Deckers Creek Shovel Corps installs a French drain to prevent ponding on top of a sulfate reducing bioreactor.

Given a preference for action, a WG must decide what resources to bring to bear for repairs or replacement. The WG may use volunteer labor, in-kind donations, and any savings and private donations to address the problem, or it may seek additional funding from agencies to modify the project.

Using volunteers and in-kind donations to improve the project has several advantages. First, it may happen much faster, since agency funding may have to wait for a new funding cycle to come around. The more important advantage, however, is that asking for help from the community brings new resources into controlling nonpoint source pollution. Volunteers are more likely to volunteer on additional occasions, to support the organization financially and possibly to take on leadership tasks. Volunteers in groups form friendships and learn to work as more effective teams. Businesses that donate goods or services may do so again, or connect the WG to networks of other businesses ready to pitch in. If a WG asks for help, then news that they need help will spread in the community, and will usually bear fruit. On the other hand, neighbors in the community are unlikely to help if they are not asked.

Before acting, analyze the problem. Write it down, and share the analysis with people who can critique it, such as an engineer, agency support personnel, or contractors familiar with landscaping or piping typical in AMD treatment projects. Use the problem analysis to guide you to a solution. It is easy to imagine things that could be done, but it is important to do something not because it is possible, but because it will solve a problem.

A. Landscaping and general repairs

Landscaping problems—controlling water and establishing and maintaining vegetation to prevent erosion—are good targets for volunteers using donated materials. Such issues show up on AMD remediation projects regardless of the type of BMP.

Friends of Deckers Creek recruited volunteers to form the Deckers Creek Shovel Corps to attack landscaping problems. The hope was that a group of volunteers who worked together a number of times would form friendships and comprise a team with some *esprit de corps* and determination to do the hands-on tasks needed to keep projects looking good. The group planted trees, re-plumbed a lime doser, installed French Drains, stirred a steel slag leachbed, and cut up and stacked fallen trees. The group also cleaned up a limestone leachbed and supported an equipment operator as he stirred the stone (see front cover). Projects were not frequent enough, however, for the Shovel Corps to become a truly cohesive team, even though their projects were all valuable. Nevertheless, landscaping projects are an excellent opportunity for WGs to form a cohesive team of volunteers.

1. French drains

Water running over the surface of the ground will cause erosion. Once erosion cuts a channel, it is likely to gather more and more flowing water until the channel becomes a serious source of sediment. The channel may also begin to threaten the integrity of some earthwork. The purpose of the French Drain is to get the water off the surface and then off the slope as quickly as possible.

Uncontrolled runoff may also pond in inconvenient places. In one project, runoff ponded on top of a sulfate-reducing bioreactor. This bioreactor was unable to treat AMD because it would back up and overflow when even moderate flows of AMD passed through it. The compression from the weight of the ponded water may have decreased the hydraulic conductivity in the bioreactor bed.

A site with serious erosion will not meet goals for safety or water treatment. Sites may be or appear unsafe because berms holding back large quantities of water are slowly degrading. Projects may not release clean water because the project is adding sediment, even if it is successfully treating AMD. If the sediment is flowing into one of the AMD treatment components, it will probably interfere with that component's operation sooner or later.

Water is taken off the surface by digging a trench, laying a perforated pipe, and refilling the trench with gravel. Water is removed from the slope by connecting the perforated pipe to an unperforated pipe that slopes down to the final discharge point. The drain will be most effective if the perforated section gathers the water in a relatively flat area. The trench for the perforated pipe should be backfilled with stone of some kind. Transporting an adequate amount of stone may exceed the limit of volunteers or of the vehicles available.

Local businesses, such as hardware stores or a quarry, can be approached for donations of the materials needed for the project. A local restaurant might donate or discount a meal in recognition of the project.

2. Vegetation management

Growth and change of vegetation can cause projects to fail to meet goals in many ways. A dead tree or dead branches can drop on people or vehicles visiting the site, and should be brought down safely lest they come down disastrously. Branches or trunks that have come down can prevent people from moving through the site, or make the project look uncared for, and they should be removed. Vegetation growing in a channel may trap debris that later diverts heavy flows out of the channel, and it should be removed. Frequently, blackberries or other thorny vegetation will take over re-vegetated spaces. If scrubby, thorny vegetation does not interfere with a project's goals, it may not need to be removed. However, it is important for safety and tidiness to maintain clear pathways so that people can get to wherever they need to go on projects.

Vegetation management is a common activity. Many volunteers will have plenty of experience and even equipment for managing their own vegetation and will be able to manage vegetation on a water remediation project safely and effectively.

3. Stirring limestone leachbeds

Limestone leachbeds accumulate metal hydroxides in the interstitial spaces between the rocks, and on the surface of individual rocks. The material can be removed by stirring the stone. Because such leachbeds frequently contain hundreds to thousands of tons of stone, it is not possible to accomplish this task with hand tools. However, an excavator can be hired to rework the material.

The process consists of lifting the stone and dropping it into a place with moving water. The fall jars the material loose, and the water carries it away. A place with moving water can be set up by excavating a groove in a leachbed near the drain. The cleaning power of the water can be enhanced by renting a trash pump with a fire hose nozzle.

Contractors or equipment rental companies may be willing to donate or discount the cost of the equipment rental. The WG should be very careful to manage liability if volunteers are operating a rented excavator.

4. Removing iron sludge from the surface of an AVFW

Some AVFWs accumulate a coating or crust of iron on top. These coatings can slow the passage of water or cause water to flow unevenly through the AVFW, effectively taking part of the project out of service. This crust may need to be removed periodically.

The crust can be removed by draining the AVFW so the water is below the level of the compost. It should be given a few days to dry. Volunteers with hand tools can walk across the surface and either shovel the crust or cut it into fragments and lift it into a wheel barrow to move it off of the AVFW. Cut 1’ x 8’ or 2’ x 8’ pieces of plywood can be used to help volunteers distribute their weight across a wider area to prevent compression of the compost by feet or wheels. An excavator and an operator may be needed for larger AVFWs.

Conclusion

The law of the land calls for good water quality in streams. Clean streams are economic assets to their regions. Many people are ethically driven to improve the world, and fix things damaged earlier in our history. For those reasons and others, WGs and others will continue to restore waterways from damage by acid mine drainage from abandoned mines, even though it is a difficult process.

The process is unquestionably difficult. Even the part of the work that is supported by government programs calls upon non-profit organizations to hire or serve as scientists, land agents, searchers and writers of legal documents, construction overseers, and accountants.

To restore streams, WGs must be well-governed and disciplined. Project managers must know all there is to know about remediation. Equally important, the WGs must reach deep into their communities for support, in-kind donations, labor, and inspiration.

The need for O&M will cause WGs to change somewhat by requiring a greater proportion of their creative effort. WGs will have to recruit additional resources to maintain the same level of effort in education and advocacy.

WGs should carefully plan, implement, revise, and improve programs to maintain AMD remediation projects. Table 2 summarizes some projects to start implementing.

Table 2: Summary of O&M tasks and project phases where they may occur

The O&M Phase				
BMPs	**Inspection, Monitoring, Operation, Quick Fixes**	**Volunteer group projects**	**Small projects with heavy equipment**	**Major repairs or replacement**
Aerobic wetlands	Determine load reduction	Remove debris; remove iron deposits; restore residence time; eliminate any short-circuiting		
Anaerobic vertical flow wetlands	Flush regularly, or make sure flushing mechanisms are operating; Note appearance of flushed water	Remove iron crust	Remove iron crust; Replace compost layer	Replace compost layer; Replace limestone; Replace BMP
Anoxic limestone drains	Monitor flow to assess clogging		Replace limestone	Replace limestone
Diversion well	Add limestone to well			
Doser	Confirm doser is full and functioning			
Limestone leachbeds	Remove any debris		"Lift and sift" leachbed	
Flushed limestone leachbeds	Remove debris, make sure flushing mechanisms are operating		"Lift and sift" leachbed	
Limestone sand dumps	Make sure sand is moving; shovel sand		Replace sand	Replace sand
Steel slag leachbed	Measure load of alkalinity from steel slag bed; Assess need for removing sludge from mixing or settling ponds			

Resources

Funding:

These programs may be able to supply some funding for O&M work on AMD remediation projects:

- WVDEP Division of Water and Waste Management, Nonpoint Source Program has:
    - AGO grants. http://www.dep.wv.gov/WWE/Programs/nonptsource/Pages/AGO.aspx
    - Watershed Project Grants: These funds are not designed for O&M activities, but their use for major improvements on some projects can be justified. http://www.dep.wv.gov/WWE/Programs/nonptsource/Pages/Grants.aspx
- OSMRE has the Watershed Cooperative Agreement Program. Like Watershed Project Grants, the funds are designed for construction of projects and not for O&M. However, their use for major improvements to some projects might be possible. http://www.osmre.gov/lrg/fam/6-100.pdf
- Donations from citizens and businesses. River Network provides advice for increasing donations. http://www.rivernetwork.org/resource-library/11

Expertise:

Experienced people have shared information about O&M of AMD remediation projects on the Internet.

- Hedin Environmental (www.HedinEnv.com). Under "Papers," many of the entries describe not only the technology used to treat various kinds of AMD, but expected maintenance schedules as well.
- Biomost, Inc. (www.BioMost.com). Biomost personnel have been involved in the design of more than 230 passive treatment components of all types, which are successfully treating over a billion gallons of water each year.

Conferences:

Experts on AMD remediation, including those who keep track of the performance of such projects over decades, present at various conferences.

- West Virginia Mine Drainage Task Force Symposium (www.WVMDTaskForce.com). Papers from symposia beginning in 1980 are listed and mostly available on the website.
- Pennsylvania Abandoned Mine Reclamation Conference (http://2014.TreatMineWater.org), which is organized by the Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (www.EPCAMR.org) and the Western Pennsylvania Coalition for Abandoned Mine Reclamation (www.WPCAMR.org).

Businesses:

Some businesses that are experienced in evaluating and fixing AMD remediation projects not performing up to standards.

- Hedin Environmental (www.HedinEnv.com).
- Biomost, Inc. (www.BioMost.com).
- Dietz-Gourley Consulting, LLC (www.DGengr.com).
- Skelly and Loy, Inc. (www.SkellyLoy.com)

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