

Passive Treatment Systems

for Acid Mine Drainage

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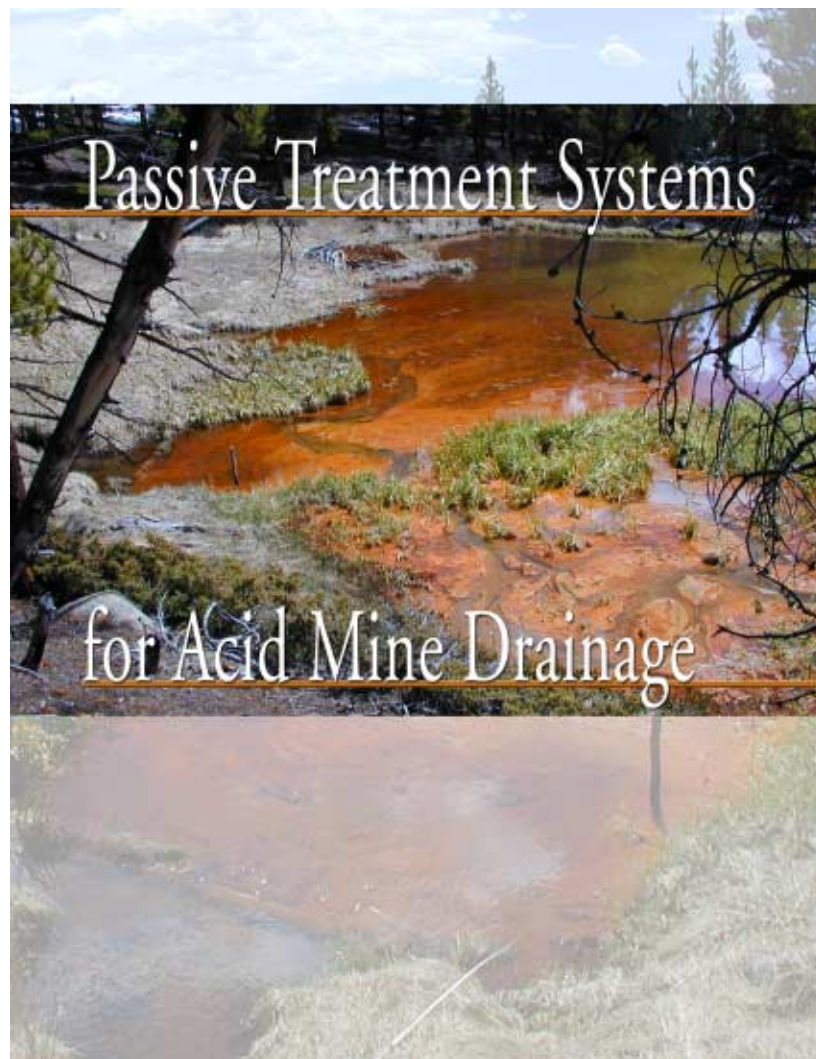
Janine Koselak: Layout and Design
Linda Hill: Editing

Lee Barkow, Director
National Science & Technology Center
P.O. Box 25047
Denver, Colorado 80225-0047

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by:

K.L. Ford
Bureau of Land Management
National Science and Technology Center



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Abstract

PASSIVE TREATMENT SYSTEMS provide an alternative method for removing metals from acid mine drainage. There are several types of passive treatment systems; they may be used on their own or in combination to treat difficult effluents. The type of system selected is dependent upon the chemistry of the acid mine drainage and the flow of the discharge, as well as State and Federal regulations. Passive treatment systems do not require power and are less expensive than active treatment systems. They also require less maintenance, which makes them advantageous in remote locations.

Keywords

Abandoned mines
Acid mine drainage
Aerobic wetland

Anaerobic wetland
Passive treatment system
Water treatment





Introduction

THERE ARE MANY TYPES of water treatment systems available for removing metals from acid mine drainage. Passive treatment systems are a relatively new technology that involves using sulfate-reducing bacteria or limestone or both to neutralize acidity and precipitate metals. These systems are sometimes called “wetlands” or “bioreactors.” Passive treatment systems differ from active systems (water treatment plants), which commonly use power; use more hazardous chemicals such as hydrated lime, caustic soda, or ammonia; and are more expensive. Passive treatment systems are preferred for sites managed by the Bureau of Land Management (BLM). This Technical Note is intended to help BLM field personnel objectively evaluate the potential of passive treatment systems for treating flowing adits with acid mine drainage. It provides a brief overview of acid mine drainage and describes the types of passive systems available, type of site characterization needed to evaluate the use of passive systems, criteria for selecting a passive system, general design parameters, and expectations for performance.

Chemistry of Acid Mine Drainage

THE PENNSYLVANIA Department of Environmental Protection (1999) provides a comprehensive description of basic acid mine drainage chemistry, which is reprinted here with permission:

There are four commonly accepted chemical reactions that represent the chemistry of pyrite weathering to form AMD. An overall summary reaction is as follows:



Pyrite + Oxygen + Water → “Yellowboy” + Sulfuric Acid

The first reaction in the weathering of pyrite includes the oxidation of pyrite by oxygen. Sulfur is oxidized to sulfate and ferrous iron is released [equation 2]. This reaction generates two moles of acidity for each mole of pyrite oxidized.



Pyrite + Oxygen + Water → Ferrous Iron + Sulfate + Acidity

The second reaction involves the conversion of ferrous iron to ferric iron [equation 3]. The conversion of ferrous iron to ferric iron consumes one mole of acidity. Certain bacteria increase the rate of oxidation from ferrous to ferric iron. This reaction rate is pH dependent, with the reaction proceeding slowly under acidic conditions (pH 2-3) with no bacteria present, and several orders of magnitude faster at pH values near 5. This reaction is referred to as the “rate determining step” in the overall acid-generating sequence.



Ferrous Iron + Oxygen + Acidity → Ferric Iron + Water

The third reaction that may occur is the hydrolysis of iron. Hydrolysis is a reaction that splits the water molecule [equation 4]. Three moles of acidity are generated as a byproduct. Many metals are capable of undergoing hydrolysis. The formation of ferric hydroxide precipitate (solid) is pH dependent. Solids form if the pH is above about 3.5, but below pH 3.5, little or no solids will precipitate. [Other metals such as aluminum, manganese, and trace metals such as arsenic, cadmium, copper, lead, and zinc will also coprecipitate with iron, to some degree.]



Ferric Iron + Water → Ferric Hydroxide (yellowboy) + Acidity

The fourth reaction is the oxidation of additional pyrite [or other metals] by ferric iron [equation 5]. The ferric iron is generated in reaction steps 1 and 2. This is the cyclic and self-propagating part of the overall reaction and takes place very rapidly and continues until either ferric iron or pyrite [and other metals] is depleted. Note that in this reaction, iron is the oxidizing agent, not oxygen.

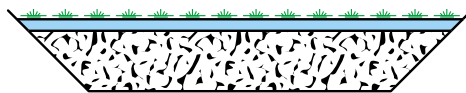


Pyrite + Ferric Iron + Water → Ferrous Iron + Sulfate + Acidity

Types of Passive Treatment Systems

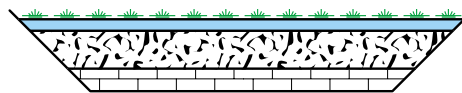
PASSIVE TREATMENT SYSTEMS provide a controlled environment in which natural chemical and biological reactions that help in the treatment of acid mine drainage can occur (Pennsylvania Department of Environmental Protection 1999). There are several types of passive treatment systems; some of the more common ones are shown in Figure 1. Each type may be used on its own, or more than one may be used in sequence to optimize treatment of difficult effluents. However, the design selected will ultimately depend upon site characteristics and other specific criteria.

A. Aerobic Wetlands



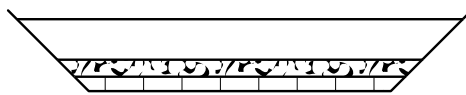
1-3 in. water
1-3 ft. organic matter

B. Anaerobic Wetlands



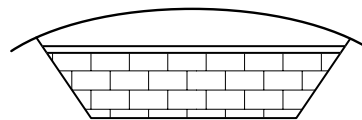
1-3 in. water
1-2 ft. organic matter
.5-1 ft. limestone

C. Successive Alkalinity Producing Systems (SAPS)



3-6 ft. water
6-12 in. organic matter
1-2 ft. limestone drainage system

D. Anoxic Limestone Drains (ALD)



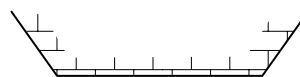
2-4 ft. soil
20-40 mil plastic liner surrounding or covering limestone trench or bed of limestone

E. Limestone Pond



3-6 ft. water
1-3 ft. limestone

F. Open Limestone Channel (OLC)



Small or large sized limestone placed along sides and in bottom of culverts, diversions, ditches, or stream channels

FIGURE 1. Schematic diagram of common passive treatment systems used to treat acid mine drainage (adapted with permission from Skousen 2001).

Aerobic wetlands are shallow (1- to 3-foot deep) ponds; they may be lined or unlined and some are nearly filled with soil or limestone gravel. They facilitate natural oxidation of the metals and precipitate iron, manganese, and other metals (equation 4). Anaerobic wetlands are used to neutralize acidity and reduce metals to the sulfide form (the reverse of equation 2). This reaction consumes H^+ and therefore acidity. Anaerobic wetlands may be lined or unlined shallow ponds filled with organic matter, such as compost, and underlain by limestone gravel. Water percolates through the compost and becomes anaerobic where equation 2 is reversed and metals precipitate as sulfides. Microorganisms facilitate this reaction by first consuming oxygen. Alkalinity and H_2S are produced. If the system is improperly sized, if flow dries up, or if extended low temperatures are encountered, the microorganisms will die and the performance will be decreased. Some anaerobic wetlands discharge a sulfide “sewage” effluent, particularly during the first few years.

Anoxic limestone drains consist of a buried limestone gravel system that requires the exclusion of oxygen and aluminum in the water. If oxygen or aluminum are present, iron and aluminum hydroxides clog the system, causing failure. Alkalinity producing systems are a combination of an anaerobic wetland and an anoxic limestone drain. Other types of passive treatment systems include various limestone treatment configurations, ranging from limestone ponds to open limestone channels in which water flows down a steep slope with limestone riprap. These systems oxidize and precipitate metals (equation 4) and add alkalinity to the water.

Another type of passive treatment system uses lime dispensing technology to neutralize acidity and precipitate metals in a settling pond. These units do not require power or hazardous chemicals and are inexpensive. BLM is currently conducting pilot tests on the Aquafix technology.

Passive treatment systems are a valuable option for treating acid mine drainage at remote BLM locations. The advantages of passive treatment systems are that they:

- do not require electrical power
- do not require any mechanical equipment, hazardous chemicals, or buildings
- do not require daily operation and maintenance
- are more natural and aesthetic in their appearance and may support plants and wildlife
- are less expensive

Of course, there are disadvantages with any water treatment system. The disadvantages of passive treatment systems are that they:

- may require complex discharge permits unless taking a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) action
- may not meet stringent water-quality-based effluent standards
- may fail because of poor design or severe winter conditions
- are a relatively new technology and an area of active research; as such, there have been failures along with success stories

All of the passive treatment systems described will accumulate metal precipitates and will eventually have to be replaced. Skousen (2001) and Hedin et al. (1994) indicate that these systems can be expected to perform for 20 years. The precipitate is not normally a hazardous waste. Nonetheless, regular monitoring, inspection, and maintenance are required, although to a much lesser extent than with active water treatment systems.

Site Characterization

SITE CHARACTERIZATION is exceedingly important because it is used to design passive treatment systems. Acid mine drainage is often characterized by acidic pH and orange-yellow precipitates (ferric hydroxides or “yellowboy”). The pH ranges from circumneutral to 2.5 and, uncommonly, even lower. It is not enough to perform routine metals analyses and measure pH to adequately characterize an acid mine drainage flow for the purpose of evaluating treatment systems. In addition to dissolved metals (including aluminum and manganese) and pH, it is necessary to measure dissolved oxygen, major cations, anions (especially sulfate), and iron couples (Fe^{+2} and Fe^{+3}) at the mine opening. In addition, alkalinity and acidity need to be measured. Acidity is contributed not only by pH, but also by iron, manganese, and aluminum. Alkalinity and acidity are both measured in mg/L calcium carbonate equivalence. The crucial determination is net alkalinity. Net alkalinity is total alkalinity minus acidity. In the worst acid mine drainage sites, net alkalinity may be negative (or acidity) if acidity exceeds alkalinity.

In addition to these chemistry parameters, it is crucial to measure flow rates and get a topographic survey of the site. Flows can be measured by simple



means, such as bucket and stopwatch, or more complicated methods, such as sharp-crested weirs, flumes, or current meters. It may be necessary to consult with a hydrologist to ensure accurate flow rates. Chemistry and flows should be measured seasonally for at least a year to understand the conditions necessary to select a treatment system. If tailings and rock dumps are present, they may require additional characterization (Ford 1999).

Selection Criteria

THE CHEMISTRY AND FLOW of the acid mine drainage discharge are critical to the proper selection of a system. Figures 2 and 3 show a selection scheme. Generally, net alkaline water is needed for an aerobic wetland. If the water is net acid but has low dissolved oxygen, ferric iron, and aluminum, an anoxic limestone drain may be selected. Higher concentrations of dissolved oxygen, ferric iron, and aluminum are more suited for anaerobic wetlands, successive alkaline producing systems (SAPS), or limestone channels. Anaerobic wetlands are normally six times larger (and more costly) than aerobic systems.

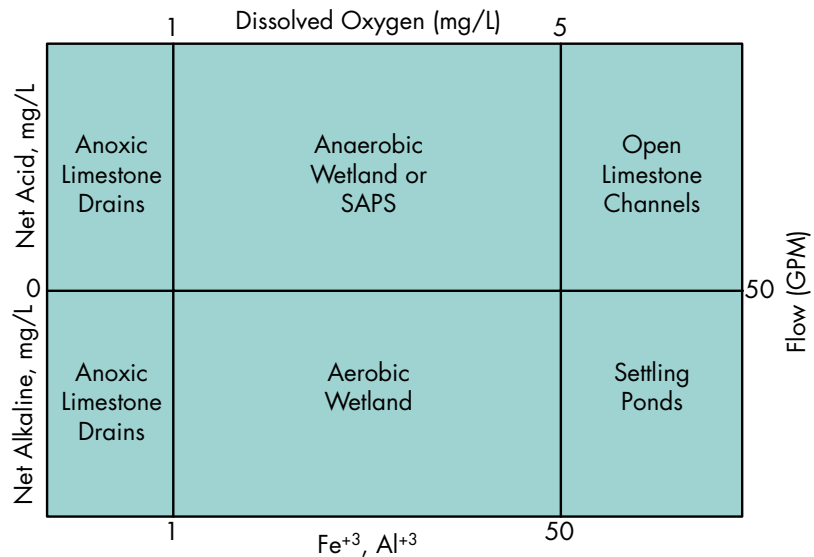


FIGURE 2. Passive treatment system selection.

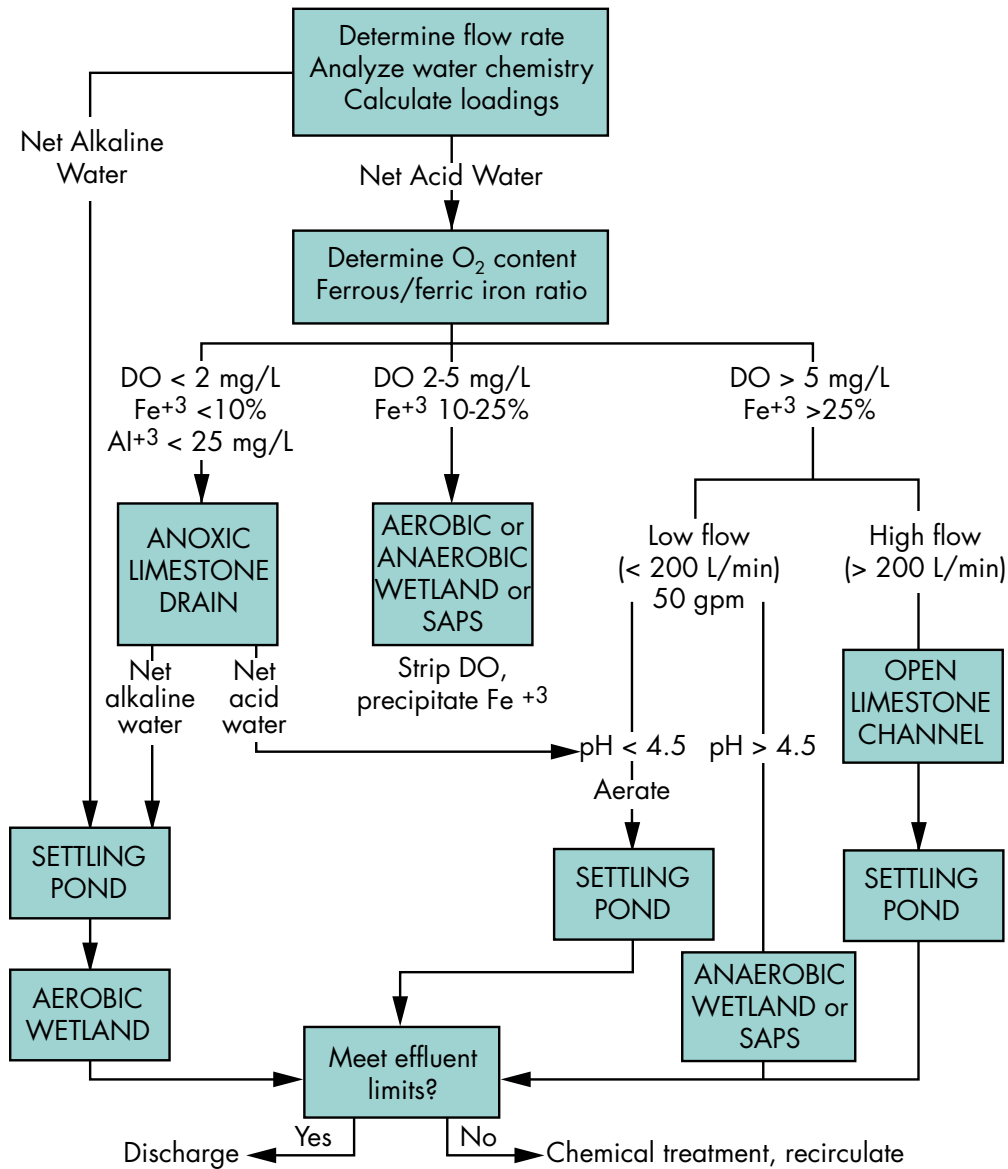


FIGURE 3. Flowchart for selecting a passive acid mine drainage treatment system based on water chemistry and flow (adapted from Hedin et al. 1994 and reprinted with permission from Skousen 2001.)

Conceptual Design

CONCEPTUAL DESIGN is used to evaluate the approximate size and cost of passive treatment systems. Passive treatment systems are often designed based on loadings of metal or acidity in grams per square meter per day



(g/m²/d). Grams/day is computed by multiplying the concentration in mg/L times the flow in gallons per minute times 5.47 (1 mg/L equals 5.47 g/day):

$$\text{mg/L} * 3.8 \text{ L/gal} * \text{flow gal/min} * \text{g/1000 mg} * 60 \text{ min/hr} * 24 \text{ hr/day} = 5.47 \text{ g/day} [6]$$

Aerobic wetlands are sized for 10 g of Fe/m²/d and 0.5 g Mn/m²/d to achieve 3 mg/L iron and 2 mg/L manganese. For example, if the Fe loading was 260 grams/day, dividing by 10 g/m²/day results in a wetland size of 26 m². Lower effluent concentrations can be sized proportionately. In the example, doubling the wetland size to 52 m² should reduce iron and manganese concentrations by half. Manganese is the limiting contaminant, as it requires 20 times more area per mg/L. Anaerobic wetland area is designed using an acidity loading factor of 3.5–7 g/m²/d (Hedin et al. 1994; Pennsylvania Department of Environmental Protection 1999). Anoxic limestone drain sizing is more complicated; additional details can be found in Pennsylvania Department of Environmental Protection's 1999 report. Open limestone channels are sized using 0.03–0.19 mg/L acidity per meter of channel length (Skousen 2001) with a slope of greater than 20 percent for optimum performance.

Gusek (1995) reports that the capital cost of passive wetlands ranged from \$0.32–\$0.46 per kg of metal removed, while for lime precipitation (an active system), capital cost ranged from \$0.66–\$0.89 per kg. (Note: these costs may not fully account for the added expense of remote locations typical of BLM sites). However, operation and maintenance costs ranged from 5–10 times higher for active systems.

Effluent Regulations and Expectations

THE ENVIRONMENTAL PROTECTION AGENCY (EPA) or the State may require a National Pollutant Discharge Elimination System (NPDES) permit for effluent from a passive treatment system entering waters of the State. The actual permit is not required if BLM is taking a CERCLA action; however, compliance with the State or EPA substantive requirements (e.g., effluent limitations) is required. The regulator has an option of requiring either a technology based effluent limitation or a water quality standards based

effluent limitation. Water quality standards based limitations are extremely stringent and most passive treatment systems will not achieve them, as they are equal to instream water quality standards for the protection of aquatic life and may require low parts per billion in metals concentration. (These standards are usually hardness based, so calcium and magnesium levels will have to be analyzed). Some States may allow mixing zones for dilution, thus relaxing the published standards.

However, technology-based standards may be achievable with a properly designed passive treatment system. In addition, passive treatment systems are allowed as a best practical technology (BPT) under the Clean Water Act. They were developed from the need to treat acid mine drainage from coal mines in States such as Pennsylvania and West Virginia where acid mine drainage is a severe problem. EPA has published BPT effluent limitations for treatment of wastewaters from coal mines in 40 CFR 440.30:

Parameter	Total Metal Concentrations (30-day average)
Iron	3.5 mg/L
Manganese	2.0 mg/L
pH	6–9 pH units

EPA has also published BPT effluent limitations for copper, lead, zinc, gold, and silver acid mine drainage sites in 40 CFR 440.102:

Parameter	Total Metal Concentrations (30-day average)
Copper	0.15 mg/L
Zinc	0.75 mg/L
Lead	0.3 mg/L
Mercury	0.001 mg/L
pH	6–9 pH units

Note: the regulations for flotation mills stipulate a cadmium limitation of 0.05 mg/L.

Several lessons have been learned from passive treatment systems constructed in the West with respect to performance expectations. Wetland systems relying on sulfate reduction are biologically based. Cold winters may kill the organisms



and reduce the effectiveness of the system. Anaerobic wetlands using compost or manure materials may generate odors and sewagelike effluent that creates another water quality problem.

Conclusion

IN SUMMARY, passive treatment systems have application in remote BLM sites where some treatment is necessary, but where a low-maintenance, cost-effective treatment system is desired. Since passive treatment systems are a relatively new technology, it is important to get an experienced designer to design the system. The source chemistry and flow over time, as well as the regulatory environment must be understood in order to make an informed decision when selecting a passive treatment system. Certain conditions, such as severe winters or dried-up flow, may affect the performance of certain passive treatment systems, especially anaerobic wetlands and successive alkaline producing systems where sulfate-reducing bacteria may die off. Sites with extremely low pH (<3) may not be fully amenable to limestone neutralization, and a more caustic reagent, such as caustic soda (NaOH), may be required. Since passive treatment systems are a relatively new technology, it may be desirable to construct a pilot treatment plant first to evaluate the performance (effluent quality) of the system. Finally, monitoring, inspection, and maintenance are still required for passive treatment systems and should not be overlooked.

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