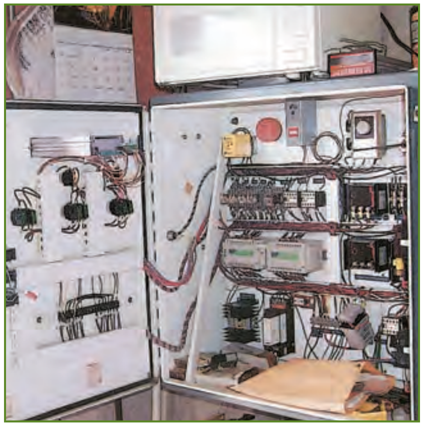
Slippery Rock Watershed Coalition

NATURALLY INNOVATIVE SOLUTIONS

The endeavor underway to restore the streams of Pennsylvania so that they may support fish poses several challenges. Cost, liability, and the risks associated with using experimental technology are just a few of the hurdles faced each day. In addition, every individual abandoned mine discharge is unique. Each discharge has a different flow, contains different dissolved metals, and has different levels of acidity and alkalinity. Unfortunately, there is not yet one cure-all method that can be applied to all mine discharges.



Typical equipment used to actively treat mine drainage (Photo courtesy of Robert Beran)

Active Treatment

The continuous use of equipment and chemicals is an effective but expensive way to treat mine drainage.

Since the Surface Mining Control and Reclamation Act of 1977, drainage from operating coal mines have had to meet strict guidelines. Mining companies have traditionally used active, chemical treatment to meet these standards set forth by the Pennsylvania Department of Environmental Protection and the U.S. Department of Interior. These methods require the continuous addition of chemicals such as limestone, hydrated lime, quick lime, soda ash briquettes, caustic soda, and ammonia. These chemicals are quite expensive as is the equipment necessary to aerate and mix them with the drainage. In addition to these costs, continuous maintenance and the removal of the sludge that accumulates in settling ponds after treatment is required. It is not unusual for these individual systems to exceed $10,000 per year to operate. This remains a financial responsibility of the coal company long after all mining and reclamation at the site has been completed. It is estimated that the total water treatment costs for the coal mining industry exceeds $1,000,000 per day. This severe financial burden has led to the bankruptcies of many companies.

The majority of Pennsylvania's mine drainage problems come from abandoned sites in which the mining company involved has long been out of business. Although active treatment does successfully treat mine drainage, the high costs and maintenance involved makes the innovation of new treatment options to address these abandoned sites necessary.

Natural wetland ecosystem *(Photo courtesy of Jennings Environmental Education Center)*

Passive Treatment

The development of passive technologies that rely on natural processes to treat mine drainage may prove to be the ultimate answer to improving Pennsylvania's water quality.

Passive technologies strive to reproduce nature's own healing methods. The term passive implies that there is no reliance on the continuous physical activity of a person or machine to treat mine drainage. Instead, these innovative technologies take advantage of natural chemical and biological processes to improve water quality. This virtually eliminates all costs of operation and maintenance normally associated with active treatment.

The development of these technologies could not have occurred without the painstaking research of countless professional in the fields of science and engineering. Initial research in the 1970's revealed that natural ***wetlands*** captured and retained mine drainage and, in most cases, effectively reduced acidity and promoted the oxidation of metals without becoming severely damaged themselves.

This led to the increased interest in constructing wetlands for the sole purpose of treating mine drainage. Experimental concepts became working, full-scale models at hundreds of sites during the mid 1980's and early 1990's. Many theories were tested at these sites which led to discoveries that ultimately improved the function of constructed wetlands as water treatment devices. Two critical findings dealt with the vegetation within the wetlands and the soil in which this vegetation grows. At first, sphagnum moss wetlands were replicated. Sphagnum moss is not easily attained and difficult to transplant so

Let Nature Run Its Course?

If left alone, the water quality of acid mine drainage will eventually improve through a series of natural processes. As the drainage flows into and through streams, rivers and lakes, its toxic characteristics decrease as a result of several chemical and biological reactions and dilution with uncontaminated water. This natural process can be seen in streams and rivers with orange staining and sediment, called "yellow boy", coating the bottom. Yellow boy is iron that at one time was dissolved in mine drainage. Extremely low pH is necessary for iron to remain dissolved in water. When drainage with low pH and dissolved iron flows into streams with high pH or alkalinity, the pH of the drainage is raised. The iron can no longer remain dissolved and becomes a solid. Iron ***precipitate*** then coats the bottom of the stream, suffocating anything that lives there. The same is true for manganese and aluminum. Manganese precipitate stains stream bottoms black and aluminum is noticed as a white precipitate. The ultimate cost of this is hundreds of miles of degraded streams of little or no ecological or recreational value.

The effect of abandoned mine drainage at DeSale, Northern Butler County5
(Photo courtesy of Stream Restoration Inc.)

other types of wetland vegetation were tried. Cattails were found to be an excellent alternative. The use of cattails led to another important discovery. It was first theorized that cattails were responsible for the removal of metals dissolved in the mine drainage. Upon further research it was found that bacteria were primarily responsible for metal removal. This bacteria used wetland soils and the root systems of the vegetation as habitat. This led to an attempt to find the best organic material suited for supporting this diverse constructed wetland environment. Soil, peat moss, ***spent mushroom compost***, straw/manure, sawdust and hay bales have all been used to nurture the beneficial bacteria and wetland plants.

As models and ideas to treat mine drainage were refined, unique and innovative systems were developed. Several of these systems no longer resembled typical wetland environments.

Years of laboratory research and monitoring full-scale models have led to the development of several passive treatment options. Each option treats a particular type of mine drainage. Often, several of these options are used in conjunction with each other to achieve optimum treatment.

Constructed Wetlands

This form of passive treatment simply mimics the functions of a natural wetland. First, the system is designed to slow the flow of water. This allows any suspended solids, such as sand or silt to settle out. This is usually accomplished in a settling pond prior to actual treatment and significantly extends the life span of the system.

Students from Moniteau High School, Butler County, testing the effectiveness of a passive treatment system treating abandoned mine drainage *(Photo courtesy of Jennings Environmental Education Center)*

Constructed wetland at Jennings Environmental Education Center
(Photo courtesy of Jennings Environmental Education Center)

Next, the system takes advantage of a wetland's natural ability to retain water. Passive treatment processes take much longer to achieve successful results than active treatment methods. This makes extended retention time within the system critical for the successful treatment of mine drainage. Correct sizing of the system and dense wetland vegetation, such as cattails, help achieve acceptable retention time.

After flow is slowed in a settling pond, the mine drainage travels through a series of treatment cells that are generally filled with cattails growing in some sort of soil substrate. These cells are very shallow, less than 18 inches deep, and are spread out over a relatively large area. This design provides more surface area compared to deeper cells that hold the same volume of water in less space. Increased surface area guarantees that a majority of the mine drainage will be exposed to oxygen. The term ***"aerobic"*** means "only active in the presence of oxygen" and accurately describes how this type of wetland treats mine drainage. ***Oxidation*** is a natural reaction that occurs in the presence of oxygen. An iron nail will rust, or is oxidized, because it is exposed to the air (oxygen). Under the right conditions, iron and other metals dissolved in mine drainage will oxidize and become a solid when exposed to the air. To further enhance exposure to oxygen, waterfalls are constructed between treatment cells. Waterfalls aerate the mine drainage and increase dissolved oxygen levels.

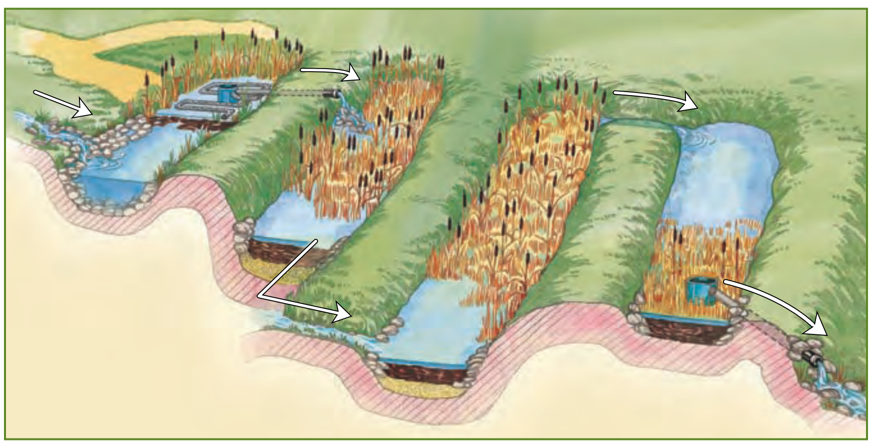


Illustration of the constructed wetland at Jennings

Open Limestone Channel
(Photo courtesy of US Dept. of the Interior, Office of Surface Mining Reclamation and Enforcement)

This system is most effective when mine drainage has low acidity (a pH of 6 or higher) and high alkalinity. If pH is extremely low (high acidity) and there is little alkalinity, metals will remain dissolved in water.

A constructed wetland must be large enough to effectively treat the drainage. This is often a limiting factor for this type of system if adequate space is not available.

Open Limestone Channels (OLCs)

When mine drainage contains high acidity and low levels of alkalinity in addition to dissolved metals, a system designed to introduce alkalinity must be developed. One of the simplest methods is an ***open limestone channel***. This passive treatment technique looks very similar to rock lined ditches frequently seen along roadways. The basic premise behind this system is that acidic mine drainage can be treated through contact with large limestone rocks. As the limestone dissolves, the alkalinity of the drainage is increased. Oxygen is also introduced to the water through aeration as it swiftly tumbles over the limestone rocks. This increases the oxidation rate of dissolved metals.

Retention time is extremely important to the effectiveness of this form of treatment. Water must remain in contact with the limestone long enough for the limestone to be dissolved to introduce alkalinity. Since water cannot be retained in a swift moving channel, the length of the channel is critical for optimal effectiveness.

When the pH of the drainage is significantly raised, dissolved metals begin to ***precipitate*** out of the water. This metal precipitate will coat the limestone if the water is not moving quickly enough to carry it. This reduces the effectiveness of the limestone to release alkalinity although there is some discussion as to how much it is reduced. This is an excellent method of introducing alkalinity to seeps and discharges before acidic drainage enters a stream.

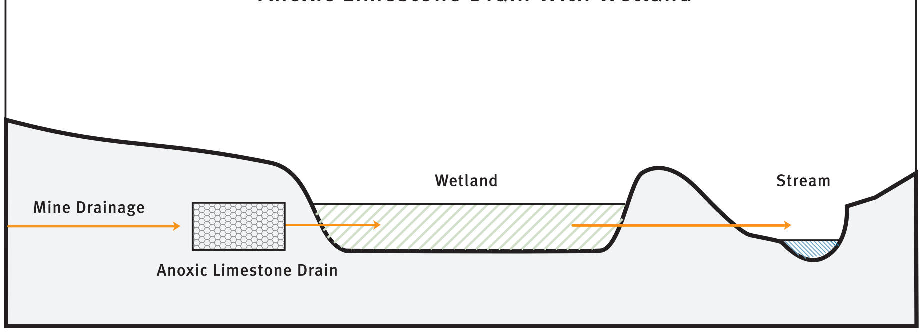
Anoxic Limestone Drain (ALD)

An ***anoxic limestone drain*** is simply a buried cell of limestone aggregate. This technique makes use of the same principle as an open limestone channel except that oxygen is not introduced to the drainage. The term *"anoxic"* means "absence of oxygen." The lack of oxygen reduces the chance that metals will oxidize and precipitate out of the water and armor the limestone. An anoxic environment is achieved by burying the drain beneath several feet of clay. Often a plastic liner is placed between the limestone and clay to provide an additional barrier. This environment also promotes the production of carbon dioxide, the same gas that bubbles in carbonated beverages, which increases the ability of the water to dissolve the limestone. The clay "cap" is similar to the lid on a bottle of soda. It effectively seals in the carbon dioxide allowing the soda to retain its "fizz".

Anoxic limestone drains may be long and narrow or extremely wide. As the mine drainage flows through the drain, alkalinity is produced as the limestone aggregate is dissolved.

When the now alkaline drainage exits the drain and is exposed to oxygen, once dissolved metals form solids. This is often evident by the bright orange color of the discharge. A settling pond is

Anoxic Limestone Drain With Wetland



Construction of an anoxic limestone drain in northern Butler County
(Photo courtesy of Stream Restoration Inc.)

constructed after the drain to collect the metal precipitates before they enter the stream.

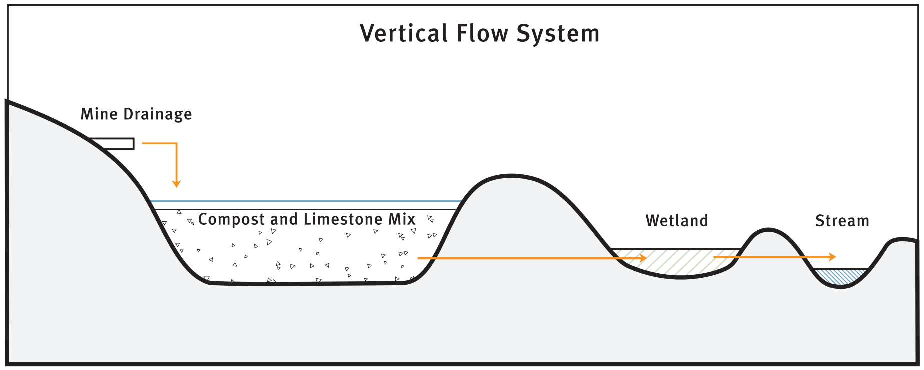
Not all water can be effectively treated with an ALD. Water containing significant levels of dissolved oxygen, aluminum, or ***ferric iron*** will quickly plug the drain with metal precipitates.

Vertical Flow System

When there is not enough space available to construct an effective wetland or if drainage is highly acidic and contains dissolved oxygen and/or aluminum, it may be necessary to install a ***vertical flow system***. A vertical flow system is a type of pond that overcomes these limitations by combining the effectiveness of an anoxic limestone drain with the benefits of a constructed wetland.

Vertical flow is achieved within the pond by allowing gravity to force water down through a layer of decaying organic material mixed with limestone aggregate. Drains located beneath the pond cause the water to flow down rather than across the surface like the constructed wetland. The saturated organic material consumes oxygen as it decays, effectively "stripping" it from the water creating an anoxic environment.

Spent mushroom compost is a commonly used organic material. It is a recipe of hay, straw, horse and chicken manure and the mineral gypsum which is made by mushroom producers to grow mushrooms. When this mixture is exhausted, or spent, of the nutrients necessary to grow mushrooms it must be replaced. This waste produced by Pennsylvania's number one agricultural industry is also eagerly used by gardeners as a soil supplement.



Vertical flow system under construction (Photo courtesy of Stream Restoration Inc.)

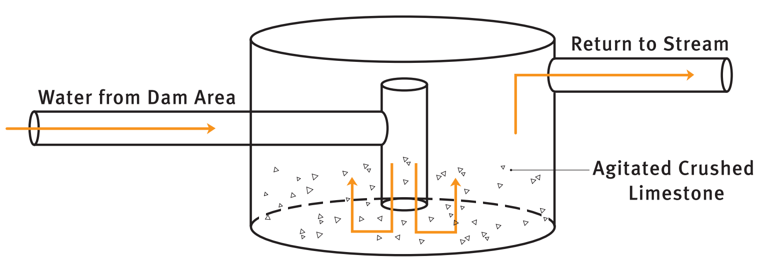
Completed vertical flow system (Photo courtesy of Stream Restoration Inc.)

The drainage is treated as it flows through the layer of spent mushroom compost mixed with limestone. Alkalinity is produced, raising pH, as the acidic drainage dissolves the limestone. The spent mushroom compost produces carbon dioxide, which helps the limestone dissolve, and provides habitat for bacteria that thrive in the anoxic environment. These beneficial bacteria use the high levels of sulfate, typically found in acid mine drainage, as "food" to produce energy. The waste produced by the bacteria is additional alkalinity and hydrogen sulfide, a gas easily recognized by its rotten egg smell.

Due to the ***anaerobic*** environment, iron will not precipitate within the system and armor the limestone. A collection pond or aerobic wetland should follow the vertical flow system to encourage oxidation and collect the iron as it precipitates upon contacting the air.

Aluminum will precipitate within the system. The vertical flow system should be designed to create enough downward pressure to prevent aluminum precipitate from plugging the system. The depth of standing water, or head, in the pond controls downward pressure. Additional measures to avoid plugging may be designed into the system. Forcing water back through the system to agitate and loosen aluminum deposits may increase its life span.

Schematic View of a Diversion Well



Vertical flow systems are relatively new. Continuing research is being conducted to monitor their effectiveness over long periods of time. Different organic materials are also being tried because spent mushroom compost, although easy to obtain in Pennsylvania, may be hard to get in other states or countries.

Diversion Wells

A ***diversion well*** consists of a vertical tank filled with agregate limestone. Drainage is introduced to the tank through a pipe which extends vertically into the tank and ends just before it reaches the bottom. This effectively forces the drainage up through the limestone. Significant water pressure is needed to violently churn the aggregate within the diversion well so it will dissolve.