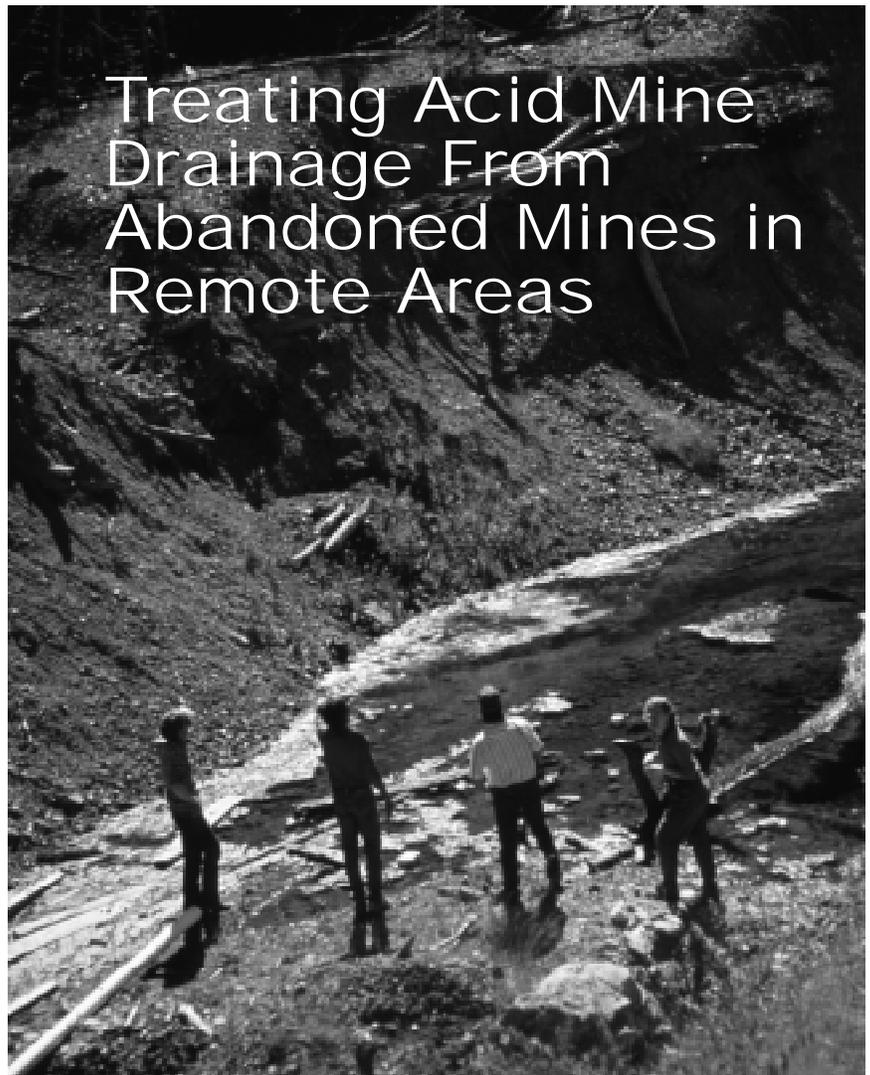


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**7E72G71— Acid Mine Drainage Study**

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# Overview

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**B**etween 20,000 and 50,000 mines generate Acid Mine Drainage (AMD) on USDA Forest Service lands, affecting approximately 14,000 miles of streams (Benner and others 1997). The majority of the AMD comes from inactive or abandoned mines. Consequently, there is limited funding for treatment and surface and groundwater resources are continually contaminated (Skousen and others 1996b).

Underground mining often requires draining (passive removal) or pumping (active removal) of groundwater so ore can be removed. Continued dewatering of the sulfide ore body and surrounding material creates the conditions for AMD production: a continuous supply of water, oxygen, and exposed sulfide minerals. In addition, groundwater flow near the underground openings is altered. The volume of an aquifer affected depends on the dimensions of the mine (its shape, depth, volume, and so forth), the premining transmissivity of

the ore body and surrounding country rock, and the enhanced transmissivity of the rock near the openings. Each of these factors, along with preexisting conditions, such as groundwater recharge rates, will determine the quality and quantity (if any) of the discharge after mining. The stability of the workings after mining is an additional consideration. Few adits remain open for more than a few years. The stability of deeper workings depends on rock quality and the mining methods used.

Any type of abandoned mine can be hard to treat. Abandoned underground mines may have cave-ins and flooding, restricted access, and unreliable mine maps. Abandoned surface mines may have huge volumes of spoil, often of unknown composition and hydrology (Ziemkiewicz and Skousen 1996). Rehandling and mixing alkalinity into the backfill of surface mines and tailings is generally prohibitively expensive. Sites can generate AMD for more than 100

years, making active treatment prohibitively expensive. These problems have been considered so intractable that they have only recently been addressed.

Passive systems can treat AMD to varying degrees at lower capital and operating costs than conventional treatment plants, and they can be installed at abandoned mines and in remote locations (Eger and Wagner 1995). Because they take advantage of natural processes to improve contaminated water conditions (Hedin and others 1994), they should not require significant operation and maintenance. However, they will still need some attention.

This report summarizes literature about many different types of mines and AMD problems. We have used the summary to determine remediation steps that offer the greatest chance of success for remote, inactive mines that produce flows of less than 20 gallons per minute.



# Chemistry

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**A**cidic drainage is a natural process that becomes accelerated and intensified by mining. When rock is exposed to weathering, it will release minerals as it comes into equilibrium with its environment (Brick 1998). Any dissolved metal leached from the rock will hydrolyze when it comes into contact with water, and will produce acid (Brick 1998). However, the primary metal related to AMD is iron. Combined with sulfate and/or sulfide, iron can cause real problems.

Pyrite, an iron sulfide found in both coal and metal mines, has the potential to produce more acid than any other mineral. It can produce 16 units of acid for each unit of pyrite (Brick 1998).

In a natural environment, the process in which rock becomes exposed to weathering and releases minerals is very slow (DeLuca 1997). Mining accelerates this process by exposing a tremendous amount of rock to

weathering in an extremely short period of geologic time. In addition, rock is pulverized in the mining process. This allows more surface area to come into contact with water, and increases the chance that the water will pick up metals (Brick 1998).

Bacteria can add to the problem by significantly speeding up the reaction time. If there were no bacteria in the system, it would take close to 15 years for ferric iron to produce acid (Brick 1998). However, the presence of bacteria will shorten the reaction time down to 8 minutes (Brick 1998).

When mine water has a pH greater than 4.5, it can neutralize acid and is said to contain alkalinity (Hedin and others 1994). Alkalinity can result from hydroxyl ions (OH), carbonate, silicate, borate, organic ligands, phosphate, and ammonia. The primary source of alkalinity in water is dissolved carbonate, which can exist in the bicarbonate or carbonate form (Hedin and others 1994). Both can neutralize proton acidity.

Alkalinity and acidity are not mutually exclusive terms. When water contains both mineral acidity and alkalinity, a comparison of the two determines whether the water is net alkaline (alkalinity greater than acidity) or net acidic (acidity greater than alkalinity) (Hedin and others 1994). Net alkaline water contains enough alkalinity to neutralize the mineral acidity associated with metals such as dissolved iron and manganese. As these metals react to become more neutral, the proton acidity that is produced is also neutralized.

However, if the mine rock contains more acid-generating minerals than alkaline materials, the alkaline materials will eventually be used up, and the water acidity will increase (Durkin and Herrmann 1996). This process can last for weeks, months, or centuries until the minerals completely oxidize and the rock comes into equilibrium (Durkin and Herrmann 1996). At that point, the water will regain a more neutral pH.



# Characterizing Mine Sites

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The first step in the remediation process is to characterize the site in terms of premining conditions, the nature of mine development, and its present or potential environmental effect on land downstream from the site (Robertson 1996). Characterizing a mine site can be divided into three steps:

## • **Planning**

Define the potential concerns for the site and the problems to consider.

Determine the information needed.

## • **Investigation**

Establish a set of techniques for investigating the site.

Evaluate existing information to determine the additional information needed.

## • **Evaluation**

Quantify potential issues to determine the real problems.

Evaluate alternative control measures to solve the problems.

Conduct a cost/benefit evaluation to decide the best remediation measure for the cost.

Throughout the investigation, the investigator must recognize new

concerns as they appear and evaluate their significance. Since some site specifics (such as slope, water chemistry, and land available for treatment) may rule out certain types of treatment, the investigator should also consider the treatment options and assess which options may be employed at the site (Robertson 1996).

Instead of concentrating on the downstream environmental impacts, the site investigator should carefully assess the acid-generating conditions of the potential source material (Robertson 1996). Once the source material has been remediated, the downstream impacts may be able to take care of themselves.

If at all possible, the investigator should determine the background metal levels before mining. This can be done by looking at a similar drainage that has not been mined. Knowing background levels is important because the water should usually be cleaned up to its premining standard, if feasible. In general, when background metal levels exceed clean water standards, the regulatory agencies will take that into account, and will require the background levels to be the standard for that site.

The investigator should look at the site material, any surface pools, any seeps at the toe of the wastes, and at the

surface runoff. The site should be looked at in the spring when the flushing is the greatest, in midsummer when staining is most apparent, and at first snowfall when hot spots can be observed. Signs to look for include staining or precipitates, dead fish or vegetation, melting snow, or steaming vents.

Initial water analyses should include pH, conductivity, alkalinity, iron, manganese, and acidity measurements (Hedin and others 1994). If an anoxic limestone drain is being considered, the acidified sample should also be analyzed for ferric iron and aluminum. A field measurement of dissolved oxygen (DO) should be made. Tailings samples should be tested for low paste-pH and high conductivity. Paste-pH helps determine the pH a soil or rock will generate as it weathers. Materials with low paste-pH will generate acid.

Since both the flow rate and the chemical composition of a discharge can vary seasonally and in response to storm events, the discharge flow rates and water quality should be measured in different seasons and under representative weather conditions. This will allow the passive treatment system to be designed for operation during all weather conditions (Hedin and others 1994).



# Solutions

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**P**assive treatment systems offer a low-cost, low-maintenance solution to AMD problems. While they will not always provide effluent that meets water quality regulations, they will improve the water quality, which is the main goal of treating AMD from abandoned mines.

Active treatment of mine drainage requires precipitating metal contaminants from the water and neutralizing acidity (Hedin and others 1994). Passive treatment differs from active treatment by distinguishing between these two objectives. It is possible to passively remove iron contaminants from mine water, but have little effect on the mine water acidity (Hedin and others 1994). Alternatively, it is possible to passively add neutralizing capacity to acidic mine water without decreasing metal concentrations. Depending on the site, meeting only one of these objectives may be necessary.

Given the right site conditions, the passive system can be designed to meet water quality standards in most cases. In general, systems that are not 100% effective are improperly designed, are undersized, or both (Hedin and others 1994). Operational problems can be attributed to inadequate design, unrealistic expectations, pests, inadequate construction methods, weather, or other natural problems (Hedin and others 1994). If properly designed and constructed, a passive treatment system can be operated with a minimum amount of attention and money.

The cost of a passive treatment system depends primarily on the amount of land needed for the system. Because passive systems rely on processes that are slower than conventional treatment, they require longer retention times and larger areas to achieve similar results (Hedin and others 1994).

Each passive treatment has an area of application. It is difficult to achieve water quality standards by passive treatment with any one system (Ziemkiewicz and others 1997). However, coupling systems could produce the desired results (Ziemkiewicz and others 1997). Four main components create acid mine drainage: water, oxygen, bacteria, and sulfides. Methods to control AMD often target one of these variables (Marcus 1997). If one variable can be removed or reduced, the problem is reduced. This can often be achieved by manipulating the site hydrology or by adding an alkaline agent. Although it is possible to remove the bacteria, they are extremely resilient, and will come back in a very short time (Brick 1998). Repeated applications of bactericide and/or application of a time-release bactericide may be able to remove the bacteria, but this treatment is still in the testing phase (Ziemkiewicz and Skousen 1996).



# Specified Passive Treatments

## Alkaline Amendments

For waters that have a net acidity greater than zero, the treatment design needs to incorporate systems that add alkalinity (Hedin and others 1994). While several different types of alkaline amendments can reduce mine water acidity, a couple of them are most suited for low-flow, remote mine sites (Ziemkiewicz and Skousen 1996).

Limestone is the most commonly used alkaline amendment. It is generally the least expensive and it has a very high neutralization capability. It can be used in almost any application. Its only downfall is that it has no cementing properties, preventing it from being used as a barrier.

Kiln dust is another very good amendment. It mainly consists of unreacted limestone, but it can absorb

moisture and sets up as hard as a rock. It is widely used as a stabilization and barrier material.

The third amendment is phosphate, which works almost as well as limestone. Unless there is a source of phosphate near the mine site, it can be a very expensive amendment. If there is a local source of phosphate, it may be more cost-effective than limestone.

## Wetlands

Wetlands can reduce AMD through physical, chemical, and biological processes. The physical processes, such as filtration and sedimentation, are important in removing particulate metals. The chemical and biological processes remove dissolved metals (Eger and others 1996). Wetlands mainly remove metals through adsorption to organic substrates, and through bacteria (Skousen and others 1996b). Because plant uptake accounts for only about 10% of the metal removal, plants are considered optional.

Acid mine drainage should not be routed into a natural wetland for treatment. Instead, a wetland should be constructed to meet the needs of AMD treatment. A natural wetland may or may not meet those needs, and may cause more problems than it solves. In addition, it is illegal to intentionally pollute a wetland.

Two types of wetlands are used for AMD treatment: aerobic (Figure 1) and anaerobic (without oxygen, Figure 2). The aerobic wetlands collect water and provide residence time. Anaerobic

wetlands generally contain a layer of limestone on the bottom. When mine water contains dissolved oxygen (DO), ferric iron, or aluminum, or is net acidic, construction of an anaerobic wetland is recommended (Hedin and others 1994). The limestone in an anaerobic wetland will raise the pH and decrease the residence time required to treat AMD. If DO, ferric iron, or aluminum is present, the limestone can become armored, limiting its effectiveness. In such cases, the limestone needs to be placed so that it is anaerobic to prevent armoring.

The processes going on at the bottom of the wetland are what makes the wetland so effective at treating mine water. Both types of artificial wetland have a constructed substrate that will pull out most of the minerals and elevate the pH (Eger 1994). The two best materials to use for the substrate are fairly fresh municipal compost or cow

manure mixed with hay. Other types of substrate material include mushroom compost, log yard waste, and peat moss (Skousen 1997).

Two problems must be recognized when using wetlands for remediation. Due to seasonal variation, the acid removal rate is not consistent (Hedin and others 1994). No design corrections are available now to solve this problem. Also, the rates of acid reduction/metal removal will decrease over time (Eger and Wagner 1995) as the substrate becomes filled with metals. However, if the input flows are low and periodic maintenance is performed, wetlands can provide long-term treatment of mine drainage (Eger and others 1994).

For wetlands to remove metals, the mine water needs to be held for 20 to 40 hours (Cohen 1996). If the mine water pH is below 5, the residence time should be 40 hours. If the pH is nearly neutral, the mine water needs approximately 20 hours of residence time. The final design and construction decisions will be based on the flow rate to be treated, the loading rates of the metals, and the space available (Skousen and others 1996b).

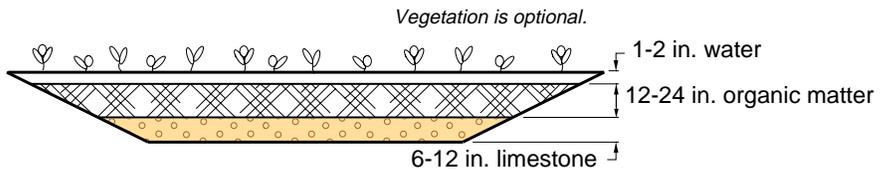


Figure 2—Basic anaerobic wetland design (from Skousen and others 1996a).

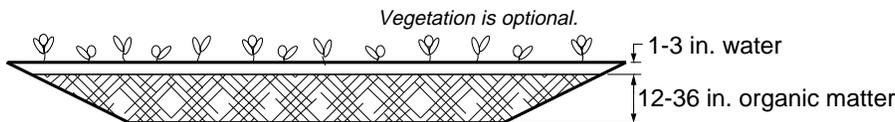


Figure 1—Basic aerobic wetland design (from Skousen and others 1996a).

## Anoxic Limestone Drains

Anoxic Limestone Drains (ALD's) are trenches of buried limestone into which mine water is diverted (Figure 3, Skousen and others 1996b). Often the limestone is covered in plastic and buried to limit the amount of oxygen in the system (Hedin and others 1994). ALD's also allow carbon dioxide to build up in the system. This is a benefit because higher levels of carbon dioxide allow more alkalinity to be added to the AMD (Hedin and others 1994). The AMD must meet specific parameters for

the ALD to work properly. The DO, ferric iron, and aluminum should be under 1mg/L; if they are not, the risk of premature failure increases (Hedin and others 1994).

In theory, an ALD that will last for 30 years requires 30 tons of baseball-sized limestone for each gallon per minute of flow (Hedin and others 1994). Because the oldest operating ALD's are only 7 years old, no one knows if the limestone will actually last for 30 years. Regardless, the ALD must be large enough to detain the mine water for about 14 hours to allow the reactions to

occur. If possible, the water should be aerated as soon as it leaves the ALD and be directed to an aerobic pond or wetland.

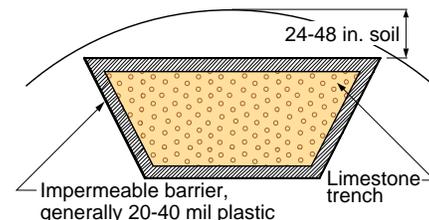


Figure 3—Basic limestone trench design (from Skousen and others 1996a).

## Alkalinity-Producing Systems

Alkalinity-Producing Systems (APS) are a combination of an ALD and an anaerobic wetland. The limitations that dissolved oxygen places on ALD design can be eliminated in an APS by combining open water and a substrate with a high organic content overlying a limestone treatment zone (Kepler and McCleary 1994). The APS design provides a relatively sound assurance that the AMD contacting the limestone will be anoxic (Figure 4).

In designing an APS system, the sizing calculations can be based upon the pH and buffering capacity of the AMD (Kepler and McCleary 1994). The initial component of an APS system is generally a settling pond. The pond

allows the mine water to use up its alkalinity buffer and remove some of the metals. When the water goes through the APS, the water is further neutralized and more of the metals are removed.

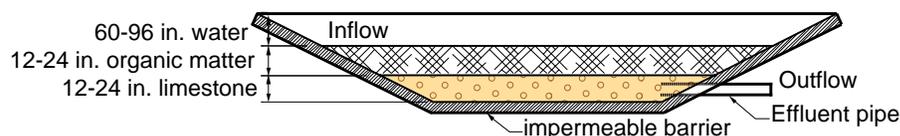


Figure 4—Basic alkalinity-producing system design (from Skousen and others 1996a).

## Limestone Ponds

Limestone ponds provide a solution for places that have room to treat AMD as

it comes from a seep or spring (Skousen and others 1996a). Limestone is placed in the bottom of the pond and the water flows up through the

limestone (Figure 5). The pond's size and design are based on the topography of the area and the water that emanates from the ground. The pond should retain the water for 1 to 2 days to enable the limestone to dissolve and to keep the seep and the limestone underwater. The pond should be built to hold 3 to 10 feet of water, to contain 1 to 3 feet of limestone at the bottom, and to keep the seep and limestone under water (Skousen 1997).

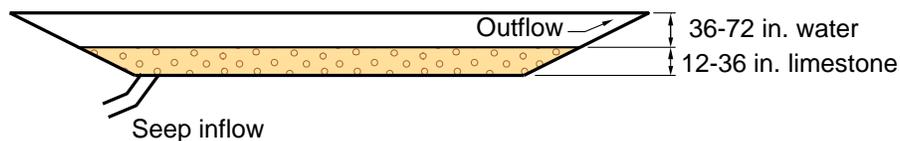


Figure 5—Basic limestone pond design (from Skousen and others 1996a).

## Reverse Alkalinity-Producing Systems

The applications for Reverse Alkalinity-Producing Systems (RAPS) are similar to those for limestone ponds (Figure 6). If the water contains oxygen, a pond can be constructed at the seep's upwelling. Organic matter may be layered in the bottom of the pond, and overlain by limestone (Skousen and others 1996b). The metals are filtered

and removed as they pass through the organic matter. Iron and sulfate are reduced to more benign forms, and the oxygen content is decreased. About 3

to 6 feet of water covers the organic matter and limestone to maintain anaerobic conditions. This system works well for moderate to low flows.

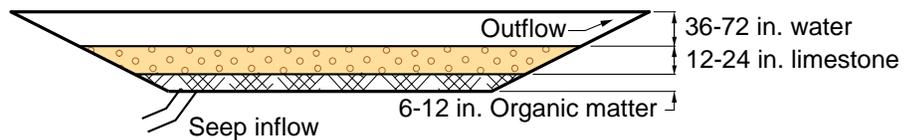


Figure 6—Basic reverse alkalinity-producing system design (from Skousen and others 1996a).

## Open Limestone Channels

Limestone will become armored when exposed to oxygen in mine water, but several studies have shown that it still adds alkalinity to the water although at a reduced rate. As a result, open limestone channels can be effective if designed properly (Figure 7).

Open limestone channels are particularly useful in steep terrain where long channels are possible. They offer

an AMD treatment opportunity where no other passive system is appropriate (Ziemkiewicz and others 1997). Since settlement basins will remove metals, they should be incorporated into the design.

The most successful channels have slopes steeper than 20% and use coarse limestone. Both the slope of the channel and the size of the limestone can minimize the settling of metals in suspension, preventing the channel from becoming plugged (Ziemkiewicz and others 1997).

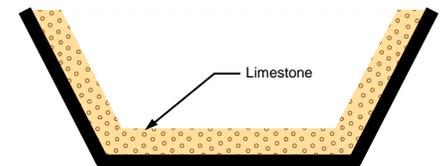


Figure 7—Basic open limestone channel design. Limestone can be placed along sides and in the bottom of culverts, diversions, ditches, or stream channels (from Skousen and others 1996a).

## Diversion Wells

The diversion well is a simple device developed for treating stream acidity caused by acid rain in Norway and Sweden (Skousen 1997). It has been adapted for AMD treatment in the Eastern United States. A typical diversion well consists of a cylinder or vertical tank of metal or concrete, 5 to 6 feet in diameter and 6.5 to 8 feet deep, filled with sand-sized limestone and sunk into the ground by a stream (Figure 8). A large pipe, 8 to 12 inches in diameter, is placed vertically in the center of the well with its end slightly above the bottom. Water is fed into the pipe from an upstream dam or deep

mine portal with a hydraulic head of at least 8 feet (the height of well). The water flows down the pipe, exits the pipe near the bottom of the well, then flows up through the limestone in the well. The flow must be rapid enough to agitate the bed of limestone particles. The acid water dissolves the limestone, generating alkalinity. The metal that precipitates out of the water is flushed through the system by water flowing out the top of the well. The churning action also helps dissolve limestone and ensures that fresh limestone surfaces are always exposed.

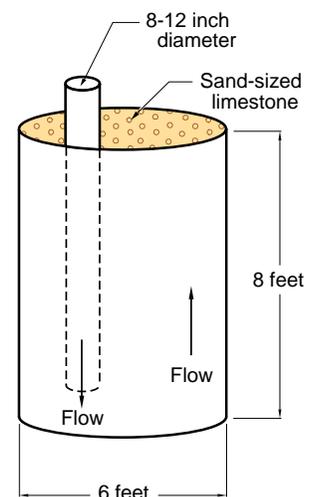


Figure 8—Basic diversion well design (from Skousen 1997).

## Limestone Sand Treatment

Sand-sized limestone may be directly dumped into streams at various locations in the watershed. The sand will

be redistributed downstream, neutralizing acid as the limestone moves along the streambed. The limestone particles can become armored, but the agitation and scouring in the streambed should keep fresh surfaces available for reaction.

Because of limestone grain size and stream redistribution, the river would probably need to be treated three times a year to maintain water quality suitable for fish populations.

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## Permeable Reactive Wall

One way to treat acidic groundwater is to build a permeable reactive wall within the contaminated aquifer (Benner and others 1997). The wall needs to be placed so that all of the groundwater in the aquifer will eventually pass through it (Figure 9). This requirement limits use of the wall to areas where the aquifer is relatively small or is confined (Benner and others 1997).

The reactive material that makes up the wall can either remove the contaminants in the water or decrease them. The material for the wall must satisfy five criteria. First the material must be sufficiently reactive to reduce sulfate concentrations. The material also must be permeable enough to accommodate the groundwater flux rates at the sites. The material must sustain its permeability and reactivity over a long time period. Finally, the material must be readily available and affordable with respect to site condi-

tions. Designs for a permeable reactive wall are still in their initial phase, but it has been determined that a substrate comprised of municipal compost, leaf compost, and wood chips mixed with pea gravel will provide an effective catalyst for cleaning groundwater. At this point, no one is sure exactly how long the reactive materials will maintain their effectiveness.

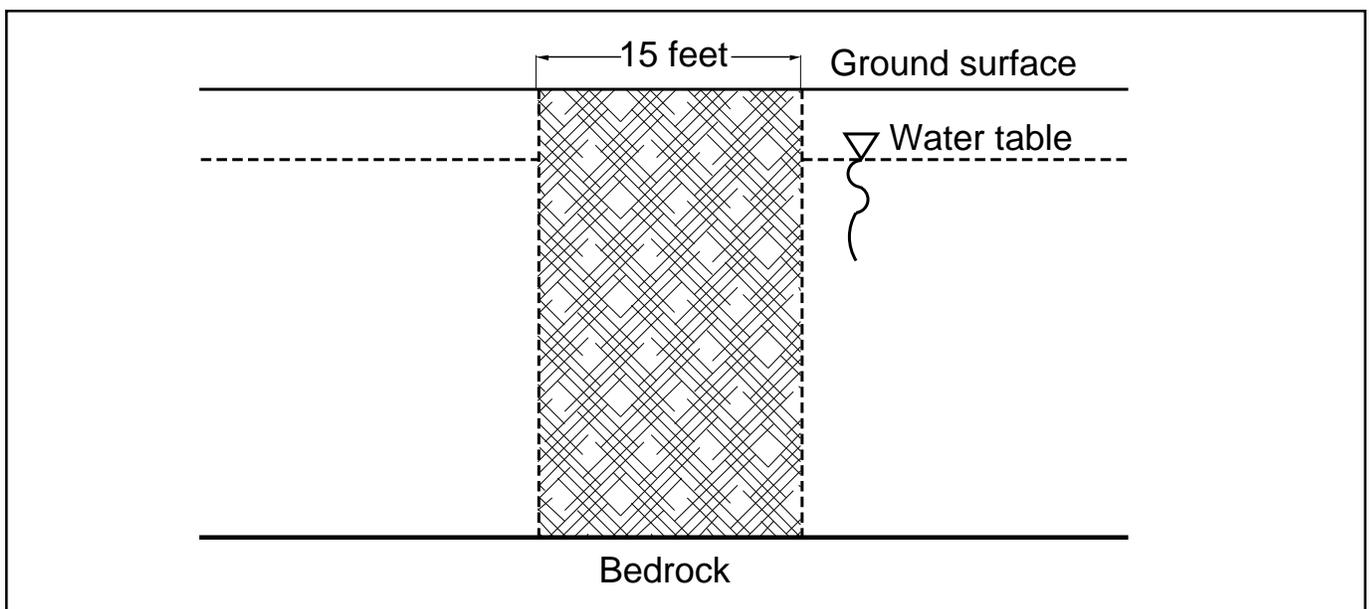


Figure 9—Basic permeable reactive wall design (from Benner and others 1997).



# Passive In-Situ Reduction of AMD

The passive in-situ methods for treating AMD focus on:

- Increasing pH to precipitate metals
- Using biological reduction agents to precipitate metals.

These treatments enhance natural processes to reduce maintenance and cost. An alternative is to create conditions that eliminate one or more of the components of AMD generation within the source area: remove the supply of oxygen, prevent water from entering the workings, and/or prevent the oxidation of sulfide minerals. Two general methods to eliminate the components of AMD generation are to flood the underground workings or to directly reduce groundwater flow through the AMD source rock.

## Mine Flooding

Flooding underground workings greatly reduces sulfide oxidation. Subsequent rock-water chemical reactions may reduce the oxidation-reduction potential enough to precipitate dissolved metals from the mine waters. Metals such as copper, lead, and zinc are transported as dissolved oxide or sulfate complexes in acid waters. In a flooded mine, dissolved oxygen that is consumed cannot be replaced by atmospheric oxygen. As this process continues, the oxidation-reduction potential decreases and sulfides begin to precipitate. A reducing agent such as sulfur is needed to promote precipitation of sulfides. The sulfur can exist as free sulfur (Lindsay 1979) or as pyrite (Guilbert and Park 1986), which is relatively soluble and is generally abundant in sulfide ore bodies. Organic carbon, such as mine timbers and other wood debris, is another reducing agent, although the supply is limited.

Inundating the exposed sulfides that generate acid can reverse the process and produce waters in which the pH is

nearly neutral. This has been demonstrated in ongoing work by the Montana Bureau of Mines and Geology at several mines near Butte, Montana. Similar conditions have been observed at several small, flooded shafts and adits throughout Montana.

Inducing flooding in some mines will require that adits be plugged. However, recognition of the geochemical process may reduce the degree of plugging needed. In mines where the final hydrostatic head on the plug may be too high, relief holes at the appropriate elevations may reduce the final head, but would yield good quality water.

## Direct Reduction of Flow

One method of AMD prevention is through the use of barriers. They can be placed to prevent the movement of water and oxygen into areas containing acid-producing rock. In general, these methods can reduce AMD, but not entirely control it (Ziemkiewicz and Skousen 1996). Barriers can be used in two different ways: grout barriers can be used to plug rock fractures within a mine, and soil barriers can be used to encapsulate acid-producing tailings. Both methods redirect groundwater flow away from acidic material.

Several methods are used in mining and construction to reduce, divert, or eliminate groundwater flow to openings. The more common methods include:

### • Grouting (Inside)

Grouting fractures to reduce flow is often used in active mines where pumping costs and water-treatment costs can be reduced if grouting is at least partially successful. The grout can be injected into the country rock outside the ore body or can be applied as a lining on the

exposed surface within the workings. Applying either technique requires detailed knowledge of the rock and grout material (for example, see Fotieva and Sammal 1987). The success of this type of grouting appears to be greatest when it is injected ahead of the water that flows into the mine.

### • Grouting (Outside)

There have been several recent attempts at drilling and grouting from the ground surface into the unmined area just outside the opening of a new mine adit. Success is generally very limited. Recent investigations by the Montana Bureau of Mines and Geology in the Butte area indicate the need for precise placement of drill holes. The area or volume of influence by the underground opening can be quite limited and require a precision of a few feet. Accurate information on the depth and position of the opening is needed and can be difficult to obtain. Several methods of mine water control using this approach are described by Szentirmai (1985), USDI Bureau of Reclamation, (1987), DuBois (1984), Ewert (1992), Fotieva and Sammal (1987), and Jacenkov and others (1984).

### • Adit Plugging

This method has been applied under a variety of conditions with mixed success. Several adit plugs have failed catastrophically a few years after placement. Site-specific, detailed information is needed on the rock quality, the predicted final hydrostatic pressure, and the effects water quality may have on the plug material. Several methods, including the one presented by Cogan and Kintzer (1987), have been developed for active and inactive mines. The possibility of unwanted side effects remains. As

discussed, flooding underground workings often causes conditions that lead to precipitation of metal-sulfides and an increase in pH, both desirable effects. However, if the hydraulic conductivity of the ore body and country rock are sufficiently high, acidic water can leak out into other adjacent areas before reducing conditions can be achieved. This makes water treatment difficult and may lead to other conditions such as slope failure. At this time, the developing consensus is that plugging coal mines is at best a temporary solution (Ziemkiewicz 1996).

• **Backfilling**

Backfilling the mine may also be a viable option. Backfilling can reduce the acid loading substantially by reducing the groundwater flow and infiltration, and dissolved oxygen (DO) and acid concentration (Skousen and others 1996b). Encouraging rapid runoff and discouraging recharge into zones of acidic backfill will also help reduce the total acid load from the site.

• **Groundwater Recharge Control**

In some mines, the ore body extended to or was near the ground surface. Mining such ore bodies necessitated shallow workings confined to vertically oriented pay zones. The majority of groundwater now entering such workings is from surface recharge originating from a relatively small area around the mine. The closer the mine is to the groundwater recharge area, the smaller the recharge area is for the mine. Reducing or eliminating infiltration in the recharge area can greatly reduce or eliminate adit discharge. Ackman and Jones (1991) describe techniques used to reduce stream flow loss to underground openings. Similar methods could be used to identify high-recharge areas of

groundwater flow to underground workings.

• **Interception/Diversion**

This method has been more commonly proposed for coal mines where the coal bed lies flat and the groundwater quality in the overburden is good. Horizontal wells are installed in the overburden to reduce flow into the mine and divert water away from the workings. This sometimes occurs naturally in hardrock mines of similar shape.

The size and shape of the mine play an important role in selecting a method to control groundwater flow. The geologic and hydrogeologic nature of the ore body and surrounding country rock also determines how groundwater flow is affected by the opening and any subsequent attempt at control. A simplifying assumption is that the size, shape, and geologic history of the ore body control the size, shape, and mining method used to extract the ore. With this in mind, a simple classification

scheme (Figure 10) has been constructed to determine the best methods to consider for a given mine.

The mine type axis of Figure 10 refers to the general location of the surface opening with respect to the workings. The adit can be the lowest point in the mine with all workings above the adit, at the highest point (rare), or at some point in between with workings above and below the adit (common). Mines that used a shaft for access may be partially flooded or completely flooded.

Accurately classifying a given site and selecting a remedy will require information on the geologic and mineralogic controls on ore placement and weathering, mining and exploration methods, and controls on groundwater flow (fracture density, aperture, and orientation). Each method of adit discharge control comes with its own set of limitations. These limitations should be well understood for the conditions of each site. No single method is a cure-all. A combination of methods will usually give the best results.

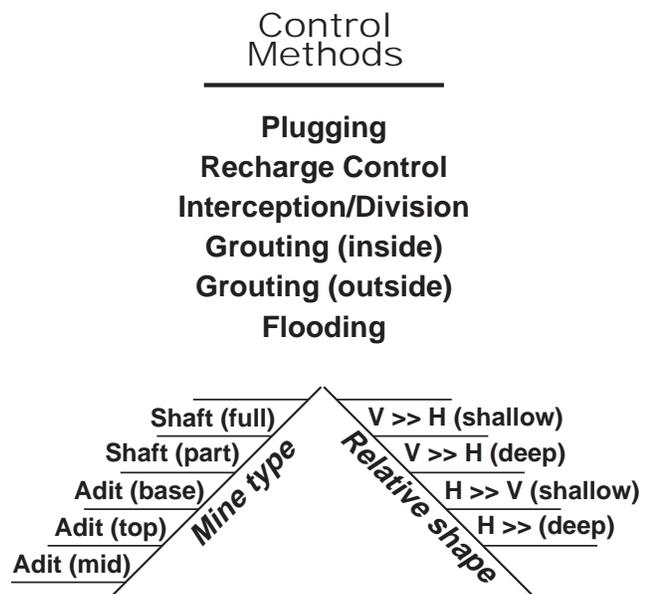


Figure 10—The mine type and the shape of the mine are considered when selecting one or more methods to control adit discharge. The vertical extent of the workings may be much greater than their horizontal extent (V>>H) or their horizontal extent may be much greater than their vertical extent (H>>V). Shafts may be fully flooded (full) or partially flooded (part).

Consider a mine that has a discharging adit at the base of the workings (adit, base), located near the bottom of the drainage (deep), with several levels of workings that extend up into the ore body ( $V \gg H$ ). Grouting from the outside of the mine would require a lot of deep drilling, which is expensive and difficult to apply with accuracy. Because of the mine's vertical extent, the workings intercept a large part of the groundwater flow. The groundwater

recharge area for the mine may be quite large and difficult to control. For this type of mine, the best approach may be grouting fractures within the mine, an adit plug, or, depending on the quality and quantity of the water, a combination of the two methods.

The approach would be different if the same mine was near the top of the drainage (adit, base; shallow;  $V \gg H$ ).

The recharge area would likely be smaller since the workings are closer to the surface. Grouting from the outside the mine or recharge control may be the preferred control method.

Once adit discharge has been controlled to the degree possible, the remaining discharge will need to be treated. The flowchart below (Figure 11) will help you choose the appropriate passive treatment system.

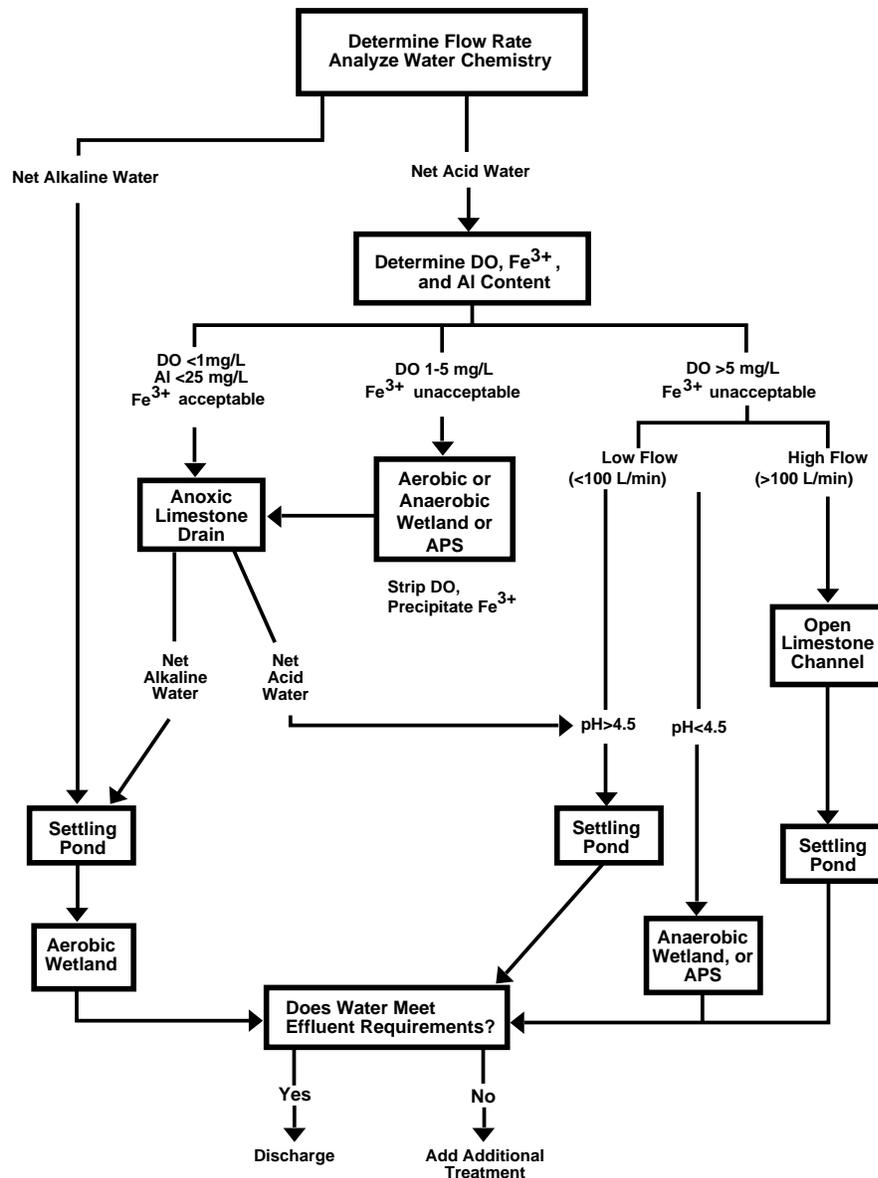


Figure 11—Flow chart for selecting the proper passive treatment design (from Hedin and others 1994).

# Planning to Control AMD at Current or Proposed Mines

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Some measures can be taken at operating mines to prevent AMD from becoming a problem. The Surface Mine Control and Reclamation Act requires operators and regulators to predict the amount of acid mine drainage that may occur on a potential mine site before disturbance (Ziemkiewicz and Skousen 1996).

Three important factors in determining and preventing AMD are: geochemical analysis of overburden, the site's hydrology after mining, and the method of overburden placement in the backfill during reclamation (Ziemkiewicz and Skousen 1996).

Geochemical analyses of overburden should take place during the planning stage of a mine. Before mining, overburden strata need to be classified according to Acid-Base Accounting (ABA). This testing process determines if the material is net alkaline or net acidic (Meek 1996). These tests will determine whether the overburden will produce acid once it has been broken up and subjected to weathering.

The hydrology of the site after mining is also important. Because the overburden is broken into smaller rocks during mining, the reclaimed ground will have a

different composition than it did before mining. This could cause water to move through the site differently than it had previously (Ziemkiewicz and Skousen 1996). Knowing where the water will go helps determine where the acid-producing material should not be placed.

By knowing the hydrology after mining, the acid-producing overburden can be placed in the backfill so that it will remain relatively dry. If that is not possible, the material can be blended with acid-neutralizing rock to develop an inert rock mass (Ziemkiewicz and Skousen 1996).



# Conclusions

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**A**cid mine drainage affects many sites and can be an incredibly difficult problem to solve. Unfortunately, there is no simple

solution because mine sites vary so much and because site characteristics determine what can and cannot be done. It may be possible to use any of the above systems—or a combination

of them—to create nearly pristine water. Even if the acid mine drainage problem may not completely disappear, reducing it will go a long way toward solving it.



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## Library Card

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Describes passive treatments for acid mine drainage suitable for mines abandoned in remote areas. A flow chart shows how treatments could be combined to reduce specific acid mine drainage problems. Although these treatments may not eliminate acid mine drainage, they should reduce it.

Keywords: mined land; passive treatments; remediation

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