

## **Aaron Run Watershed Plan**

Maryland Department of the Environment  
Land Management Administration  
Bureau of Mines

September 23, 2005

Aaron Run is in Garrett County, Maryland. It is a tributary to the Savage River, which in turn flows into the Upper North Branch Potomac River and the Chesapeake Bay.

Watershed Plan Goal:

“...Aaron Run watershed to be restored sufficiently to meet water quality standards for the parameter of pH...” (cover letter dated September 23, 2005)



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September 23, 2005

Mr. Fred L. Suffian  
Program Manager (3WP12)  
Nonpoint Source Pollution Program  
1650 Arch Street  
Philadelphia, PA 19301

Dear Mr. Suffian,

My name is Laura Haynes and I am working with Connie Lyons on the proposed Aaron Run restoration Project. Connie has asked me to correspond with you regarding your review of the Aaron Run Proposal that she submitted. The following explanations are in response to your review of the Proposal.

In response to your comments regarding item b:

Once the Water Quality Improvement Goals are met, we expect the Aaron Run watershed to be restored sufficiently to meet Water Quality standards for the parameter of pH, thus greatly reducing impact to the Savage River.

In response to item c, I have included Sections 1-3 and part of Section 4, from a previous report (North Branch Potomac River Environmental Restoration Reconnaissance Study: Acid Mine Drainage Abatement Study) to illustrate best management practice (BMP) that will be used throughout the Aaron Run Watershed Remediation Project. Treatment methods are evaluated primarily on the basis of flow and chemistry of the AMD and the receiving stream, and available area. We are in the process of evaluating four restoration sites in Aaron Run watershed to determine the best treatment methods to use considering the chemistry, topography and flow of each individual site.

Sections 1-3 of the document are included to demonstrate how sites are selected and to explain the acid mine drainage (AMD) treatment technologies commonly used. Part of Section 4 is included as an example of how BMP will be implemented to evaluate each site for the most effective remediation techniques. Because of its length and detail, I did not send the entire document. I simply wish to provide a model of the BMP that is used to evaluate AMD remediation sites.

Should you require more information or if you would like an entire copy of the enclosed document, please do not hesitate to call 301-689-6764 x 204, or e-mail me ([lsprague@allconet.org](mailto:lsprague@allconet.org)).

Respectfully,

*Laura M Haynes*

Laura M. Haynes  
Watershed Project Assistant  
Western Maryland RC&D

## **SECTION 1.0**

### **INTRODUCTION**

#### **1.1 BACKGROUND**

During a reconnaissance study of the North Branch Potomac River Basin by the Baltimore District, Corps of Engineers (COE), it was determined that mine drainage to the Upper North Branch Potomac River is the primary cause of degradation to aquatic habitat within the study area. This drainage sub-basin, the Upper North Branch Potomac River Basin, extends from Fairfax Stone, West Virginia to the confluence of the Savage River. It includes Garrett County, Maryland and Grant and Mineral Counties of West Virginia.

A study of abatement requirements for mine drainage problems in the Upper North Branch Potomac River Basin was authorized by the COE to develop cost effective solutions to the problems. The study was conducted jointly by the:

- COE,
- North Branch Study Steering Committee,
- Maryland Department of Natural Resources,
- West Virginia Department of Natural Resources,
- West Virginia Division of Environmental Protection, and
- Michael Baker Jr., Inc.

Activities surrounding the study, including study results, are documented in this report.

#### **1.2 STUDY OBJECTIVES AND SCOPE**

Objectives of this acid mine drainage study were to: 1) identify/select priority AMD problems and sources within the Upper North Branch Potomac River Basin, 2) assemble available data regarding the selected AMD study sites, 3) identify potential AMD control/treatment technologies, their limitations, and applicability, 4) determine the most cost effective technology(ies) for mitigating AMD problems at each study site on a long-term basis (20 years), and 5) estimate site acid load reductions that would result from mitigation.

The study was initiated by selecting priority AMD sites to be remediated. Existing data pertaining to the study sites and available AMD control/treatment technologies then were gathered and reviewed. Site characteristics were established from existing reports but site visits were made to

confirm and/or update information presented in the existing reports. Site characterization data, along with AMD flow properties, were compared with limitations of the available mitigation technologies to identify technically feasible solutions to the AMD problems at each site. Economic evaluations were conducted to identify the most cost effective mitigation alternative for each site.

## SECTION 2.0

### ACID MINE DRAINAGE STUDY SITES

#### 2.1 SITE SELECTION

Based on data presented in a previous report of mine drainage problems in the study area (referred to as the "Morgan Report"), 13 abandoned mine drainage sites within the Upper North Branch Potomac River watershed were identified as producing 90% of the acid load in the study area. Characteristics of these 13 sites were reviewed and seven sites were identified as having a high priority for remediation. These seven "high priority" sites then were selected for subsequent evaluation by this study. The seven selected, high priority, sites are:

1. West Virginia Site #22 - Allison Engineering; Bismarck, WV
2. West Virginia Sites #23 and #23A - Bismarck Mine; Bismarck, WV
3. West Virginia Sites #25 and #25A - Mt. Storm Mine; Mt. Storm, WV
4. Maryland Site #3 - Kempton Mine; Kempton, MD
5. Maryland Site #36 - Shallmar Mine; Shallmar, MD
6. Maryland Site #38 - Kitzmiller Mine; Kitzmiller, MD
7. Maryland Site 43/45 - Vindex Mine; Vindex, MD

Site selections were made by a committee consisting of the COE, WVDEP, WVDNR, and MDDNR.

Sites in West Virginia were selected by representatives of WVDEP and WVDNR, and representatives of COE and Office of Surface Mining (OSM) provided their concurrence with these selections. Likewise, sites in Maryland were selected by representatives of MDDNR with COE and OSM concurrence.

#### 2.2 GENERAL SITE PROBLEMS (CHARACTERISTICS)

The seven sites selected for this study are abandoned coal mine sites producing significant amounts of AMD. Both underground mine sites and surface mines are included among the seven sites and some of the study sites exhibit evidence of both types of mining. Consequently, each of the seven sites include one or more of the following: draining underground mine entries, acidic coal refuse and spoil piles producing AMD, unreclaimed highwalls, and impounded AMD. Generally, the study sites range in size from the approximately 12-acre abandoned underground mine site in Kitzmiller, Maryland (Site #38) to the 475-acre abandoned surface mine site in Bismarck, West Virginia, known as the Allison Engineering Site (Site #22). AMD from the seven sites ranges from 0.8 cfs (Shallmar, MD - Site #36) to 6.4 cfs (Allison Engineering Site - Site #22) and is characterized by high acidity

and high metals concentrations (e.g., iron, manganese, aluminum). Daily acid loadings of more than 3,000 lb have been measured at three of the seven sites.

Significant site characteristics such as topographic features, surface features related to past mining activity, and AMD source locations, magnitude, and chemistry have been gathered and compiled for each of the seven sites. Detailed descriptions of each site are presented in the Appendix. Site location plans showing AMD sampling locations and AMD analytical data are attached to each of the site descriptions. Site data presented in the Appendix were obtained from the "Morgan Report" and were modified as needed based on information obtained during site visits conducted during the week of April 17, 1995 by representatives of Baker, and on some recent water sample data provided by MDNR and WVDEP.

## SECTION 3.0

### OVERVIEW OF AVAILABLE ACID MINE DRAINAGE CONTROL/TREATMENT TECHNOLOGIES

Two distinct approaches are used to abate stream pollution caused by acid mine drainage (AMD) discharge from abandoned mine land sites. They are:

1. Implementing techniques to control (reduce and/or prevent) AMD formation.
2. Treating AMD (once formed) to meet desired water quality standards prior to its discharge. Both conventional chemical treatment systems (systems whereby alkaline chemicals are dispensed directly into the AMD), and passive measures (chemical and biological processes, e.g., wetlands) are used.

Techniques used to control AMD generation are based on the principle of excluding access of air (oxygen) and water to the exposed surfaces of acid producing materials generated during surface or underground coal mining.

Treatment techniques, on the other hand, are used to neutralize the acidity of AMD already generated and facilitate precipitation of contaminant metals to the extent necessary to meet desired water quality standards. Selection of proper chemicals and/or passive treatment measures to treat AMD varies with each AMD problem encountered.

#### 3.1 TECHNIQUES THAT CONTROL THE GENERATION OF AMD

Various methods have been used in the past and may be used successfully in the future to control AMD generation, particularly at abandoned mine land sites. AMD control can be accomplished by: 1) diverting run-off to the mine or mine spoil area, 2) backfilling the mine workings, 3) capping mine spoil areas, and/or 4) sealing entries to underground mine workings. More detailed discussions of these techniques follows.

##### 3.1.1 Diversions

Structures generally are installed to divert surface water run-off away from mining/mine spoil areas and thereby prevent its infiltration into the mine workings or mine spoil/refuse generated and placed during mining operations. Water diversion involves collection of water before it enters the mine area, and then conveying it around and away from the mine site. Water diversion decreases erosion



and sedimentation, reduces the volume of AMD generation, and reduces treatment costs by reducing the volume of water that would otherwise come in contact with acid producing rock or mine spoil. Ditches, flumes, pipes, trench drains, berms, and dikes are all commonly used for water diversion. Diversion ditches are usually constructed upslope of the surface mine and mine spoil, allowing surface water to flow around and away from the mining area..

Groundwater diversion may be effected in a surface mine by constructing drains along the bottom of the highwall to intercept incoming groundwater from the mine prior to its contact with AMD forming mine spoil.

### **3.1.2 Backfilling**

Backfilling as a technique to reduce AMD formation is particularly suitable for underground mine workings. Backfilling mine voids will reduce or preclude the collection or passage of air (oxygen) and water (surface and groundwater) into the mine, thereby reducing or preventing AMD formation. This technique has been used frequently in active underground mines, particularly for subsidence control. In such situations, reduction of AMD formation has always been an added benefit. Mine backfill material can consist of mine waste (refuse), sand, flyash, or low strength grout (flyash and cement). Backfilling of abandoned underground mines generally is difficult and costly due to the unreliability of mine maps and access difficulty. Therefore, backfilling of abandoned underground mine workings typically is carried out only for subsidence control . Although backfilling of underground mines with flyash has been proposed by various researchers to control AMD formation, its successful use is not certain because of associated costs and difficulties in obtaining reliable mine maps (abandoned mines).

Backfilling at a surface mine site consists of backfilling the unreclaimed highwall, surface mine pit, and any impoundments. Such backfilling is aimed at reducing or precluding collection or passage of air and water in acid forming rock.

### **3.1.3 Regrading and Capping**

For surface mine areas, regrading and revegetating the spoil and capping the reclaimed site with low permeability material are aimed at reducing surface water infiltration into the acid producing spoil.

Unreclaimed abandoned surface mine spoil is frequently a major AMD source. To control surface water infiltration into spoil, it is necessary that the spoil be excavated and placed back in compacted lifts (i.e., each lift compacted to at least 95 percent of the maximum dry density determined in accordance with ASTM Test Method D698) and then properly regraded to eliminate any closed contour depression that may create surface water ponding. During regrading, fine-grained alkaline

material containing unreacted calcium oxide such as Circulating Fluidized Bed (CFB) ash may be incorporated into the top three to five feet of the regraded spoil to minimize surface water infiltration and provide an alkaline amendment.

Capping the regraded spoil or refuse area with compacted clayey soil (hydraulic conductivity of  $1 \times 10^{-6}$  to  $1 \times 10^{-7}$  cm/sec) may substantially reduce the movement of oxygen (air) and water into underlying acid forming materials.

Saturated clay/capillary type barriers (caps) also have been used to control air and water infiltration into regraded mine spoil and refuse, thereby controlling AMD formation. One such barrier has been used in the Heath Steele Mine in New Brunswick, Canada and is approximately 4.5 feet thick. It consists of the following layers (listed in descending order): a 4-inch gravel layer (for erosion control), a 12-inch gravel/sand layer (evaporation barrier), a 24-inch compacted till (hydraulic conductivity  $1 \times 10^{-6}$  cm/sec), and a 12-inch layer of sand placed over the pyritic acid rock (AMD forming material). Performance of this barrier was monitored for five years and was found to be effective in excluding 98-99 percent of the surface precipitation from infiltrating into the acid forming rock (14, 15, 16).

A similar type of barrier was used and studied for more than 3 years at the Waite Amulet Mine near Rouyn-Noranda, Quebec. The barrier consisted of a 2-foot thick layer of compacted clay sandwiched between 12-inch layers of sand placed over pyritic tailings. A 4-inch gravel layer was placed on top of the barrier for erosion protection. The barrier reduced oxygen flux by 99.9 percent and excluded 96.1 percent precipitation resulting in an estimated 95.4 percent reduction in the rate of acid generation. This type of capping has a great potential for use on unreclaimed mine spoil or refuse in abandoned surface mining site to control/prevent the AMD generation (14, 15, 17).

#### **3.1.4 Mine Seals**

Mine seals are used to exclude passage of oxygen (air) to the acid producing environment of underground workings, and may be either dry seals or wet seals. These are used for sealing all mine entries, shafts, and boreholes that are opened to mine workings. Seals should be air-tight to be effective.

Dry seals are constructed by placing suitable material in mine openings to prevent air and water passage into the mine. These seals are suitable for openings where there is no water flow and little danger of a hydrostatic head developing.

Wet seals are constructed to prevent passage of air into the mine while allowing normal mine discharge to flow through the discharge outlet. These seal outlets are provided with air traps. A

variation of the wet seal is a hydraulic seal which involves placing a plug in a mine entrance discharging water. The plug prevents discharge and the mine working is flooded. Flooding excludes air from the mine and retards oxidation of acid forming materials. Hydraulic sealing of abandoned underground mines creates an impoundment in which mine seals and the mine perimeter serve as an underground dam. The success of hydraulic sealing will depend upon the ability of the entire dam structure to withstand water pressure and control mine water seepage from the seals and the mine perimeter, otherwise, the possibility for a blow-out exists.

### **3.2 AMD TREATMENT METHODS - APPLICABILITY AND LIMITATIONS**

AMD treatment methods presently practiced may broadly be classified as conventional chemical treatment or passive treatment.

Conventional chemical treatment systems directly apply alkaline chemicals continuously to AMD discharge for neutralizing mineral acidity, precipitating out metals, and raising pH. This type of treatment system is often called an "Active System". The following six types of chemical treatment are currently being utilized:

- Limestone
- Hydrated Lime
- Pebble Quick Lime
- Soda Ash Briquettes
- Caustic Soda
- Ammonia

Passive treatment systems use more naturally occurring chemical and biological processes that neutralize acidity, decrease metal concentration, and raise pH. The following seven methods of passive treatment are currently being utilized:

- Anoxic Limestone Drain (ALD)
- Aerobic Wetland
- Anaerobic Wetland
- Alkalinity Producing Systems (APS or SAPS)
- Limestone Ponds (LSP)
- Reverse Alkalinity Producing System (RAPS)
- Open Limestone Channels (OLC)

More detailed discussions of available chemical and passive treatment systems, including their limitations and applicability, are presented in the following subsections.

### **3.2.1 Conventional Chemical Treatment Systems (Active Systems)**

Conventional chemical treatment systems are classified based on the chemical used to treat the AMD. Six chemical reagents typically and widely used in treating AMD are: limestone (calcium carbonate), hydrated lime (calcium hydroxide), pebble quick lime (calcium oxide), soda ash briquettes (sodium carbonate), caustic soda (sodium hydroxide), and ammonia (anhydrous ammonia). Each chemical has unique characteristics that make it more or less appropriate for specific conditions. The best choice among the alternatives depends on both technical and economic factors.

Technical factors include: acidity level of the discharge, rate of flow, type and concentration of metals in the water, rate and degree of pH increase desired, and solubility of chemicals in the water (which influences mechanization).

Economic factors include: cost of reagents, handling cost (labor, machinery and equipment), and the number of years that treatment will be needed.

The conventional treatment system may require a settling basin or pond where treated AMD would be detained to allow precipitation of metal hydroxide (sludge). In general, as the pH of the treated water and its degree of aeration are increased, required residence time in the pond for metal removal would be decreased.

In order to select a specific type of chemical for AMD treatment, it is necessary to know how the pH of the water governs precipitation of metals contained in the water. Ferrous<sup>2+</sup> iron changes to bluish-green ferrous hydroxide at or above a pH of 8.5. Ferrous<sup>2+</sup> iron oxidizes to ferric<sup>3+</sup> iron in the presence of oxygen and converts to ferric hydroxide, a yellowish orange precipitate, at or above a pH of 3.5. Thus, in the absence of oxygen, poor water primarily containing iron in the ferrous form, requires the pH to be 8.5 before ferrous hydroxide precipitates. Consequently, the most efficient way of treating AMD having a high concentration of ferrous iron is to first aerate the water for converting ferrous to ferric iron, and then to add a neutralizing chemical to form ferric hydroxide that precipitates at a lower pH. Treatment by this method reduces the amount of neutralizing agent that would otherwise be required to precipitate iron from the water. Precipitation of manganese is variable, but generally soluble manganese<sup>2+</sup> will precipitate from water at pH 9.0 to 10.0. Aluminum precipitates at a pH of 5.5, but enters solution again at a pH of 8.5 or greater (18).

It is apparent that the appropriate treatment chemical for AMD can depend on oxidation status, and metal compositions and concentrations in AMD.

### 3.2.1.1 Characteristics of Chemicals for Active Treatment Systems

Six neutralizing chemicals are typically used for treating AMD as identified in the previous section. Characteristics of these chemicals relative to their applicability and limitations, are summarized as follows.

#### 3.2.1.1.1 Limestone (calcium carbonate)

- Used for decades to raise pH and precipitate metals in AMD.
- Cheapest, safest and easiest to handle.
- Will work well with AMD containing low pH and small concentrations of iron, manganese, and aluminum - precipitating out these metals and raising pH of the water to about 7.0. The maximum attainable pH is 7.4 (19).
- Low solubility in water, (reaction rate is slow).
- If iron concentration is above 5 mg/l, limestone will show a decreased solubility in a short time period due to armoring (coating of ferric hydroxide) of the limestone particle (18).
- For active systems, limestone is not normally used when AMD acidity values exceed 50 mg/l because of the slow reaction time (18). Passive systems are designed to accommodate the slow reaction, therefore, limestone can be used.
- If sulfate concentrations in AMD are above 2,000 mg/l, then calcium carbonate will react with sulfate to form insoluble gypsum (4). Gypsum precipitate may clog pipes or other discharge conveyance structures.
- In an anaerobic environment such as an "Anoxic Limestone Drain", limestone does not armor with metal hydroxides (20).
- May produce calcium hardness in the treated water.

#### 3.2.1.1.2 Hydrated Lime (calcium hydroxide)

- Useful, safe to handle, and cost effective in large flows and high acidity situations where a lime treatment plant with aerator is constructed to dispense and mix the chemical with water.

- Capital intensive, but cheaper for long term treatment (greater than 3 years) (21).
- Has been used for 1,000 gpm flow and 2,500 mg/l acidity (extreme condition) (21).
- Has limited effectiveness if a very high pH (pH = 9.5) is required to remove manganese.
- If ferrous iron is present, it is cost effective to use hydrated lime in conjunction with an aerator to oxidize the ferrous to ferric iron for precipitation at a lower pH.
- It is generally powdery and hydrophobic, therefore, requiring extensive mixing to make soluble in water.
- With very high sulfate concentration (>2,500 mg/l) may form insoluble gypsum.
- Use is not feasible in remote locations where electricity is not available, since the system requires electricity to power pH sensing metering devices that automatically run the pumps and aerator. Water power cannot be used.

#### 3.2.1.1.3 Quick Lime (calcium oxide)

- Recently used in conjunction with the Aqua-Fix Treatment system utilizing a water wheel concept.
- Very reactive; particularly useful for small and/or periodic flows of high acidity. Needs metering equipment (21).
- Economical, easy to handle, available in pelletized form (pebble quicklime) (21).
- Requires no electricity and can be used for treatment in remote places.
- Less costly than ammonia and sodium based neutralizing chemicals.

#### 3.2.1.1.4 Soda Ash Briquettes (sodium carbonate)

- Used in remote areas with low flow and low concentrations of acidity and metals (21).
- Used for short term applications.
- Easier to handle, but costlier than the calcium based neutralizing chemicals.

- If iron is more than 10 or 20 mg/l, a mixing system will be required to improve efficiency and treatment (18).
- If ferric iron is a major problem, it can be removed with sodium carbonate with aeration.
- Selection of this material is usually based on convenience rather than cost effectiveness.
- Low solubility relative to other sodium based compounds and is costly.

#### 3.2.1.1.5 Caustic Soda (sodium hydroxide) (18, 19, 21)

- Commonly used chemical in AMD treatment in remote locations where no electricity is required.
- Used for temporary treatment particularly in low flows and high acidity situations.
- Extremely soluble, spreads rapidly, raises the pH of water very quickly, and is commonly the chemical of choice if the manganese concentration is high.
- Can easily raise the pH to 12 or higher, so, over-application can produce very undesirable situations.
- Suitable for ferrous iron removal, but less cost effective than hydrated lime used in conjunction with an aerator.
- High cost, dangers in handling, and susceptible to freezing during winter seasons.

#### 3.2.1.1.6 Ammonia (anhydrous ammonia) (18, 19, 21)

- Used in some areas to neutralize acidity and precipitate metals in AMD.
- Extremely soluble and reacts very rapidly, behaves as a strong base and can easily raise the pH of receiving water to 9.2.
- It is effective for manganese removal (which can occur around a pH of 9.5), but is not practical since it requires a large amount of ammonia..
- It consumes acid ( $H^+$ ) and generates hydroxyl ions ( $OH^-$ ) which form a metal hydroxide

precipitate.

- At a pH of 9.2, it buffers the solution to further pH increases, since very high amounts of ammonia must be added to elevate the pH beyond 9.2.
- Caution is needed in using a pH monitoring system at pH levels above 9 since over-application of ammonia could lead to other water quality problems related to excessive concentrations of un-ionized ammonia (toxic to fish and aquatic life), nitrate and nitrite. Also may cause acidity downstream.
- Hazards are associated with handling the chemical and uncertainty concerning potential biological reactions.
- Slightly more expensive than hydrated lime, but considerably less expensive than caustic soda or soda ash in neutralizing AMD.

### **3.2.1.2 Methods of Dispensing Alkaline Chemicals for AMD Treatment**

The appropriate method for dispensing or dosing alkaline chemicals to treat AMD depends on the physical state of the materials to be used for AMD treatment (i.e., whether the alkaline material to be dosed is solid, slurry, or liquid). The dosing device used also depends on AMD flow volume and whether the dosing device to be used is for short-term treatment or for long-term treatment.

Liming dosers that have been used successfully to treat AMD flow are essentially mechanical devices that release powdered or slurried alkaline material into the AMD flow or streams. These dosers are capable of adjusting dosages in streams with substantial variations in flow and pH (hydrogen ion loads). The most commonly used devices for dosing lime (limestone, quicklime, and hydrated lime) are the electrically powered doser, the water power doser, and the rotary drum. Although commercially available dosers can handle varying stream sizes, flows and locations, water powered dosers, rotary drum dosers and even battery powered dosers may be sensitive to freezing during winter months (22). Additionally, frequent maintenance is required for successful operation of most stream liming dosers.

The three types of liming dosers identified above, the delivery system for limestone fines, and dispensers for caustic soda and soda ash are described in the following subsections.

#### **3.2.1.2.1 Electrically Powered Dosers**

Electrically powered dosers are composed of an alkaline material storage bin, a feeder screw



operated by battery or commercially available power, an automated dose control mechanism, and a distribution pipe that dispenses the powder to the stream. Typically, the limestone/lime feed is automatically regulated by either the water level in the stream or by pH. As the water level fluctuates, varying amounts of dry powdered material are transported to the storage bin, via the feeder screw, to a conveyor belt. This belt, located within a pipe, transfers the material to the point of distribution above the center of the stream. Some dosers slurry the material with stream water on-site prior to dispensing. Water is pumped from the stream to the slurry tank where it is mixed with the limestone/lime powder. The resultant slurry is pumped to a dispersion well located in the streambed, mixed with additional stream water, and dispersed just below the stream surface. Some dosers store and disperse a commercially prepared slurry of extremely fine limestone powder into streams. The slurry is pumped directly from a storage tank to a Y-connection where it is diluted with water before dispersal. The slurry in the tank is stirred frequently to avoid sedimentation. The most common of these types of dosers are operated by commercially available power. Battery-operated systems are sometimes used in remote locations. Because of power limitations, these are typically smaller installations with storage bins filled manually with bagged alkaline material.

#### 3.2.1.2.2 Water Powered Dosers

With water powered dosers, regulated streamflow controls the dispersion of alkaline material. The dosers are installed either in or adjacent to a stream and operate using either bucket feed mechanisms or an apparatus similar to a paddle wheel that turns an auger. The most common water powered doser consists of a storage bin with a small opening in the bottom, a conveyor belt, and a rocker arm with a hammer mechanism at one end, and a tipping bucket at the other end. A small portion of the stream flow is diverted through a pipe or trough into the bucket attached to the rocker arm. As the bucket fills with water, a continuous flow of alkaline material is gravity-fed to a conveyor belt located a few inches below the mouth of the material storage bin. When the bucket is filled with the stream water, it tips over, causing the conveyor belt to spill limestone or lime into the bucket. The movement of the bucket also causes the hammer mechanism to strike the side of the storage bin, loosening any powder that had lodged onto the sides of the bin. Variations of the feeding mechanism are also commercially available.

MDNR installed four water-powered lime dosers along the North Branch Potomac River for stream restoration 3 to 5 years ago. The dosers have been operating approximately 2 years treating AMD and are producing pH levels of 6.5 or higher.

#### 3.2.1.2.3 Rotary Drum Dosers

Rotary drums are cylindrical containers filled with limestone aggregate. They are powered by water diverted from the stream and directed across a sluiceway. In the bottom of the sluice are openings

located directly above each drum. As water falls through the openings in the sluice, blades attached to the exteriors of the drums initiate their rotation, as in a waterwheel. Limestone aggregate is either manually loaded into each drum or automatically fed to the drums through the reciprocating feeder at the bottom of a hopper. In these self-feeding drum systems, a flexible shaft is used to convey power directly from the rotating drum shaft to the reciprocating feeder. The speed at which the drums rotate as well as the amount of aggregate supplied to the drum and ultimately to the stream, are controlled by the volume of water passing through the sluiceway. Thus, within the capacity of the drum, the amount of limestone needed to maintain a target pH/alkalinity is available regardless of flow conditions. Grinding of the limestone aggregate within the drum is a wet autogenous process (i.e., the process uses the aggregate itself as the abrasive agent). The aggregate is then mixed with sluice water entering the drums through tiny holes in the drum exterior. The drum rotation causes abrasion, which produces fines that are released into the stream through the same holes in the drum exterior. Recent developments include the use of screens with various mesh sizes to control particle size. Output of the produced fines is controlled by the screen size and the rotation speed (rpm) of the drum. Several drums can be operated in series, with increased water flow increasing the number of drums in operation.

One limitation of the water-powered drum doser is a minimum flow requirement through the drum. This minimum flow ranges from 0.02 to 5.2 cubic meters per second (derived empirically) depending on the amount of limestone being dosed and the number of drums used.

#### 3.2.1.2.4 Delivery System for Limestone Fines

Limestone fines are used to neutralize an acid stream. Information from various studies indicate that sand sized limestone (0.063 to 6.3 mm range particle size) works well in neutralizing stream acid (22, 23).

The delivery system provides for limestone fines to be applied directly to streambeds using a dump truck and a dozer. Typically, the amount of fines dumped is two times the acid load in the stream. Limestone fines applied to the streambed may not provide prolonged neutralization and may not successfully treat episodic floods and maintain a pH >6.0. As such, limestone fines may have to be applied once yearly. However, in some cases, fines have lasted as long as three to four years and continue to provide neutralization.

Since trucks are used for transporting and dumping limestone fines onto the streambed, suitable access to the site is necessary.

Using a dual treatment system, a doser plus streambed application of limestone fines, would make the use of dosing equipment much more feasible for year-round operation of AMD treatment.

#### 3.2.1.2.5 Dispenser for Caustic Soda (NaOH)

The conventional system consists of a horizontally mounted 10,000 gallon storage tank for caustic soda, and a flume-type chemical feeder. Gravity serves as the source of power, with a constant head valve in the chemical feeder controlling a constant feed. Some feed options that are available for this system are: variable chemical feed pump with pH probe controller; solenoid valve with pH probe controller (gravity); and constant chemical feed pump with electric pinch valve and pH probe control (19).

#### 3.2.1.2.6 Soda Ash Dispenser

Soda ash is produced in a solid pellet form called briquettes, and is used in gravity fed devices composed of a hopper mounted over a basket. The number of briquettes to be used each day is determined by the rate of flow and the quality of water to be treated (19, 21)

For short-term, isolated cures, some operator's use a much simpler system that employs a box or barrel with water inlets and outflows. The operator simply fills the box or barrel with briquettes on a regular basis. This system has less control on the amount of chemical used. This method of treatment is controlled by dissolution of the briquettes. Depending upon the acidity in the drainage, the final treated water may not be within desired pH range. It is also to be noted that drainages with significant iron concentration may cause the briquettes to be coated, rendering them ineffective (19, 21).

### 3.2.2 Passive Treatment Systems

Passive treatment of AMD has been demonstrated as a feasible alternative to conventional chemical treatment in some cases; however, the technology is still evolving. As stated previously, passive treatment systems use more naturally occurring biological and chemical processes such as bacterial sulfate reduction and limestone dissolution, to neutralize acidity and decrease metal concentrations. Compared to conventional chemical treatment, passive methods generally require more land area, but may utilize less costly reagents and require less operational attention and maintenance.

Design of any of the seven passive treatment systems identified previously typically requires an understanding of significant site characteristics such as available area, topographic features, and site hydrology as well as properties of the AMD to be treated. Of particular concern are the following AMD properties:

- Flow Rate (maximum and minimum)

- Acidity and Alkalinity
- Total Ferric and Ferrous Iron Concentrations
- Manganese Concentration
- Aluminum Concentration
- Dissolved Oxygen Content
- Suspended Solids Content

The performance of systems using limestone for treatment are impacted by the calcium carbonate content of the limestone and limestone dissolution rate; therefore, these parameters also require consideration during design.

### **3.2.2.1 Anoxic Limestone Drain (ALD)**

An ALD is a buried bed of crushed limestone aggregate through which acidic water can be diverted to increase pH and alkalinity. The drain is designed to maintain an anoxic environment within the limestone. Ideally, the drain should be a pool and should be completely full so that as water is added at the inlet end, water at the outlet end overflows through an airtrap outlet (pipe with double elbow). In plan view, the shape of an ALD typically is narrow (typically 2 to 9 feet) and elongated like a drain. Lengths ranging from 100 to 2,000 feet have been reported (1). Most drains are 2 to 5 feet deep (1).

ALD's raise pH and add alkalinity to acid water under anoxic conditions. Once water exits the drain, the water is aerated and sufficient area must be provided for metal oxidation, hydrolysis, and precipitation to occur. The type and size of area required (e.g., ditch, settling pond, or wetland) depend on metal content of the water.

ALD's are applicable for water having a low dissolved oxygen content which can be maintained when the water is intercepted by the drain. They also may be applicable for water having a dissolved oxygen content greater than 2 mg/l if the metals content is low.

Limitations of the ALD technology are:

- Limestone and mine water must be kept anoxic.
- DO is  $\leq 2$  mg/l unless metal content is very low (2).
- Oxidation-reduction potential measurement, Eh, is zero or less (3).
- Ferric iron content is  $< 25$  mg/l (2).

- Aluminum content is  $< 25$  mg/l (1).
- Acidity is  $\leq 300$  mg/l unless flow from the ALD will pass through another treatment facility designed for alkalinity addition (e.g., anaerobic wetland, APS, etc.) (3).
- Generates alkalinity in water of up to 300 mg/l when functioning properly (3).
- Need facility at discharge end for metals precipitation. Sufficient area must be available for metal precipitation.
- Typically limited to flow rates  $\leq 100$  gpm. ALD's may be feasible for flow rates greater than 100 gpm if space is available and the water has low levels of iron, manganese, and aluminum. Experience with flow rates up to 500 gpm has been reported by others. Higher success rates have been demonstrated with flow rates  $\leq 100$  gpm (1).
- The limestone is subject to armoring and clogging. Armoring reduces limestone dissolution by 80% (will dissolve at 20% maximum efficiency when armored) (5).
- If internal water velocities are too slow to carry aluminum hydroxides out of the drain, the drain will be subject to clogging.
- If sulfate is present in concentrations much above 2,000 ppm, it will begin precipitating as gypsum (4).

ALD's have been used for AMD treatment since the mid 1980's. Skousen (Reference #1) reported in 1991 that the technology was a relatively recent discovery and that 50 ALD's had been installed in the Appalachian states as of fall, 1991. An ALD designed by Michael Baker, Jr., Inc. was installed in Webster, West Virginia in 1984 to treat AMD from an abandoned coal refuse site on an experimental basis. This ALD is still treating site AMD effectively.

### **3.2.2.2 Aerobic Wetland**

An aerobic wetland is a simple wetland that is used to collect water and provide residence time so that metals in the water can precipitate. Consequently, they promote mixed oxidation and hydrolysis reactions. The water usually has net alkalinity and metals precipitate as the water is held within the wetland. Alkalinity is needed to not only elevate pH and thereby facilitate metals precipitation, but also to avoid a major pH drop due to ferrous iron oxidation, hydrolysis, and precipitation.

Constructed aerobic wetlands typically consist of: 1) a basin having a natural or constructed low permeability barrier of soil or geosynthetic material to minimize seepage, 2) the substrate such as soil or another suitable medium overlying the barrier to support emergent vegetation (e.g., cattails), and 3) water flowing over the soil surface. Sometimes aerobic wetlands are equipped with aeration structures such as a rock-lined waterfall or a stair-step structure to increase the dissolved oxygen content of the inflowing water.

Skousen reports that wetland species are planted in these systems for aesthetics and to add some organic matter, but the organic matter is not necessary to the function of the system. (8) However, Skousen also reports that the most important role wetland plants serve in AMD treatment systems may be their ability to stimulate microbial processes. (2) Plants provide sites for microbial attachment, release oxygen from their roots, and supply organic matter for heterotrophs.(6)

Aerobic wetlands are applicable when the inflowing water is net alkaline and sufficient area is available for wetland installation.

Limitations of this technology are:

- After AMD passes through this type of wetland, the water may still require additional chemical treatment but may require a lower amount of chemical (2).
- Net alkaline water is required (alkalinity > acidity) (7).
- A circumneutral pH greater than 5 (e.g., 6 to 8) is required.
- Because aeration only provides enough oxygen to oxidize about 50 to 70 mg/l of ferrous iron to ferric iron, water with higher concentrations of ferrous iron will require operation of a series of aeration units-wetland cell combinations (7).
- Can require considerable area, depending on water flow rates and metal concentrations.
- Typically, gently sloping sites will be required. Otherwise, a considerable amount of earthwork may be required.
- The wetland system eventually will fill up with metal precipitates and may require reconstruction (removal of sediments) or replacement. The rate at which precipitates will accumulate is site and AMD specific but measurements at wetlands for AMD treatment in Ohio and Pennsylvania indicate increases in sludge depth of 3 to 4 cm/yr and 2 to 3 cm/yr, respectively (9).

Wetlands have been used for decades in the treatment of municipal wastewater, but only within the last 10 years have they received serious attention for treatment of AMD. Researchers have documented many sites where AMD has been improved after passing through natural and constructed wetlands (2).

### **3.2.2.3 Anaerobic Wetland**

Anaerobic wetlands are referred to as “compost wetlands”. A compost wetland adds alkalinity and is provided when the mine water does not have enough alkalinity to buffer the acidity produced by metal hydrolysis reactions. This type of wetland is similar to the simple aerobic wetland except that it has a thick organic substrate through which inflowing water can be directed. The substrate typically has a high calcium carbonate content, approximately 10% measured on a dry weight basis. Sometimes a layer of crushed limestone is included below the organic substrate and incoming flow is directed into the limestone. Flow then emanates upward into the organic compost layer (also laterally outward if the limestone does not extend across the full length of the wetland).

Four processes occur within a constructed wetland of this type, each having the ability to remove metals from acid drainage. Metal removal results from: 1) plant uptake, 2) adsorption to organic substrates, 3) oxidation and hydrolysis, and 4) microbial reduction processes through the metabolism of anaerobic bacteria. Bacteria reduce sulfate into sulfide which can then combine with hydrogen and iron. The net gain is an increase in pH and alkalinity, and a decrease in metals and acidity (8). Thus, compost wetlands generate alkalinity through a combination of bacterial activity (bacterial sulfate reduction) and carbonate dissolution.

Anaerobic wetlands are applicable when the inflowing water is net acidic and sufficient area is available for wetland installation.

Limitations of this technology are:

- If the pH of the inflow is  $< 3$ , limestone addition to the substrate will be required (7).
- $DO \leq 2$  mg/l will be required if a limestone layer is provided below the organic compost and inflow is directed into the limestone layer.
- Wetland performance is affected by temperature. Lower rates of acidity and metal removal occur in winter than in summer, particularly if subsurface flow is not achieved (10, 11).
- Can require considerable area, depending on water flow rates and metal concentrations.

- Typically, gently sloping sites will be required. Otherwise, a considerable amount of earthwork may be required.
- Freeboard should provide for accumulation of metals and additional organic matter. Although some organic matter will be added to the wetland naturally, the filtering capacity of the organic substrate will ultimately be finite as all exchange and complexation sites become metal saturated. Substantial inputs of organic matter could be required. Also, accumulation of sediments over and within the substrate could reduce substrate permeability.
- The wetland system eventually will fill up with metal precipitates and may require reconstruction (removal of sediments) or replacement.
- If sulfate is present in concentrations much above 2,000 ppm, it will begin precipitating as gypsum (4).

As stated previously, wetlands have been considered and implemented for AMD treatment for the last 10 years.

#### **3.2.2.4 Alkalinity Producing Systems (APS or SAPS)**

An APS combines the ALD and anaerobic wetland technologies and is used when the raw water is acidic and has a dissolved oxygen (DO) content greater than 2 mg/l. Basically, an APS is a pond having the following materials installed at the bottom of the pond (listed in ascending order): 1) pipe underdrain system, 2) limestone layer overlying and surrounding the pipe system, and 3) layer of organic material. The pond is designed to provide for 4 to 8 feet of ponded water over the organic material. The semi-aerated water is introduced at the top of the pond. Water percolates through the organic material under its own head (4 to 8 feet of water) and any ferric iron in the water is either filtered out by the organic material or reduced by microbial iron reduction to ferrous iron. The reduced (oxygen poor) water then continues downward into the limestone, picking up additional alkalinity by limestone dissolution. The water then outflows through the pipe underdrain at the bottom of the APS. As with the ALD technology, the outflow is then aerated and metals removed by a sedimentation pond, wetlands, etc. For applications involving highly acidic water and/or area limitations, successive Alkalinity Producing Systems (i.e., APS followed by a sedimentation pond/wetland), SAPS, are used.

Limitations of this technology are:

- The organic layer must be porous and may limit discharge from the facility.



- Can require considerable area depending on water flow rates, net acidity, and metal concentrations, and consequently, the need for a system of successive APS (SAPS).
- Typically, gently sloping sites will be required. Otherwise, a considerable amount of earthwork may be required.
- Freeboard should provide for accumulation of metals and additional organic matter. The filtering capacity of the organic substrate will ultimately be finite as all exchange and complexation sites become metal saturated. Substantial inputs of organic matter could be required. Also, accumulation of sediments over and within the substrate could reduce substrate permeability.
- If sulfate is present in concentrations much above 2,000 ppm, it will begin precipitating as gypsum (4).

Kepler and McCleary (12) and Skousen (13) have reported four successful AMD passive treatment systems incorporating the APS/SAPS technology. The first system reportedly was installed in 1989.

#### **3.2.2.5 Limestone Ponds (LSP)**

A limestone pond (LSP) is a relatively new AMD passive treatment method whereby a treatment pond is constructed over an acidic seep or other acidic discharge for neutralization purposes. Limestone is placed at the bottom of the pond and water from the seep flows upward through the limestone. A free water surface is maintained over the limestone. A water depth of 4 to 10 feet is typical and is based on site specific features such as topography and characteristics of the water source (8).

LSP's raise pH and add alkalinity to acid water. They operate under anoxic conditions if the limestone is kept inundated. Once water exists the pond, the water is aerated and sufficient area must be provided for metal oxidation, hydrolysis, and precipitation to occur. The type and size of area required (e.g., ditch, settling pond, or wetland) depend on the metals content of the water.

LSP's are applicable when the raw water is acidic, has a low dissolved oxygen content and the source(s) is located at the pond site. An LSP may be applicable for water having a dissolved oxygen content greater than 2 mg/l if the metals content is low.

Limitations of this technology are:

- Limestone must be kept inundated with the mine water.
- DO is  $\leq 2$  mg/l unless metal content is very low.
- Eh is zero or less.
- Ferric iron content is  $\leq 25$  mg/l.
- Aluminum content  $< 50$  mg/l.
- Acidity  $\leq 300$  mg/l unless flow from the LSP will pass through another treatment facility designed for alkalinity addition (e.g., anaerobic wetland, APS, etc.).
- Need facility at discharge end for metals precipitation. Sufficient area must be available.
- Flow rate limitations presented for an ALD apply to the LSP
- The limestone is subject to armoring and clogging. Armoring reduces limestone dissolution by 80%. If armoring/clogging occurs, the limestone will require periodic stirring with a backhoe to either uncover the limestone from precipitates or to knock or scrape off the precipitates. The pond width and depth should be selected to allow a backhoe access to all areas of the pond bottom.
- If sulfate is present in concentrations much above 2,000 ppm, it will begin precipitating as gypsum (4).

### **3.2.2.6 Reverse Alkalinity Producing Systems (RAPS)**

A RAPS represents a combination of the APS (Alkalinity Producing System) and LSP (Limestone Pond) technologies. It consists of a pond installed over a seep or water discharge point similar to a LSP except that the RAPS is designed for raw water that is not anoxic. A layer of organic material is placed in the bottom of the pond and is overlain by a layer of limestone. Since water flows up from the pond bottom (below the organic material), metals in the raw water can be filtered and adsorbed as they pass through the organic material, microbial iron and sulfate reduction can occur, and the oxygen content of the water can be decreased by microbial decomposition of the organic material (8). The water then continues upward through the limestone, picking up more alkalinity. Treated water flows out of the RAPS through an open channel spillway.

Once water exits the RAPS, the water is aerated and sufficient area must be provided for metal

oxidation, hydrolysis, and precipitation to occur. The type and size of area required (e.g., ditch, settling pond, or wetland) depend on the metals content of the water.

A RAPS is applicable when the raw water is acidic, has a dissolved oxygen content greater than 2 mg/l and when the AMD source(s) is located at the pond site.

Limitations of this technology are:

- The organic layer must be porous.
- Typically, gently sloping sites will be required. Otherwise, a considerable amount of earthwork may be required.
- The filtering capacity of the organic substrate will ultimately be finite as all exchange and complexation sites become metal saturated. Reductions in permeability leading to clogging will occur. When this occurs, replacement of the organic material and overlying limestone will be required.
- If sulfate is present in concentrations much above 2,000 ppm, it will begin precipitating as gypsum.

Historical data documenting use of the RAPS technology has not been reported.

#### **3.2.2.7 Open Limestone Channels (OLC)**

OLCs were introduced in a fall 1994 Green Lands article as another possible solution of introducing alkalinity to acid water (8). Long channels lined with limestone are used to convey acidic water to a stream or other discharge point. Culverts, diversion/collection channels, stream channel, etc., may be lined with the finely or coarsely graded crushed limestone. Water neutralization and some metals precipitation occur within the channel; however, depending on the metals content of the raw water, discharge will have to pass through a sedimentation pond or aerobic wetland prior to discharge to the receiving stream.

OLCs' are applicable when the raw water is acidic and where long channels can be constructed between the source and receiving stream or other point of discharge.

Limitations of this technology are:

- Sufficient distance must be available between the source and ultimate point of discharge to

facilitate construction of a channel long enough to provide the retention time needed for neutralization. Otherwise, discharge from the channel will have to be directed to another type of treatment facility for alkalinity addition (e.g., anaerobic wetland, APS, etc.).

- Some metals precipitation will occur within the channel and armor the limestone, thereby reducing the effectiveness of the limestone (5, 8).
- Sufficient metals precipitation may not/should not occur within the channel; therefore, a settling pond or aerobic wetland should be provided at the downstream end of the channel.
- May need facility at discharge end for metals precipitation. Sufficient area must be available.
- The limestone is subject to armoring, clogging, and even burial in gently sloping channel sections where water velocities are low. Armoring reduces limestone dissolution by 80%. If armoring/clogging occurs and system performance is reduced to unacceptable levels, the limestone will have to be stirred with a backhoe to either uncover the limestone from precipitates or to knock or scrape off the precipitates (5, 8).
- If sulfate is present in concentrations much above 2,000 ppm, it will begin precipitating as gypsum (5).

Ziemkiewicz, Skousen, and Lovett surveyed five abandoned mine land sites in northern West Virginia where channels of open limestone were used to conduct acid water from the sites. Acidity reduction was noted at all of the sites and some of the channels achieved 100% acidity reduction. All of the channels are relatively short (< 800 ft.). Results of the survey are presented in Reference 5.

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## SECTION 4.0

### REMEDICATION OF STUDY SITES - FEASIBILITY EVALUATIONS

Section 3.0 of this report presents an overview of available AMD treatment technologies. Seven passive treatment systems are described in that section of the report and all of these passive systems are applicable for long-term treatment of AMD. Conventional treatment systems also are applicable for long-term treatment; however, of the six chemicals described in Section 3.0, only two chemicals, limestone and quicklime are used for long-term treatment. The other chemicals, hydrated lime, soda ash, caustic soda, and ammonia, are effective in treating AMD but are generally limited to short-term applications because of cost. Since long-term remediation is the focus of this study, only mitigation technologies that are applicable for long-term treatment will be evaluated relative to site remediation. They are:

#### Passive Technologies

- Anoxic Limestone Drain (ALD)
- Aerobic Wetland
- Anaerobic Wetland
- Alkalinity Producing Systems (APS or SAPS)
- Limestone Ponds (LSP)
- Reverse Alkalinity Producing System (RAPS)
- Open Limestone Channels (OLC)

#### Conventional Technologies - (Addition of following Chemicals by Either Dosing or Direct Application to the Stream)

- Limestone Fines Application to Stream
- Limestone Dosing Using a Rotary Drum Type Doser
- Quicklime/Limestone Dosing Using Other Doser Types

Technical feasibility of these long-term mitigation technologies for a specific application is controlled primarily by AMD properties and, for passive treatment systems, site characteristics such as available land area. Parameters that may limit technology feasibility are:

#### AMD Properties

- Flow rate in gpm

- Dissolved Oxygen in mg/l
- pH
- Eh
- Acidity in mg/l
- Alkalinity in mg/l
- Total Iron in mg/l
- Ferric Iron in mg/l
- Ferrous iron in mg/l
- Manganese in mg/l
- Aluminum in mg/l
- Sulfate in mg/l

#### Site Constraints

- Insufficient Area
- Gradient Too Steep
- Gradient Too Gentle

AMD properties and topographic characteristics of each site were compared with limitations of the various long-term mitigation technologies to identify technically feasible site remediation alternatives. Comparisons of AMD properties at each site with technology limitations are presented on Tables 4-1 through 4-7. When site AMD properties exceeded limitations of a particular mitigation technology, that technology was identified as not feasible for implementation at the site in question and was eliminated from further consideration for site remediation. Technologies identified as feasible with respect to AMD properties also were screened relative to site constraints. Mitigation technologies found to be compatible with both groups of screening criteria (AMD and site characteristics) have been identified as technically feasible for the site conditions evaluated. Table 4-8 documents results of the technology screening process for the seven study sites by identifying elimination criteria for each technology. Technologies not having an elimination criterion are considered to be technically feasible for the site evaluated. Decision tracking for each site is summarized on Tables 4-9 through 4-15.

Possible remediation alternatives for each study site were developed based on the technically feasible mitigation technologies. AMD control technologies identified in Section 3.0 were incorporated where applicable. Economic feasibility of each site remediation alternative was evaluated based on cost. Cost estimates were prepared for each alternative to a conceptual level of detail and these estimates include both capital and operation/maintenance costs.

Each study site is described in the following subsections. Each site has been identified by the same site numbers provided in the "Morgan Report". Accompanying each site description is an



**TABLE 4-4**  
**MARYLAND SITE #3 - KEMPTON MINE**  
**PHYSICAL PARAMETER LIMITATIONS OF MITIGATION TECHNOLOGIES**

Physical Parameters	Meas. Values, Max/Min (h)	Design Limits									
		ALD	Aerobic Wetland	Anaerobic Wetland	SAP/APS	LSP	RAPS	OLC	Limest. Fines	Dosing Quick Lime/Limest.	
Flow, gpm	1212/885 (i)	< 500 (b)	(j)	(j)	(j)	< 500 (b)	(j)	(a)	*	> 4 cfs (m)	
D.O., mg/l	1.8/1.1	< 2 (f)	*	> 2 (e)	> 2	< 2 (f)	> 2	*	*	*	
pH	3.8/3.2	< 5	> 4	> 3 (d)		< 5		*		*	
Acidity, mg/l	573/253	< 300 (g)	NET	(j)	NET	< 300 (g)	NET	*	NET	NET	
Alkal., mg/l	0/0	*	ALK. (l)	*	ACIDIC	*	ACIDIC	*	ACIDIC	ACIDIC	
Tot. Fe, mg/l	71.7/60	*	(j)	(j)	*	*	*	*	*	*	
Fe <sup>+++</sup> , mg/l	0	< 25	(j)	(j)	*	< 25	*	*	*	*	
Mn, mg/l	6.2/5.8	*	*	*	*	*	*	*	*	*	
Sulfate, mg/l	589/409	< 2,000	*	< 2,000	< 2,000	< 2,000	< 2,000	< 2,000	< 2,000	< 2,000	
Al, mg/l	22/11.6	< 25	*	*	*	< 25	*	*	*	*	
Eh		< 0	*	*	*	< 0	*	*	*	*	
Fe <sup>++</sup> , mg/l	71.7	*	< 70 (c)	(j)	*	*	*	*	< 100 (k)	< 100 (k)	

\* = Not applicable or not available.

- (a) Based on channel length & width restrictions and req'd contact time. 100% neutralization can be achieved with a 3-hr residence time; 90% with 1-hr.
- (b) Little experience with flows greater than 500 gpm. Suitability for flows greater than 100 gpm based on low Fe, Mn, and Al levels.
- (c) Unless series of aeration unit - wetland cell combinations is provided.
- (d) > 3 for anaerobic wetland unless limestone is added to the substrate, in which case, pH < 3 is OK.
- (e) Organic layer strips DO.
- (f) Unless the metals content is very low.
- (g) Unless discharge from it will pass through another treatment facility involving alkalinity addition.
- (h) Does not represent air shaft discharge.
- (i) Total discharge from site is this maximum value plus air shaft flow of 1,347 gpm.
- (j) Restricted by available area at the site.
- (k) If > 50 mg/l, may require post neutralization aeration & significant reaction retention.
- (l) Acidic if pre-treatment precipitation is required.
- (m) Drum doser.

**TABLE 4-5**  
**MARYLAND SITE #36 - SHALLMAR MINE**  
**PHYSICAL PARAMETER LIMITATIONS OF MITIGATION TECHNOLOGIES**

Physical Parameters	Meas. Values, Max/Min (b)	Design Limits												
		ALD < 500 (b)	Aerobic Wetland (j)	Anaerobic Wetland (j)	SAP/APS (j)	LSP < 500 (b)	RAPS (j)	OLC (a)	Limest. Fines *	Dosing Quick Lime/Limest. > 4 cfs (m)				
Flow, gpm	395.6/210													
D.O., mg/l	4.1 (i)	< 2 (f)	*	> 2 (e)	> 2	< 2 (f)	> 2	*	*	> 2	*	*	*	*
pH	4.5/3.7	< 5	> 4	> 3 (d)		< 5		*	*		*	*	*	*
Acidity, mg/l	288/21	< 300 (g)	NET	(j)	NET	< 300 (g)		*	*	NET	*	NET	NET	NET
Alkal., mg/l	1/0	*	ALK. (l)	*	ACIDIC	*		*	*	ACIDIC	*	ACIDIC	ACIDIC	ACIDIC
Tot. Fe, mg/l	2.61/0.19	*	(j)	(j)	*	*		*	*	*	*	*	*	*
Fe <sup>+++</sup> , mg/l	1.82/0	< 25	(j)	(j)	*	< 25		*	*	*	*	*	*	*
Mn, mg/l	0.44/0.23	*	*	*	*	*		*	*	*	*	*	*	*
Sulfate, mg/l	463.6/132	< 2,000	*	< 2,000	< 2,000	< 2,000		< 2,000	< 2,000	< 2,000	< 2,000	< 2,000	< 2,000	< 2,000
Al, mg/l	16.67/4.57	< 25	*	*	*	< 25		*	*	*	*	*	*	*
Eh		< 0	*	*	*	< 0		*	*	*	*	*	*	*
Fe <sup>++</sup> , mg/l	0.79/0.19	*	< 70 (c)	(j)	*	*		*	*	*	*	< 100 (k)	< 100 (k)	< 100 (k)

\* = Not applicable or not available.

- (a) Based on channel length & width restrictions and req'd contact time. 100% neutralization can be achieved with a 3-hr residence time; 90% with 1-hr.
- (b) Little experience with flows greater than 500 gpm. Suitability for flows greater than 100 gpm based on low Fe, Mn, and Al levels.
- (c) Unless series of aeration unit - wetland cell combinations is provided.
- (d) > 3 for anaerobic wetland unless limestone is added to the substrate, in which case, pH < 3 is OK.
- (e) Organic layer strips DO.
- (f) Unless the metals content is very low.
- (g) Unless discharge from it will pass through another treatment facility involving alkalinity addition.
- (h) Does not represent individual treatment locations. Representative of flows discharging from the site.
- (i) Only represents one individual treatment location.
- (j) Restricted by available area at the site.
- (k) If > 50 mg/l, may require post neutralization aeration & significant reaction retention.
- (l) Acidic if pre-treatment precipitation is required.
- (m) Drum doser.

TABLE 4-8  
ELIMINATION CRITERIA FOR MITIGATION TECHNOLOGIES BY SITE

Mitigation Technology	Site #38 Kitzmilller	Site #3 Kempton	Site #36 Shallmar	Site #43/45 Vindex	Bismarck Site #23 & 23A	Mt. Storm Site #25 & #25A	Site #22 Allison
ALD	2, 5, 7, 9	5, 9	2, 7, 9	2, 5, 9, 12			
Aerobic Wetland	6, 7, 9	6, 9		6, 7, 9	6, 9	6	
Anaerobic Wetland	7, 9	2, 9	7, 9	7, 9	2, 9, 11		2, 12
SAPS/APS	7, 9	2, 9	7, 9, 15	2, 9	9, 11	9, 15	2, 12, 15
LSP	2, 5, 7, 9	9, 12	2, 7, 9, 15	2, 5, 7, 9, 12	9, 15	2, 12	5, 12
RAPS	7, 9	2, 9	7, 9, 15	7, 9	9, 15	9, 15	2, 5, 15
OLC		9, 15	7, 9	9	9, 15		
Limest. Fines	13		13, 15	13	5, 9, 15	5, 15	
Dosing Quick Lime/Limest.					5, 11, 14, 15	5, 11, 14, 15	5, 11, 14

- Criteria:
1. Aluminum Concentration
  2. D.O. Concentration
  3. Fe+++ Concentration
  4. Eh Potential
  5. Flow Rate
  6. pH, alkalinity
  7. Gradient Too Steep
  8. Gradient Too Gentle
  9. Insufficient Area
  10. Low Reaction Time
  11. Costly
  12. Acidity too high, secondary additional alkalinity addition required and no space available.
  13. Inaccessible by dump truck.
  14. Electricity not available.
  15. Source location characteristic.

**TABLE 4-12**  
**MARYLAND SITE #3 - KEMPTON MINE**  
**DECISION TRACKING FOR MITIGATION TECHNOLOGIES**

	<b>ALD</b>	<b>Wetland</b>	<b>SAP/ APS</b>	<b>LSP</b>	<b>RAPS</b>	<b>OLC</b>	<b>Limestone Fines</b>	<b>Dosing Quick Lime/Limestone</b>
<b>Precluded by Chemistry/Flow?</b>	Yes	Yes	Yes	Yes	Yes	No	No	No
<b>Precluded by Available Area?</b>	Yes	Yes	Yes	Yes	Yes	Yes	No	No

**TABLE 4-13**  
**MARYLAND SITE #36 - SHALLMAR MINE**  
**DECISION TRACKING FOR MITIGATION TECHNOLOGIES**

	<b>ALD</b>	<b>Wetland</b>	<b>SAP/ APS</b>	<b>LSP</b>	<b>RAPS</b>	<b>OLC</b>	<b>Limestone Fines</b>	<b>Dosing Quick Lime/Limestone</b>
<b>Precluded by Chemistry/Flow?</b>	Yes	No	No	Yes	No	No	No	No
<b>Precluded by Available Area?</b>	Yes	No*	Yes	Yes	Yes	Yes	Yes	No

\*Except for location where aerobic wetland is suitable.