

# ACCEPTING THE CHALLENGE

*A primer about the history, cause, and  
solutions to abandoned mine drainage*



A SLIPPERY ROCK WATERSHED COALITION PUBLICATION

## Forward

The Slippery Rock Watershed Coalition (SRWC) formed in December 1994 to address the abandoned mine drainage impacting the Slippery Rock Creek Watershed. The SRWC is a public-private partnership effort consisting of governmental agencies, private industry including mining companies and environmental consultants, nonprofit organizations, educational institutions, and concerned citizens. To date, approximately 18 passive treatment systems have been installed that are treating about 750 million gallons of mine drainage every year, which has resulted in over 10 miles of streams that have been restored. Some of these streams now have fish living in them for the first time in 50-100 years.

After several years of success, the SRWC wanted to write a book for the general public to provide an overview of the history, cause, and solutions to abandoned mine drainage as well as describe the overall approach and successes of the Slippery Rock Watershed Coalition. The book entitled *Accepting the Challenge* was first published by the nonprofit organization Stream Restoration Incorporated in 2001.

Approximately 6,000 copies of the book have been printed to date and distributed to people throughout the world. The books were given free of charge to anyone who was interested in the subject matter and therefore there was not a sustainable funding source for the printing of future copies other than grants and individual donations. As we were running out of copies of our third printing, the Slippery Rock Watershed Coalition realized that by creating an electronic version, we could make the book available to the entire world via the internet as well as make the book more interactive.

Through a generous grant provided by the [Foundation For Pennsylvania Watersheds](#), we have converted *Accepting the Challenge* to a digital format. As part of the project, we have created links from italicized words in the narrative to the glossary in the back by simply clicking on the word. We also created an expanded Table of Contents by utilizing the Bookmarks feature in PDF documents. In addition, we created links (indicated by blue underlines) within the narrative to related web based resources as well as provided a listing of links to additional related resources and lesson plans in the back of the book. Finally, we provided a number of links to video content located on the internet indicated by the movie icon. These videos provide an opportunity to further explore various subject matters in the book and at times to help the reader envision and appreciate the industrial heritage of Pennsylvania.

We hope by providing this book in electronic format, we will be able to greatly expand its availability as a resource and help more people “Accept the Challenge” to restore their own watersheds.

For additional information please check the [Slippery Rock Watershed Coalition](#) and/or [Stream Restoration Incorporated](#) websites.

Thank you,

Slippery Rock Watershed Coalition

April 2011

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*A Slippery Rock Watershed Coalition Publication*

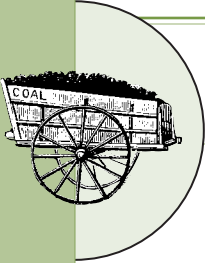
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## CONTENTS

2	<b>CHAPTER ONE</b> Digging Up the Past
24	<b>CHAPTER TWO</b> Relics Upon the Land
36	<b>CHAPTER THREE</b> The Source and the Impact
44	<b>CHAPTER FOUR</b> Naturally Innovative Solutions
58	<b>CHAPTER FIVE</b> Making it Happen
70	<b>GLOSSARY</b>



## DIGGING UP THE PAST

For centuries, humans have struggled to extract **coal** from below the earth's surface in order to provide a cheap and plentiful source of energy. During this time, technology was continually being developed to improve the way this resource was to be mined and used. Many inventions that affect our daily lives are the result of this perpetual search for an efficient source of energy.

The story behind the universal use of coal is a testament to the human spirit filled with perseverance and dedication.



Coal carts exiting a drift mine in Butler county  
(Photo courtesy of Sam Brydon)

### FUELING HISTORY

*Using coal as a source of fuel spawned important technological advancements that unlocked the mineral's true energy potential and ultimately improved our way of life.*

It is not precisely known when the energy value of coal was first discovered. Evidence suggests that several ancient civilizations knew that coal burned but this discovery played only a small role in the advancement of their cultures.

The Chinese were thought to have first pioneered the use of coal as fuel during the Han dynasty (206 BC to 220 AD). Upon returning to Italy following his visit to China, Marco Polo wrote of these people using unusual black stones as fuel.

The first use of coal in Europe was by the Romans when they occupied Scotland. The coal was referred to as "sea coal" for it was found washing onto the beaches. Actually the coal did not come directly from the sea. It had been dislodged from exposures found along the coast by the relentless pounding of waves.

When the Romans withdrew from Scotland in the fifth century AD, the unique resource they had discovered and used was left behind and forgotten.

Centuries later the use of coal slowly resurfaced in Britain. At first, little use could be found for coal. It was not used to heat homes because most houses had no chimney, but had simply a depression in the floor for a fireplace. The noxious smoke and fumes released by the burning coal proved to be unbearable.





Neatly stacked logs covered by leaves and soil create the slow smolder necessary to produce charcoal.  
(Photo courtesy of National Park Service, Hopewell Furnace NHS)

It was not until the iron industry had exhausted the forests of Europe did a real interest in coal develop, raising the price of wood and **charcoal**, which is made by partially burning wood using only a small amount of oxygen. Soon, as coal became cheaper than wood, chimneys became a common addition to most homes.

Coal eventually found a place in early industry thanks to a significant advancement in technology. In 1612, the invention of a special furnace, known as a **reverberatory furnace**,

allowed coal to replace wood as the primary fuel for separating, or **smelting**, copper, tin, and lead from **ore**, and for making glass. Unlike previous furnaces, this innovative furnace could heat the material to be smelted without mixing it directly with the fuel. Separating the fuel from the ore prevented any impurities normally associated with coal from tainting the smelted material. Although this new invention worked well for producing tin, copper, and glass, it could not generate the intense heat needed to produce iron. A **blast furnace** was the

## BURIED SUNSHINE

*Reading layers of earth and rock like a complicated mystery novel, geologists are able to piece together the 4.5 billion-year history of our planet. Coal has a short but fascinating chapter near the end of this long and complex reference book called Earth.*

365 million years ago, during what is referred to as the Carboniferous Period, Pennsylvania would have been a very interesting place to visit. A bathing suit and sunscreen would have been in order for Pennsylvania was located near the equator and enjoyed a tropical climate, much like the Everglades in southern Florida. Most of western Pennsylvania was covered by vast swamps rich with vegetation consisting mainly of ferns and fern-like plants. These were no ordinary plants, some may have reached heights of 75 feet. These lush, tropical forests created tons of debris, such as leaves, twigs, branches and trunks,

which fell into the warm, murky water below. This sluggish stew of decaying plant material slowly formed a thick mat of organic material called peat. Sand and silt gradually accumulated on top of this peat. Over time, the heat and pressure created by the weight of this overlying sediment compacted the peat, squeezing out virtually all the water, forming a hard, black concentrated carbon-rich material.

This “living fossil”, called coal, has stored the sun’s energy beneath the earth for millions of years. When burned, this concentrated energy is released. Coal burns much hotter and longer than wood, which makes it such an extremely valuable energy resource.

only furnace capable of producing such extreme temperatures. Blast furnaces are named for the loud roar that is heard when air is violently introduced to the fire with large bellows to create the intense heat necessary to melt iron. Coal could not be used in a blast furnace. It is much softer than charcoal, and would “slump” into a dense mass under the intense heat and choke the furnace. In addition, the impurities found in coal, such as sulfur, caused the iron that was produced to be very brittle.

Not until the practice of charring coal was developed in 1642 was the full potential of coal realized. Charring coal by partly burning it in covered heaps, similar to the way charcoal is made, produced a hard cinder of almost pure carbon that would burn with a clean, smokeless heat. This cinder, called **coke**, revolutionized the industrial uses for coal and spawned the Industrial Revolution in Europe.

With the settlement of the New World, coal was again basically ignored as a fuel source. The virtually unlimited



Remains of an iron furnace (Photo courtesy of Steve Smith)

## DID BEER CHANGE THE WORLD?

By the end of the 1600's industrial and economic growth in Europe, ironically an area laden with coal, had become stagnant. Mass deforestation had driven the cost of wood and charcoal out of the reach of many struggling industries. The brewing industry was among those desperately in need of an alternative fuel. Brewers tried using coal-fired ovens to dry malt, a “stew” of grain, usually barley, that is steeped in water until it sprouts; however, the coal's foul smoke and many impurities affected the taste of the beer, just as it had affected the quality of iron when used in blast furnaces. Frustrated, brewers tried charring coal just as wood is charred to form charcoal. When the resulting coal cinders, or coke, were used in the malt ovens, the best beer England had ever tasted was produced.

**Abraham Darby**, an English Quaker familiar with both the brewing industry and the iron industry, determined what was good for malt must be good for iron. In 1709, using a leased blast furnace and coke he prepared himself, Mr. Darby produced the first quality iron ever made from coal. This monumental event proved that iron could be made by using England's seemingly limitless coal fields rather than its vanishing forests. The Industrial Revolution had begun.





supply of timber made it unnecessary to pursue the difficult and dangerous practice of mining coal. But wood eventually became scarce and expensive. The same situation that had occurred in England a century before, occurred in the United States. The New World now had to look beneath the surface of the earth for an alternative energy source.

Commercial coal mining in the U.S. began in the mid 1700's in Virginia. The first coal production in Pennsylvania began in 1761 at Coal Hill, what is now Mt. Washington in Pittsburgh. Coal once again became the principle fuel of choice for use in iron furnaces and glass works, and eventually provided fuel for James Watt's monumental invention of the 1800's, the steam engine.

Coal in Pennsylvania, as in the rest of the United States, fueled the American Revolution, the Industrial Revolution, two World Wars and thrust the United States to the forefront as the industrial capital of the world. Today, the United States is the second largest global consumer of coal. Most of this coal is used to satisfy our increasing demand for electricity. Eight out of every ten tons of coal consumed nationwide is used by an electric generating plant. Pennsylvania is the third largest consumer of coal in the United States. Electric generation consumes 90% of all coal used in the state. In addition to electric generation, coal remains the primary fuel for the iron industry and for the production of chemicals, paper, cement and even food.

## MINING THROUGH TIME

*The rise in popularity of coal as an energy source greatly increased the demand for its mass production. Improved methods of extraction and transportation have led to the methods used today, as well as several inventions we now take for granted.*

During more than 200 years of mining, Pennsylvania has produced nearly a fourth of all the coal ever extracted in the United States. In 1918, Pennsylvania

exceeded the production of 276 million tons of coal, more than any state has ever produced in one year.

Thousands of men have lost their lives during the slow and painful evolution of mining. It took hundreds of years for technology to improve the working conditions and efficiency of a coal mine. To this day, removing a mineral from below the earth's surface is a difficult and dangerous task.



*Mule driver and his mule. On average, a mule would haul 100 tons of coal per day. (Photo courtesy of the Historical Society of Western Pennsylvania)*

## UNDERGROUND MINING

*As the supply of coal easily accessible from the earth's surface dwindled it became necessary to venture underground.*

### Conventional Mining

Underground mining began by “tunneling” into a hillside. These types of mines are called **drift mines**. Using picks, bars, and hammers, miners would tunnel through the coal seam, leaving pillars of coal behind to support the mine roof. As the miners retreated from the mine they would remove these supporting pillars and let the mine collapse. The practice of leaving pillars of coal to support the mine roof is still employed today but several other techniques are used that have greatly improved mine safety. Using wooden timbers to support the mine roof was

common well into the 1940's. Eventually steel beams replaced wooden timbers, but often the weight of the roof is enough to bend even steel beams.

**Roof bolting** is a modern method of strengthening the mine roof.

Roof bolts compress the layers of rock that make up the roof into one strong layer, much the way that many layers of plywood are bonded together to produce one strong sheet. Powerful electrically powered, hydraulic driven machines drill holes, insert, and tighten the roof bolts.

Breaking coal from the seam with a pick was difficult and exhausting work. Blasting coal with explosives requires much less effort. Early advancements in drilling and blasting, or “shooting the coal” greatly improved the efficiency and productivity of a mine.



*Miner with lunch pail inside a mine supported by wooden timbers  
(Photo courtesy of the Historical Society of Western Pennsylvania)*

To shoot the coal, a hole must be drilled to receive the explosive. A **coal auger** was a primitive tool used to drill the hole. It resembled a brace and bit commonly used by carpenters. This was slow and grueling work. Eventually hand held electric drills made this job easier. Now miners use hydraulic drilling machines on wheels that can be easily “driven” to the working face of the coal seam to quickly drill a hole.

Once a hole is drilled, the “shot fireman” loads the hole with explosives and detonates it. The coal shatters and falls

to the floor where it can be loaded and transported out of the mine. To improve the effectiveness of each blast, the **cutting machine** was developed in the 1930's. This machine, resembling a huge chainsaw on wheels, undercuts the coal, making a space for the coal to expand during blasting. This allows more coal to be shattered with each blast.

For centuries coal was loaded into carts by hand. Carts were then pulled out of the mine by ponies, oxen, mules, or goats. Eventually electric locomotives replaced the hard working animals and





Mule driver exiting a mine with a full cart of coal. Notice the driver is not holding reins. Voice commands were used to guide the mule through the mine. (Photo courtesy of the Historical Society of Western Pennsylvania)

hand loading gave way to loading machines and conveyor systems, which transport coal from the mine similar to the way groceries are moved through the checkout line by a belt conveyor at the supermarket.

Approximately one quarter of all coal mined underground is still done conventionally.

### Continuous Mining

Primitive cutting machines led to the invention of the **continuous miner** in the mid 1950's. This invention reduced the steps of drilling, cutting, blasting, and loading into one continuous operation. A continuous miner is a maneuverable machine with a turning cutting drum mounted on the front. The cutting drum has carbide-tipped teeth that literally

tear the coal from the working face. A continuous mining machine is capable of removing twelve tons of coal per minute. As the coal is removed from the seam it is automatically loaded by a conveyor system and transported out of the mine. The continuous miner excavates "rooms" out of the coal seam, leaving behind pillars of coal that along with roof bolts support the roof. Because pillars of coal are left behind, only about 50 percent of the coal can be recovered using this process. Continuous coal mines account for more than half of all coal mined underground in the U.S.

### Longwall Mining

The **longwall mining machine**, also developed in the mid 1950's, is the most efficient method of removing coal from underground. A well planned longwall mining operation is capable of recovering 85 percent of the coal in a seam. Unlike conventional and continuous mining, pillars of coal are not left to support the roof, instead, as the mining machinery is moved ahead the roof is allowed to collapse.

A longwall miner consists of a large cutting wheel, called a shearer head or cutting plow, that moves back and forth on a track parallel to the working face. The **working face** of a longwall mine can be longer than two football fields, often 1000 feet or more, hence its name. As the shearer cuts away at the working face like a carpenter's plane removing a

## DIGGING UP THE PAST

thin layer of wood, the coal falls into a conveyor system called a "**pan line**." The pan line transports the coal to coal cars or a belt conveyor to be transported out of the mine. A moveable hydraulic shield temporarily supports the roof of the mine and protects the miners and equipment. As the operation moves ahead, the shield is moved as well, allowing the roof behind the longwall miner to collapse.

Allowing the roof to collapse can cause surface **subsidence** problems. Very specific geologic conditions must exist for a longwall mine to be considered. For this reason longwall mining only accounts for five percent of all underground mining in the U.S.



Miners were often paid by the carts of coal they produced rather than an hourly wage.  
(Photo courtesy of the Historical Society of Western Pennsylvania)

## LIFE IN THE “HOLE”

Around the turn of the 20th century, miners had to endure horrendous working conditions for very little money. In 1910 alone, over 500 Pennsylvania coal miners lost their lives beneath the earth. These conditions gradually improved as miners organized to demand improved safety standards.

A coal miner often began his career at a very early age. At the age of nine he may have become a **breaker boy** and separated slate and rock from the

coal as it was brought out of the mine to the **breaker**, a machine that “broke” coal into various sized pieces. By 12, he may have become a door boy, or **nipper**, spending ten or twelve hours in the solitary darkness of the mine opening the mine doors whenever a mule-drawn mine car passed through. At 15, he could have become a mule driver, leading the mules through the darkness as they pulled mine cars filled with coal. After a few years, he would have graduated to mining coal.

## STEAMING AHEAD

As mines moved further underground, flooding became an increasingly significant problem. Many methods of pumping out the mines were tried but all were stalled by one seemingly insurmountable problem. There was no source of continual and reliable power. As late as the 1700’s primitive pumps had to be driven by unpredictable wind and water or the tired muscles of man or beast. This problem faced by the miners of the late 1600’s and early 1700’s led to arguably the most significant invention in the history of technology.

Two important discoveries led to this historic invention. First it was discovered that the earth’s atmosphere exerts a surprising amount of pressure. A simple vacuum, such as a suction cup stuck to a window, illustrates this point. When air is expelled from beneath the suction cup by pressing it against the window, atmospheric pressure will hold the suction cup in place. Second, the force of steam was beginning to be recognized. An example of this is the ability of steam to lift the lid on a boiling pot of water.

Brilliant minds of the late 1600’s worked tirelessly to harness these principles. Finally, in 1712 a craftsman named **Thomas Newcome** built the first atmospheric steam engine. Although primitive, this ingenious apparatus provided a continuous source of power to drive a pump which removed 120 gallons of water per minute from a deep mine well over 100 feet beneath the ground. This incredible device was immediately put to work pumping out deep mines all over England.

In 1763 a young instrument maker began improving upon Newcome’s legendary engine. This young instrument maker was **James Watt** who went on to invent the first true steam engine which forever changed industry and transportation .

Imagine what life would be like without engines, originally developed to improve coal mining, tirelessly performing countless tasks such as transporting us wherever we want to go.



*Tipple and caretaker's shed at the Foltz Hill Mine, Brady Township, Butler County*  
(Photo courtesy of Sam Brydon)

Needless to say, spending long hours in a dark, damp, cold mine deep within the earth was uncomfortable and extremely dangerous. Often coal seams were no more than two to four feet thick, requiring miners to spend twelve or more hours a day lying on their bellies in a puddle of water. Because of their small stature, young boys were often recruited to mine thin seams. As mining technology improved, thin seams were often abandoned for thicker ones that allowed miners to stand, or at least kneel.

Miners faced deadly obstacles every minute they spent underground. There are countless stories and accounts of disasters striking virtually every mining community in Pennsylvania.

The possibility that the mine would collapse, burying those within alive, lurked in the back of every miner's mind. Often the miners' best friends were the rats that lived alongside them as they worked. Rats had the mysterious ability to sense a collapse before it occurred. If the rats evacuated the mine, the miners quickly followed. Miners often showed

their gratitude by sharing their lunch with the valuable vermin. Today, improved methods of stabilizing the mine, strict safety standards and accurate geologic surveys have drastically reduced the chances of a collapse.

Gas is yet another danger that lurks within the mine. **Methane**, a gas with a foul odor produced naturally by humans while digesting food, commonly occurs underground. Pockets of methane, created millions of years ago by decomposing plants, are colorless, odorless and extremely flammable. Methane can fill a mine silently and a lone spark from a steel pick striking hard rock may ignite the gas causing an explosion. The resulting fire may burn for many years before it can be extinguished.

**Carbon monoxide** is another gas fairly common to the mine. This is the same gas that comes from the exhaust of a car. Carbon monoxide is created by mine fires and can be deadly. Canaries were used for years to detect combustible and poisonous gasses within the mine. If the canary died unexpectedly, chances are the air was not safe. Today special lamps and sophisticated detection devices monitor for the presence of dangerous gases.

Providing the miner with a source of fresh air has always been a challenge. Since the earliest days of mining it has been recognized that lives depend on proper ventilation of the mine. The Romans dug intricate ventilation shafts and lit fires beneath these air ways. The fire created strong updrafts which circulated fresh air into the mine. Fires have long since been replaced with fans and complicated ventilation systems.

Coal dust has plagued coal miners for centuries. Almost every aspect of the mining process, such as drilling, blasting and loading, creates dust, a very fine powder like the soot found in a fireplace. Coal dust causes an array of respiratory problems such as **emphysema** and lung cancer. Most common was the dreaded **black lung disease**. Violent and uncontrollable coughing was its most common symptom.

*"In the mining town, if you arose and went outdoors early of a summer morning, as you walked by the little wooden row houses, you would hear the miners in the morning ritual of coughing, great racking, gasping coughs, which lasted 10 or 20 minutes. This sound was as natural as the birds singing in the trees. If you became a miner, you knew that you would do "bull work", and when you reached old age*



*(anything past 50), you would gasp and wheeze, and spit up in the coal bucket by the coal stove. This was the life of a miner.” - Eric McKeever Tales of The Mine Country*

Strict health and safety standards now require that coal dust be contained. Drilling and mining equipment continually spray the working face with water to limit the dust that is produced. In addition to respiratory problems, coal dust is potentially explosive. **Rock dust**, which is finely ground limestone resembling baking flour, is applied to the walls, ceiling, and floor of a mine to neutralize the explosive properties of coal dust. For this reason the inside of a working coal mine is white, not black, as might be expected.



A man trip transports passengers to the working face of the coal. Note the rock dust on the walls of the mine. (Photo courtesy of Joseph Aloe, Quality Aggregates Incorporated)

## SURFACE MINES

*As mining equipment improved, coal located near the surface of the earth could be economically removed.*

Surface mining is one of the oldest forms of mining in the world. Mining, in its simplest form, began by using picks and shovels to remove coal exposed in streambeds or located beneath a few feet of soil. Inadequate technology limited the amount of surface mining done until the early twentieth century. Significant surface mining did not begin in Pennsylvania until the mid 1930's. Now, improved equipment allows operators to recover coal buried more than 200 feet underground.



The mammoth dragline in operation (Photo courtesy of Darrel Lewis, Allegheny Mineral Incorporated)



Dragline buckets can hold up to 220 cubic yards of overburden. (Photo courtesy of Steve Smith)





*Stripping shovel in the pit of an operating area mine  
(Photo courtesy of Pennsylvania Department of Conservation and Natural Resources)*

## DIGGING UP THE PAST

Today surface mines account for more than half of all coal mined in the United States.

**Surface mining** is attractive to coal producers for a number of reasons. It is generally cheaper to mine coal using surface techniques. In addition, the amount of coal that can be recovered from a seam is greater, averaging 85 percent compared to approximately 50 percent recovered using most underground mining techniques. Surface mining is also safer for the miners when compared to the many dangers faced underground.

Surface mining is also called “strip mining” because the surface of the land must be stripped away to reveal the coal. Restoring the land to its original form, referred to as **reclamation**, is an important step in the surface mining process. Modern reclamation standards require all disturbed land to be returned

to productive use. This commonly means that all open pits and cuts are filled, leveled, and replanted with vegetation so the site will suitably support wildlife, agriculture, recreation, or commercial and residential development.

The way in which coal is removed during surface mining depends upon the type of landscape to be mined.

### **Area Mining**

Area mining is the preferred method if the terrain of the area to be mined is relatively flat. During area mining the soil and rock above the coal seam, called **overburden**, is removed in a series of long narrow cuts to reveal the coal below. Today, open cuts are generally no more than 1500 feet long, but in the past they could extend for over a mile. As mining progresses to the next cut, the overburden is **spoiled** into the previously mined cut and bulldozers regrade the area to conform to the premining shape of the land. This allows reclamation to occur as coal is being mined.



## CHAPTER ONE

Digging large holes requires large, powerful equipment. The monstrous **dragline** is often the machine of choice. This huge machine uses an enormous bucket attached to cables that are supported by a **boom**. The bucket is lowered and dragged across the overburden effectively scooping up tons of soil and rock. The bucket is raised and the entire machine rotates to dump the spoil into the neighboring pit. One of the largest draglines has a boom as long as a football field which supports a bucket capable of holding enough spoil to fill six large semi-trucks. Draglines are best suited for relatively soft overburden.

When the overburden is hard it may be necessary to use explosives to break it into manageable pieces. Holes are drilled in the overburden to receive the explosives. Once blasted, the overburden can be excavated using a **stripping shovel**, which is a machine mounted on crawler tracks similar to the tracks on a bulldozer. Crawler tracks allow the large machine to maneuver within the pit. The stripping shovel, so called because it “shovels” the overburden rather than dragging and scooping, has a bucket connected to an arm which is supported by a boom. Larger stripping shovels tower more than eight stories high. Smaller mines do not require such large machinery. Often bulldozers remove the overburden instead of stripping shovels.

### Contour Mining

**Contour mining** is commonly used if the landscape to be mined is hilly or mountainous. During contour mining the side of a hill or mountain is removed. Mining begins where the coal seam intercepts the surface. This is called the **cropline**. Working toward the center of the hill, overburden is removed until it is no longer economically feasible to do so. A vertical cut, resembling a steep cliff, marks the final face where the mining operation stops. This cut is referred to as a **highwall** and is not permitted to remain. The hill must be restored to its original shape prior to mining.



*Reclamation of a contour surface mining site  
(Photo courtesy of US Dept. of the Interior, Office of Surface Mining Reclamation and Enforcement)*



## RELICS UPON THE LAND

The years of mining with unsophisticated technology and no environmental regulations have left the land and water of Pennsylvania scarred with relics from a bygone era. It may be difficult to imagine that abandoned mine sites and virtual ghost towns were once bustling communities that housed hundreds of families whose husbands, children, and fathers were employed by the town's sole source of income, the coal mine. Sadly, the most visible evidence that remains of this era are the over 250,000 acres of abandoned mine lands, coal refuse piles and old mine shafts spanning 45 of Pennsylvania's 67 counties. What was once the source of economic development and a way of life for thousands of people is now producing a disastrous effect on our environment.



*The once bustling mining community of Hilliards , Butler County, in 1911.  
(Photo courtesy of Dr. Dean DeNicola)*

Pennsylvania currently has approximately 7,800 old, abandoned, or inactive underground mines that are contributing to one of the most severe environmental problems in the country. This legacy now provides a unique challenge to the citizens of the Commonwealth to restore our ecosystem and to preserve our rich cultural history.

### ACID MINE DRAINAGE

*The degradation of thousands of miles of freshwater streams is the most significant impact of the hundreds of abandoned mine sites in Pennsylvania.*

**Acid mine drainage (AMD)** is the result of materials, normally found buried deep underground, becoming exposed to water and oxygen. **Pyrite**, or Fool's Gold, is the material primarily responsible for the formation of acid mine drainage. Pyrite is a mineral containing iron and

*Severely eroded coal refuse piles  
(Photo courtesy of US Dept. of the Interior, Office of Surface Mining Reclamation and Enforcement)*



## CHAPTER TWO

sulfur that is often found in or near coal seams. Oxygen and water react with the pyrite creating a mild form of **sulfuric acid**, with similar acidity to vinegar. This acidic solution is capable of dissolving many of the minerals and metals it may come in contact with. The resulting mine drainage can contain not only iron but also other metals such as aluminum and manganese. This combination of acid and metals can have a disastrous effect on a stream habitat. Acid mine drainage is often easily recognized by reddish-orange staining of rocks, discolored

water, and the absence of vegetation; however, in many cases the water can appear clear and clean.

Several standard mining methods of the 1800's and early 1900's that had greatly improved efficiency and safety are now contributing to much of Pennsylvania's AMD problems. Approximately 4,600 miles of Pennsylvania's freshwater streams have been impacted by acid mine drainage flowing from abandoned deep and surface mines.



*Abandoned mine drainage (Photo courtesy of Stream Restoration Incorporated)*

## DIGGING UP THE PAST

### LOCATION, LOCATION, LOCATION

While this made for easy transportation of coal it now provides for easy transportation of AMD into the stream.

To be profitable, early coal mines needed an efficient means to transport the coal from the mine to the consumer. Most coal was moved by train. Trains, however, need a fairly flat surface to operate. Stream valleys provided this flat surface, thus, many early mine entrances were located beside a stream.



*Historically, streams were valued for transportation and as a source of power. Mills, such as the remains of this saw mill at the Jennings Environmental Education Center, were a common site along Pennsylvania's many waterways.*

*(Photo courtesy of Jennings Environmental Education Center)*



## UNDERGROUND MINING

*Physical evidence of past underground mining may often remain on the surface. These clues can often reveal the history and location of a once working mine. These sites are rich in history and problems.*

### Coal Refuse Piles

Coal refuse piles are mounds of soil, rock, coal and coal-like materials located where coal is prepared for market, often near the mine entrance. These materials are not marketable and need to be removed from the rest of the coal after leaving the mine. This is accomplished by separating the coal from the waste. Historically, young boys did this by hand. Since these materials come from deep within the mine they often contain the mineral pyrite and are a source of AMD. There are approximately 2.6 billion cubic yards (approximately 62 million tractor-trailer loads) of coal **refuse piles**

dotting the landscape of Pennsylvania. A convoy of trucks twice encircling the globe would be needed to remove Pennsylvania's coal refuse piles. Many of these piles are in or near streams, thus contributing greatly to the state's coal mine drainage problem.

### Entries

Today, entries to abandoned underground mines may appear as nothing more than a hole in the ground, but when the mine was operating they were a miners only link to the surface. Holes found around an abandoned mine site may either have been a means to enter the mine or a method of ventilation for the mine. Long after the mine has shut down, entries will continue to circulate oxygen within the mine. This constant supply of air provides the perfect environment for the formation of acid mine drainage. Abandoned mine entries also pose a safety hazard.

## TAKING ADVANTAGE OF GRAVITY

Miners in early underground mines were faced with a problem to which most of us can relate. Dig a hole and chances are it will fill with water. Having a mine fill with water was both uncomfortable and dangerous to the early coal miner. To solve this dilemma miners used the cheap and plentiful force of gravity. Rather than dig down to the coal seam, mine entrances were often located at the lowest point of the coal bed where it was exposed at the surface. This allowed water to drain out of the mine rather than collect where the miners must work. This inexpensive and efficient method of draining the mine was so effective it continues to work years after the mine has closed. Many abandoned mines have miles of underground "tunnels" that act as reservoirs to brew AMD. The result is

a steady stream of damaging mine drainage flowing from hundreds of abandoned drift mines throughout Pennsylvania. Improved mining technology, such as pumps and ventilation systems, make this method of keeping the mine safe and relatively dry obsolete. Today, every part of a mine must be located below the level of the entry, thus inhibiting the discharge of mine drainage from the entry.



*Acid drainage continuously flows from this abandoned underground mine in northern Butler County. (Photo courtesy of Stream Restoration Incorporated)*





*60,000 cubic yards of coal refuse lie within a tributary near the community of Goff Station in northern Butler County. This pile has since been removed due to ongoing reclamation efforts occurring throughout Pennsylvania.  
(Photo courtesy of Stream Restoration Incorporated)*





Subsidence depressions may cause extensive property damage.  
(Photo courtesy of US Dept. of the Interior, Office of Surface Mining Reclamation and Enforcement)

Often these entries are hidden by vegetation and go unnoticed until someone falls or a curious child decides to explore.

### Subsidence Depressions

**Subsidence depressions**, which look like sink holes, occur when the surface of the ground sinks due to significant excavation beneath the surface. Due to erosion over time, the roof of an underground mine may no longer be able to support the weight of the overlying rocks and will collapse. Areas susceptible to subsidence depressions may look stable for many years. Structures may be built in these areas, later to be severely damaged when the ground sinks. Subsidence depressions tend to collect water. This water often drains into the abandoned mine, contributing to the formation of acid mine drainage. These mine-related depressions can be dangerous. Vegetation often conceals the depression increasing the chance of an unexpected fall and injury.

## SURFACE MINES

*Abandoned surface mines are also contributing to the state's mine drainage problems. Evidence of abandoned surface mining operations are commonly seen in Pennsylvania and pose serious safety concerns.*

### Highwalls

During surface mining, a hillside is often removed to reveal the underlying coal. This vertical open cut is similar to cuts frequently seen along roadsides where a hillside has been removed to make room for the road. If the mine ceases to operate, the cut that remains is called the **final face** of the mine and is often referred to as a **highwall**. Highwalls are

extremely steep and can be dangerously high. Erosion, slumping and rockslides are commonly associated with highwalls. Today, surface mine operators are required to restore the surface of the earth to its original shape, called approximate original contour. Hillsides must be repaired so that no highwall remains.

A relatively small, yet dangerous, highwall and open pit, abandoned after a surface mining operation  
(Photo courtesy of DEP, Knox District Mining Office)





### Spoil Piles

**Overburden** removed during surface mine operations was placed in a pile near the newly exposed **pit**. These piles can become quite expansive depending on the size of the operation. These huge piles of earth contain minerals, such as pyrite, that can produce acid mine drainage when exposed to oxygen and water. Often the materials found closest to the coal seam contain these acid producing minerals. Similar to digging a hole with a shovel, the material to last be removed from the hole is placed on top of the pile and in direct contact with the air and water. Abandoned spoil piles produce a significant amount of acid mine drainage. In addition, vegetation rarely grows on these piles so wind and

rain easily erode them. This erosion causes sedimentation and increased turbidity in streams, which can choke fish and hurt vegetation.

Today surface mine operators are required to return all spoil to the pit. Usually acid producing materials are identified before mining and handled separately during the mining process. These materials are then returned to the pit “high and dry”. This simply means the material is buried deep enough under ground to avoid contact with oxygen, but not placed on the pit floor where it may come in contact with ground water. Often lime or **limestone** is mixed and buried with the spoil to neutralize the acidic material.



*Very little vegetation will grow on spoil piles, encouraging erosion and the weathering of acid bearing materials. (Photo courtesy of Jennings Environmental Education Center)*



*Abandoned mining equipment, like this stripping shovel, are a widespread reminder of busier times. (Photo courtesy of Stream Restoration Inc.)*

### Open Pits

Open pits are the holes from which coal was removed during a surface mining operation. These holes often collect large amounts of water and are commonly seen as deep ponds spanning several acres. Bordered by dangerous highwalls and large spoil piles, open pits are extremely dangerous. These pits can be attractive swimming holes to those unaware of the many hidden dangers. Several unfortunate individuals are badly injured or killed in these pits each year.

Surface mine operators are no longer permitted to leave the pit exposed.

All disturbed ground must be returned to the pre-mining shape (approximate original contour) and vegetation replaced.

The estimated cost to reclaim the land and water in Pennsylvania affected by these past mining practices is \$15 billion. No single organization or agency can possibly afford to tackle this immense challenge. Only through the partnership of concerned citizens, agencies, and industries will Pennsylvania's landscape be repaired.





## THE SOURCE AND THE IMPACT

Identifying that a stream has been impacted by acid mine drainage and determining the extent of the impact may require months of careful observation. Monitoring several physical, chemical, and biological parameters of the stream environment will provide the information necessary to accurately assess its quality. These parameters measure flow and dissolved materials, and reveal what lives and does not live in the water. Conducting these simple tests and sampling techniques provide important pieces to the complicated puzzle of understanding and correcting mine drainage.

### TALKIN' CHEMISTRY

*Several easy-to-perform chemical tests in the form of kits and meters are available to provide a general understanding of what is dissolved in the water at the time the test is performed. While these simple tests provide a quick field reference, trained laboratory professionals are necessary for an accurate analysis of water quality.*

#### pH

**pH** is a measurement of the acidity of water. pH is measured on a scale that ranges from 0-14, with 7 being neutral, anything below 7 being acidic, anything above 7 being basic. The pH scale is logarithmic, meaning that each change in pH is ten times greater than the preceding number on the scale. Typically mine drainage is acidic.

*Performing a simple analysis of water quality (Photo courtesy of Jennings Environmental Education Center)*

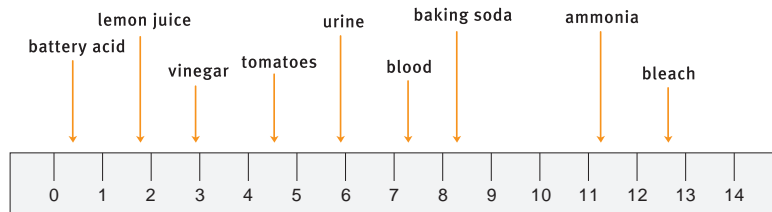
The acidity of water ultimately affects what will live there and what will be dissolved in the water. Healthy streams should have a pH no lower than 6 and no higher than 9.

#### Alkalinity

**Alkalinity** measures the water's ability to **buffer**, or neutralize acids. For example, if acid is introduced to two glasses of water, one with high alkalinity and one with none, the pH of the water containing alkalinity would remain stable while the pH of the water with little or no alkalinity would drop. Alkalinity is determined by the soil and bedrock through which a stream flows. A stream flowing through limestone bedrock will have considerably more alkalinity than one flowing through sandstone. The measure of a stream's alkalinity will determine how that stream will respond to the introduction of acidic



### pH of Some Common Substances



mine drainage. Alkalinity is measured as **parts per million (ppm)**. Parts per million is the same as **milligrams per liter (mg/l)**. Levels between 20 ppm - 200 ppm are typical for freshwater.

#### Dissolved Oxygen (DO)

Oxygen dissolved in water is necessary for the survival of most aquatic life, including fish. There are three ways in which oxygen can become dissolved in water: **aeration**, **diffusion**, and **photosynthesis**.

Aeration is the introduction of air into water by stirring or mixing. Waterfalls and **riffle areas** (rapids are riffle areas on a larger scale) in a stream provide a natural method of mixing and stirring.

Diffusion from the atmosphere occurs whenever water comes in direct contact with the air. This takes place on the surface of a body of water.

**Photosynthesis** is a process in which green plants use carbon dioxide, water, and sunlight to produce food. Oxygen is a by product of this process and is released into the water by aquatic vegetation. Plants also consume oxygen during respiration. A proper balance of aquatic vegetation is needed for optimum dissolved oxygen levels.

Many factors such as temperature, flow, and turbidity affect **dissolved oxygen (DO)**. Dissolved oxygen is measured in parts per million with levels in a stream varying between 0 ppm - 18 ppm. It is physically impossible for a stream to contain more than 18 ppm of DO. Most aquatic life cannot withstand DO below 5 ppm. A healthy stream generally has DO higher than the minimum level required by aquatic life to buffer against possible fluctuations caused by drought, temperature, or pollutants.

#### Turbidity

**Turbidity** measures the amount of suspended solids (sand, silt, organic materials, etc.) in the water. Turbidity in a stream can increase as a result of erosion. Mining, construction and agriculture are activities that may contribute to erosion. Increased turbidity reduces the amount of light that can penetrate the water. As a result, photosynthesis in plants is reduced, decreasing the amount of oxygen dissolved in the water. Soil particles in the water also absorb heat, raising a stream's temperature, which also affects dissolved oxygen levels. Increased turbidity decreases visibility and makes it difficult for aquatic organisms to locate food. Turbid water can clog gills making breathing difficult.

Turbidity is measured in **nephelometric turbidity units (NTU's)**. To safely maintain aquatic life a freshwater stream should not exceed 100 NTU.



Dissolved oxygen meter (Photo courtesy of Alan J. King)

### Sulfates

Sulfate in water is the result of the weathering of sulfate bearing minerals such as pyrite. Since pyrite is the principle cause of acid mine drainage, sulfate is an excellent indicator that streams may be impacted by a mine discharge. A sulfate level of 250 ppm or higher in water is considered to be unsafe to drink.

### Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as iron and sulfates. Distilled water, having no dissolved solids, has virtually no conductivity. Conductivity is primarily affected by the geology of the area through which the water flows. Conductivity is measured in micromhos per centimeter. Streams that support a healthy population of fish and aquatic insects range from 150 to 500 micromhos per centimeter.

These parameters are all interrelated. What affects one will affect the other.

## ACID MINE DRAINAGE: A PROFILE IN POLLUTION

Unfortunately, there is not one set of standards that will identify mine drainage 100% of the time. However there are many typical characteristics that may lead you to believe that there is abandoned mine drainage impacting a stream.

**Color**—Mine Drainage may take on a variety of colors that can be easily recognized as a pollution problem. Most common is an orange/red residue and staining called **yellow boy**. This sludge like material is iron that was previously dissolved in the water but has since returned to its solid form. Certain types of mine drainage may appear milky or have a white cast to it. This signifies the presence of aluminum. Often the most polluted mine drainage is crystal clear, appearing to be pure water. This is the result of the water being so acidic that all pollutants are completely dissolved.

**pH**—Typical acid mine drainage has a pH of less than 6 although mine drainage greater than 6 (alkaline mine drainage) can also occur. For this reason pH should never be the sole method of determining a mine drainage problem.

**Iron**—Elevated levels of iron are almost always associated with mine drainage.

Levels greater than 5 ppm are usually indicative of mine drainage. It is not uncommon for levels of iron to exceed 100 ppm. If the stream bottom is coated with yellow boy, the iron may no longer be dissolved in the water and will not register on an iron test.

**Dissolved Oxygen**—Typically mine drainage has very low (less than 3) levels of dissolved oxygen.

**Sulfates**—High concentrations of sulfates are typically found in mine drainage. For this reason, sulfates are generally a good indicator of mine drainage. Sulfate levels exceeding 50 ppm reveal a possible mine drainage problem.



Abandoned Mine Drainage  
(Photo courtesy of Jennings Environmental Education Center)



## LIFE ON THE BOTTOM

*A healthy stream contains a myriad of interconnected and often unnoticed life that precariously depends on an ever changing environment. These organisms act as a natural barometer measuring a stream's health over an extended period of time.*

Life in a stream begins when organic materials, such as fallen leaves, land in the water and sink to the bottom. Bacteria, attracted to this material as a food source, quickly begin the decomposition process. The resulting bacteria-laden organic material, called

**detritis**, is the keystone for an intricate underwater food web.

Detritis is the primary food source for many cold-blooded aquatic organisms called **macroinvertebrates**. These are organisms with no backbone but are large enough to see with the unaided eye. Organisms such as stonefly nymphs and mayfly nymphs tear apart the decaying plant material with powerful mouth parts. This beneficial dismemberment of detritis has earned these animals the distinction of being called **shredders**. Other aquatic insects armed with mouth parts specifically adapted for removing algae from rocks and vegetation are called **scrapers**.

These shredders and scrapers are sloppy eaters. They reduce the decaying plant material and algae into bite size particles that become suspended in the stream. Many aquatic organisms depend on this floating food. **Collectors**, such as caddisfly larvae, attach themselves where food continuously floats by.

Ferocious predators, such as dobsonfly larvae, tirelessly hunt the stream bottom for tasty shredders, scrapers, and collectors. Strong and fast, these organisms are the lions of the stream.

Acid mine drainage can have a devastating impact on the stream environment and on the creatures that live there. Yellow boy (pg. 47) coats the bottom of a stream, suffocating all organisms that live on the bottom and destroys their food supply. High acidity affects respiratory functions and reproduction. Dissolved metals act as lethal poisons. Silt clogs gills, lowers visibility and can ultimately affect the amount of oxygen dissolved in the water.

The PA Fish and Boat Commission estimates the value of lost recreational fishing opportunities due to AMD at \$67 million per year.

Common adult, aquatic organisms



Students collecting aquatic organisms (Photo courtesy of Jennings Environmental Education Center)

## 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.

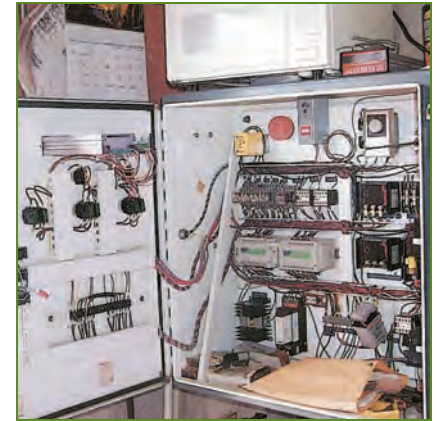


Typical equipment used to actively treat mine drainage (Photo courtesy of Robert Beran)

### 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

## NATURALLY INNOVATIVE SOLUTIONS

### 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 County  
(Photo courtesy of Stream Restoration Inc.)



## CHAPTER FOUR

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.

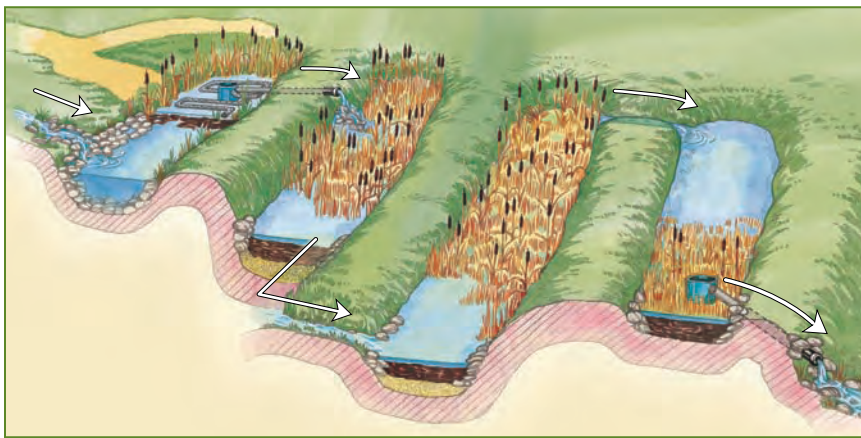


Illustration of the constructed wetland at Jennings



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



## CHAPTER FOUR

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.

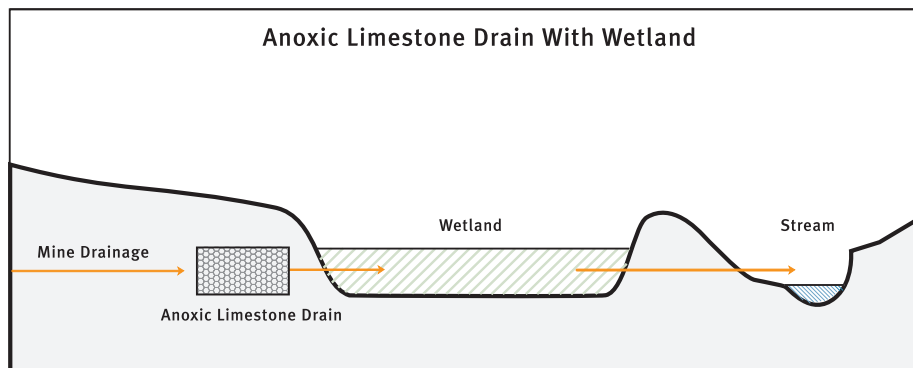
### Anoxic Limestone Drain (ALD)

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



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.

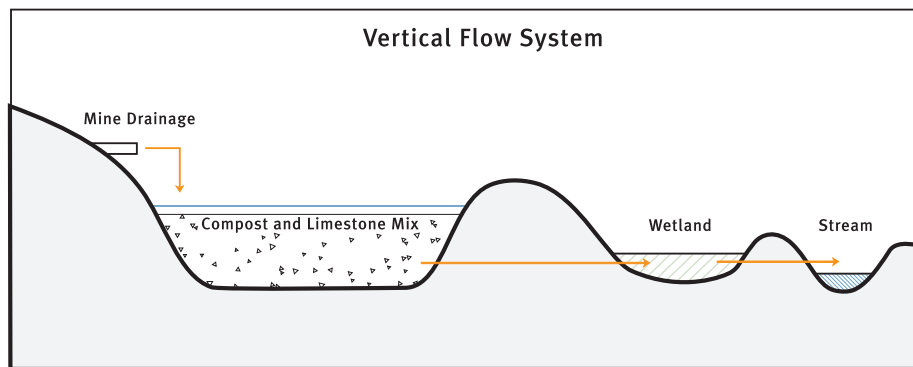
Not all water can be effectively treated with an ALD. Water containing significant levels of dissolved oxygen, aluminum, or **ferric iron** will quickly plug the drain with metal precipitates.

### 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.

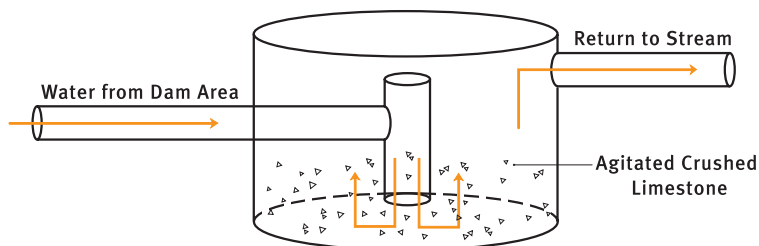
Aluminum will precipitate within the system. The vertical flow system should be designed to create enough downward pressure to prevent aluminum precipitate from plugging the system. The depth of standing water, or head, in the pond controls downward pressure. Additional measures to avoid plugging may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

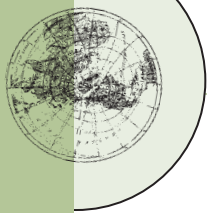
Vertical flow systems are relatively new. Continuing research is being conducted to monitor their effectiveness over long periods of time. Different organic materials are also being tried because spent mushroom compost, although easy to obtain in Pennsylvania, may be hard to get in other states or countries.

### Diversion Wells

A **diversion well** consists of a vertical tank filled with aggregate 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.

Schematic View of a Diversion Well





## GETTING STARTED

Determining which passive treatment method is best suited for a specific drainage problem can be a tricky task. Several variables exist which make each individual contaminated discharge unique. These variables require every system to be custom designed to fit the parameters associated with the affected site. This individual attention allows each damaged site to teach us something new about fixing an old problem.



*Monitoring the effectiveness of a passive treatment system  
(Photo courtesy of Alan J. King)*

### HOMework FIRST

*Just as assignments in school provide the hands-on experience necessary to build a solid educational foundation, a great deal of research and studying is required before a polluted discharge can be remedied.*

A great deal of homework is required before a type of system is chosen or developed. This homework uncovers valuable information critical to the successful treatment of the degraded water. Using this information, important steps should be methodically taken to ensure that the correct passive technology is applied and properly constructed.

#### Identify the source of the drainage

Similar to a research assignment, this step helps determine where the mine

drainage is coming from. Obtaining mine, soil, and topographic maps of the area provides an understanding of what type of mining occurred and how it may have affected the landscape. These valuable resources may reveal tunnels, shafts, or waste piles that could be a source of contaminated drainage. Many important decisions, such as drainage characteristics and erosion control methods, are based on this information.

#### Determine water quantity

This information is the cornerstone to determining the type and size of system or systems to be installed. An accurate measurement of AMD discharge rates will prevent the under-sizing of a system, which may result in the unsuccessful treatment of AMD. Nothing technical needed here, a bucket, stopwatch, and simple calculator work well. Gallons per minute can be easily calculated by timing how





Typical "V notch" weir used to measure the flow of a small stream  
(Photo courtesy of Jennings Environmental Education Center)

long it takes to fill a bucket of known volume. For example, if it takes 5 seconds to fill a 1 gallon bucket, divide 60 seconds by 5 to determine that the flow is 12 gallons per minute. Weirs are another method used to determine flow rates. Often weirs are constructed at the discharge point. These simple devices resemble a miniature dam. Water flows through a notch cut into this dam.

By measuring the height of the water in this notch and using a simple equation, flow rates can be determined. Often mine drainage has a diffuse flow over a large area making it impossible to measure accurately. Collection ditches are often necessary to collect the water and channel it to a localized discharge point.

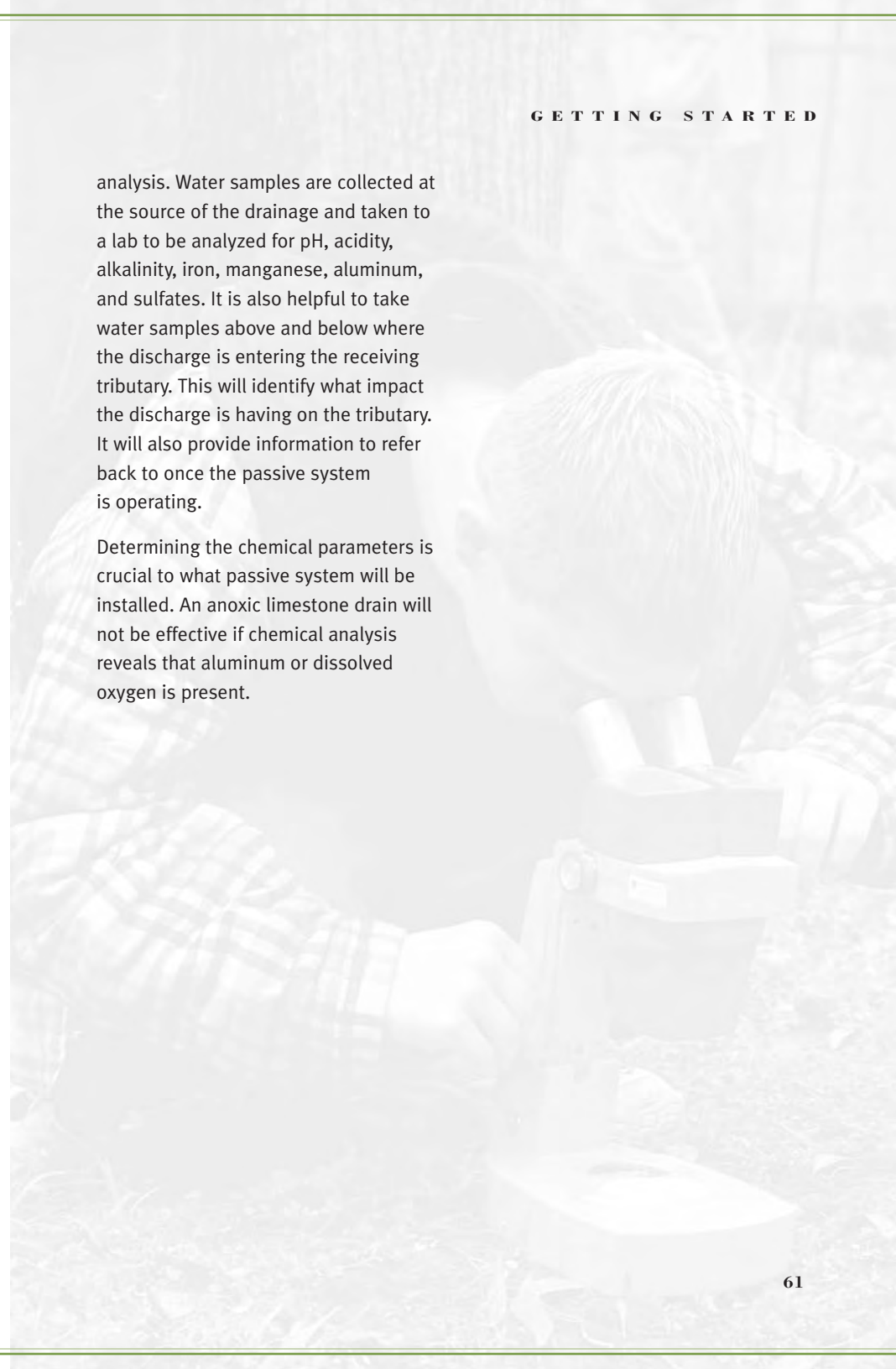
It is important for the water flow to be measured several times throughout the year. Flow can change drastically depending on the season or due to storm events. For a passive system to successfully treat AMD throughout the year, it must be able to handle fluctuations in flow.

#### Determine water quality

Chemical analysis in the field is done to gain a general understanding of what is dissolved in the water. Careful chemical monitoring of the discharge is done in the laboratory for complete and accurate

analysis. Water samples are collected at the source of the drainage and taken to a lab to be analyzed for pH, acidity, alkalinity, iron, manganese, aluminum, and sulfates. It is also helpful to take water samples above and below where the discharge is entering the receiving tributary. This will identify what impact the discharge is having on the tributary. It will also provide information to refer back to once the passive system is operating.

Determining the chemical parameters is crucial to what passive system will be installed. An anoxic limestone drain will not be effective if chemical analysis reveals that aluminum or dissolved oxygen is present.







*Iron precipitating out of severely degraded mine drainage formed this eight foot "wall of iron" in Indiana County, PA  
(Photo courtesy of Stream Restoration Inc.)*





Members of the Slippery Rock Watershed Coalition at the Jennings Research and Demonstration Site  
(Photo courtesy of Alan J. King)

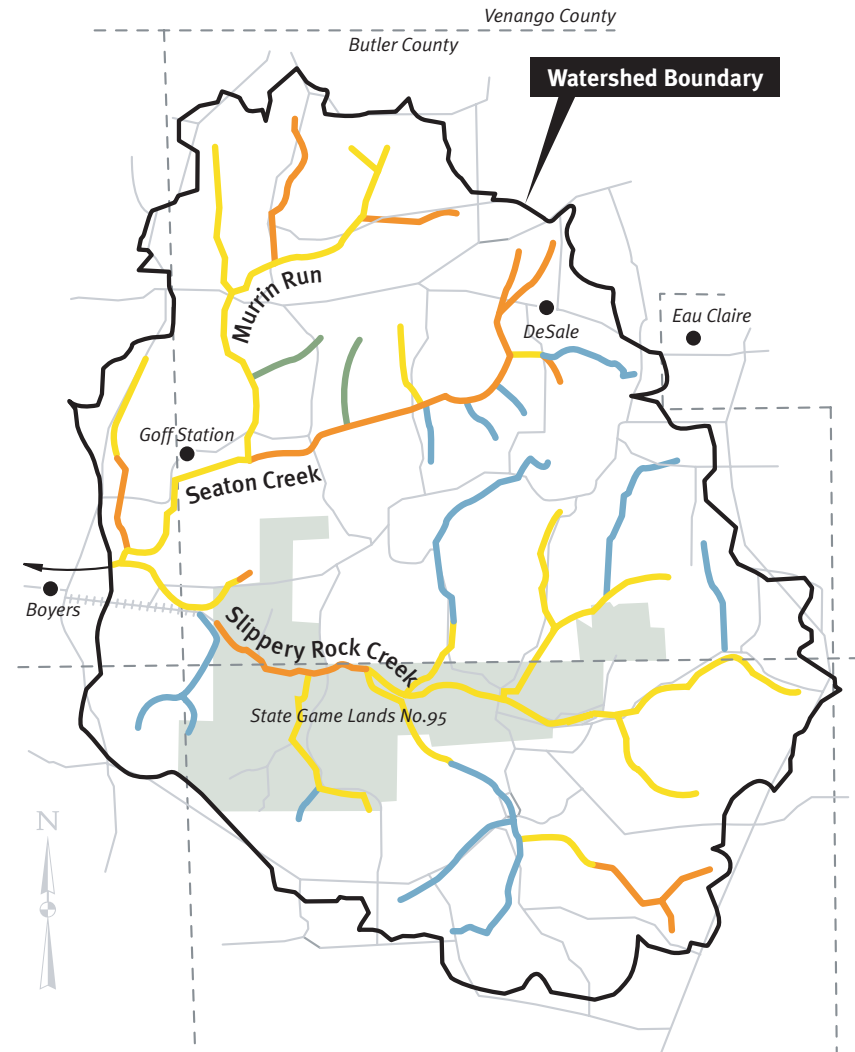
## ACCEPTING THE CHALLENGE

*Pennsylvania has the largest inventory of abandoned mine land problems in the entire United States. No one government agency, business, or concerned group of individuals can hope to restore the entire state. Only through cooperative partnerships, statewide concern, and the innovation of improved treatment techniques will this unfortunate legacy be resolved.*

Throughout Pennsylvania the effort is underway to improve freshwater streams impacted by acid mine drainage. Hundreds of passive systems have been designed and constructed for polluted discharges with unique flows and water chemistry.

Many of these systems are the result of the dedication and hard work of government agencies and private watershed associations throughout Pennsylvania and the rest of the country. One such grassroots effort to improve water quality is taking place in western Pennsylvania. The Slippery Rock Watershed Coalition is a unique blend of citizens, industries, state and federal agencies, and colleges and universities dedicated to restoring an area in northern Butler county that has been impacted by over a century of mining. This area, called the Slippery Rock Creek Study Area, is a 27 square mile drainage basin comprising the headwaters of the Slippery Rock Creek. Every tributary within this watershed is negatively impacted by acid mine drainage which stems from over 260 known abandoned, underground mine openings and more than 15,000 acres of unreclaimed

## SLIPPERY ROCK WATERSHED COALITION STUDY AREA



- **GOOD** (pH > 6, acidity < alkalinity, iron < 1mg/l)
- **ACID SENSITIVE** (pH 5 to 6, sulfates < 50mg/l)
- **ACID MINE DRAINAGE IMPACTED** (pH 5 to 6, sulfates > 50mg/l)
- **POLLUTED** (pH < 5, acidity > alkalinity, iron > 1.5mg/l)



Charles Cooper, CDS Associates Inc. engineer, overseeing the construction of a vertical flow system at the Jennings Research and Demonstration Site (Photo courtesy of Stream Restoration Inc.)

surface mines. Residents of what was once bustling mining communities located along these streams jokingly refer to the Slippery Rock Creek as “Sulfur Creek” due to the orange color of the water and stream banks. The Pennsylvania Department of Environmental Protection, District Mining Office, Knox Office, has inventoried virtually every potentially dangerous or environmentally degrading relic of historical mining activity in this area. The result of this painstaking inventory is a collection of water quality data, detailed maps and recommended prescriptions for restoration. The Slippery Rock Watershed Coalition uses this valuable Comprehensive Mine Reclamation Strategy as a master plan to reclaim the headwaters of the Slippery Rock Creek.

The combined talents, experience, knowledge, and vast resources of all Slippery Rock Coalition members has, to date, effectively eliminated over 210 tons of metals and 335 tons of acidity from entering the Slippery Rock Creek every year. Over 1,450 gallons per minute of mine drainage are being abated and about 150 acres of land have been reclaimed. In 1998, fish were observed in a four-mile section of the creek, which has probably been devoid of most aquatic life for over a century. News of the Coalition’s success has spread quickly. Community support and state funding opportunities will allow many proposed restoration projects to occur. The complete restoration of the study area may one day be achieved thanks to the cooperative efforts of a dedicated group of people.

### Demonstrating Success

The goal of the Slippery Rock Watershed Coalition is to not only restore the Slippery Rock Creek to a viable fishery but also to provide educational opportunities to students of all ages and the general public. This is accomplished through partnerships with educational institutions that provide opportunities for demonstration, research, and interpretation. Students from local high schools, colleges, and universities monitor the tributaries of the study area, conduct environmental assessments, participate in system installation, and conduct valuable, ongoing research studying the long-term effectiveness of passive technology. These opportunities and all information are open to any interested group or individual.

The Jennings Environmental Education Center, a Pennsylvania state park within the Department of Conservation and Natural Resources, is one of the Coalition’s several educational partners. Jennings is a truly unique acid mine drainage, research and demonstration site. It offers possibly the best working model of passive treatment techniques, most notably a uniquely designed vertical flow system, in the world. The vertical flow system at Jennings was designed to treat water that had been unsuccessfully treated by a previously installed anoxic limestone drain and aerobic wetland. The source of the drainage is an abandoned deep mine that operated from the early 1900’s to 1940’s. This abandoned mine releases 30 gallons per minute of drainage containing a pH of 3, 50 milligrams per liter of iron, and 20 milligrams per liter of aluminum.

Students participating in an environmental education program at the Jennings Environmental Education Center (Photo courtesy of Jennings Environmental Education Center)





## CHAPTER FIVE

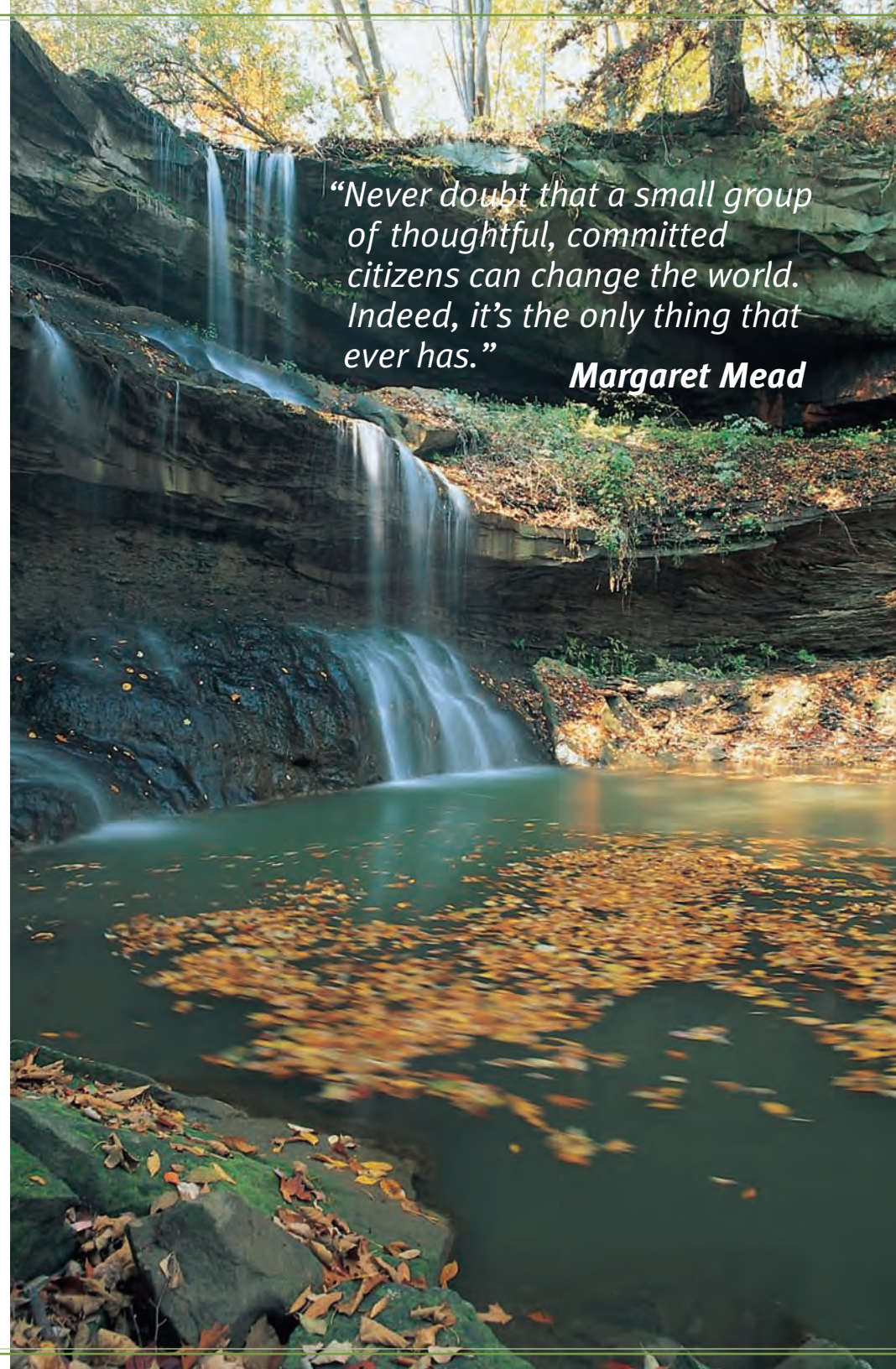
Using 300 tons of spent mushroom compost mixed with 380 tons of limestone aggregate, a 150 foot long, 50 foot wide, 6 foot deep vertical flow system was constructed. The drainage was improved, raising the pH to 7 and reducing iron and aluminum to less than 1 milligram per liter.

Students and volunteers worked side by side with engineers, designers and equipment operators to construct this innovative way of treating acid mine drainage. From its inception, this vertical flow system was designed to demonstrate research in action. Jennings offers year round educational programs that explain the passive treatment of acid mine drainage, introduce stream ecology, and interpret the cultural history of coal mining in the area. The Jennings site is open to the public 365 days a year. Interpretive exhibits at the site describe its long history and the many accomplishments that have taken place there. For more information about Jennings, the Slippery Rock Watershed Coalition, or acid mine drainage in general, call the Jennings Environmental Education Center, Monday through Friday, from 8:00 a.m. to 4:00 p.m. at (724) 794-6011.

This book does not contain the magic formula for restoring land and water to its pre-mining condition. It does, however, offer hope that progress is being made. Theories and ideas concerning abandoned mine restoration are put to the test everyday. Someday, a groundbreaking discovery may come from one of these ideas and that idea may come from the least likely source imaginable. For this reason, the Slippery Rock Watershed Coalition firmly believes that every interested and concerned citizen has something positive to contribute. It will continue to welcome any individuals with an interest in watershed restoration and share all achievements and discoveries with the world.

*“Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it’s the only thing that ever has.”*

**Margaret Mead**



## GLOSSARY

***abandoned mine drainage (AMD)*** *p. 25*  
Drainage flowing from or caused by surface mining, deep mining or coal refuse piles that is typically highly acidic with elevated levels of dissolved metals.

***Abraham Darby*** *p. 7* An English Quaker familiar with both the brewing industry and the iron industry. He determined that coke was suitable for producing iron.

***aeration*** *p.38* The introduction of air into water by stirring or mixing.

***aerobic*** *p. 50* A term referring to processes or organisms that occur or are active in the presence of oxygen.

***alkalinity*** *p. 37* The measurement of the ability of water's capacity to neutralize acids.

***anaerobic*** *p.56* A term referring to processes or organisms that occur or are active in the absence of oxygen.

***anoxic limestone drain (ALD)*** *p. 52*  
An anoxic limestone drain (ALD) is a buried bed of limestone constructed to intercept subsurface mine water flows. ALD's are used to prevent contact with atmospheric oxygen and retain carbon dioxide, which in turn, generates more alkalinity. Sediment ponds are constructed after an ALD to accumulate the iron oxide precipitates.

***black lung disease*** *p.17* A condition of the lungs that is caused by the inhalation and deposition of coal dust within the lungs resulting in violent and uncontrollable coughing.

***blast furnace*** *p. 4* A tower like furnace which uses a blast of air forced into the furnace from below to produce the intense heat needed to separate metals from the impurities in the ore.

***boom*** *p. 22* A long beam which can be swung laterally and vertically above its pivot. At the far end cables and a digging bucket can be mounted.

***breaker*** *p. 14* A machine which combines coal crushing and screening. Normally consists of a rotating drum in which coal is broken by gravity impact against the walls of the drum.

***breaker boy*** *p.14* A young boy who worked in the breaker where he separated slate and rock from the coal.



**buffer** *p.37* The ability to resist changes in pH when an acid or base is added. For example, alkalinity buffers the stream against acid mine drainage. However, if the drainage uses up the alkalinity, the stream loses its buffering capacity.

**carbon monoxide** *p.17* (CO); A colorless, odorless, highly poisonous gas produced by the incomplete burning of any carbonaceous material.

**charcoal** *p.4* The residue, primarily carbon, from the partial combustion of wood or other organic matter.

**coal** *p.2* Coal is a combustible rock of organic origin composed mainly of carbon (50-98%), hydrogen (3-13%) and oxygen, with lesser amounts of nitrogen, sulphur and other elements. Some water is always present, as are grains of inorganic matter that form an incombustible residue known as ash.

**coal auger** *p.11* (1) A primitive tool resembling a brace and bit used to drill a hole in the coal in which explosives would be placed. (2) A special type of continuous miner that consists of a large diameter screw drill which cuts, transports, and loads the coal onto vehicles or conveyors.

**coke** *p. 6* A hard, dry carbon substance produced by heating coal to a very high temperature in the absence of air. Coke is used in the manufacture of iron and steel.

**collectors** *p. 43* Aquatic organisms who feed on the bite-sized suspended particles that are left over by the shredders and scrapers.

**continuous miner** *p. 12* A piece of mining equipment which produces a continuous flow of ore from the working face.

**contour mining** *p. 22* A technique of open cut mining in which coal beds are mined in relatively level benches along a hillside.

**cutting machine** *p. 11* A machine, usually used in coal, that will cut a 10- to 15-cm slot. The slot allows room for expansion of the broken coal after blasting.

**detritis** *p. 42* Freshly dead or partially decomposed organic material.

**diffusion** *p. 38* (1) The intermingling or mixing of the molecules of two or more substances. (2) The process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration.

**dissolved oxygen** *p. 38* The amount of oxygen gas (O<sub>2</sub>) dissolved in a given volume of water at a particular temperature and pressure. Usually expressed in concentrations in parts per million (ppm) or milligrams per liter (mg/L).

**diversion well** *p.57* A vertical tank filled with limestone aggregate that generates alkalinity by turbulently mixing and abrading the limestone into fine particles.

**dragline** *p.22* An excavating machine that uses a bucket operated and suspended by lines or cables, one of which lowers the bucket from the boom; the other, from which the name of the machine is derived, allows the bucket to swing out from the machine or to be dragged toward the machine to remove overburden above a coal seam.

**drift mine** *p.10* A mine that opens into a horizontal or practically level seam of coal. This type of mine is generally the easiest to open as the mine opening enters into the coal outcrop.

**emphysema** *p.17* An abnormal swelling of lung tissue which causes difficulty in breathing.

**ferric iron** *p.54* An oxidized form of iron (Fe<sup>+3</sup>). The precipitate is yellow to red in color.

**final face** *p.33* The exposed area of a coal bed.

**highwall** *p. 22,33* The unexcavated face of exposed overburden and coal in a surface mine.

**James Watt** *p.15* (1736 -1819) An instrument maker who improved upon Thomas Newcome's atmospheric steam engine and went on to invent the first true steam engine.

**limestone** *p.34* A sedimentary rock consisting chiefly of calcium carbonate primarily in the form of the mineral calcite and with or without magnesium carbonate. It can be formed through either organic or inorganic process. Limestone effervesces freely with any common acid.

**longwall mining machine** p.13

One of three major underground coal mining methods currently in use. Employs a steel plow, or rotation drum, which is pulled mechanically back and forth across a face of coal that is usually several hundred feet long. The loosened coal falls onto a conveyor for removal from the mine.

**macroinvertebrates** p.42 Organisms with no backbone but are large enough to see with the unaided eye.

**methane** p.17 ( $CH_4$ ); The most simple of the hydrocarbons formed naturally from the decay of vegetative matter, similar to that which formed coal. It is the principal component of natural gas.

**milligrams per liter (mg/L)** p.38 A unit measure of the concentration of a component substance measured by the amount of milligrams of that substance that exists in one liter of a particular liquid which is typically water.

**nephelometric turbidity units (NTU's)**

p.39 A unit measure of turbidity in which the intensity of light scattered by the sample under defined conditions is compared to the light scattered by a standard reference suspension under the same conditions.

**nipper** p.14 A young boy whose job it was to open the mining doors whenever a mule-drawn mine car passed through. Also called a trapper or door boy.

**open limestone channels (OLC)** p.51

A limestone-lined ditch that increases oxidation and generates alkalinity through limestone dissolution.

**ore** p.4 The naturally occurring material from which a mineral or minerals of economic value can be extracted.

**overburden** p.21 Layers of soil and rock covering a coal bed. Overburden is removed prior to surface mining and replaced after the coal is removed.

**oxidation** p. 50 A natural chemical reaction that occurs in the process of oxygen.

**pan line** p.13 A conveyor system which transports the coal to coal cars or a belt conveyor to be transported out of the mine.

**parts per million (ppm)** p. 38 The unit measure of the concentration of a component substance. For example a 1 ppm concentration of iron is 1 part iron to 999,999 parts of other material. It also is equal to mg/L.

**Passive Treatment** p. 46 The use of naturally occurring chemical and biological reactions to effectively and economically remove contaminants from mine drainage.

**pH** p.37 The negative log<sub>10</sub> of the hydrogen-ion activity in solution which is a measure of the acidity or basicity of a solution. The pH scale is from 0-14. A low pH is acidic where as a high pH is basic and 7 being neutral.

**photosynthesis** p.38 A complex process by which plants use carbon dioxide, water, and sunlight to produce oxygen, carbohydrates, and other nutrient molecules.

**pit** p.34 The area exposed to extract coal by removing the overburden.

**precipitate** p.47, 51 A substance which separates from a solution as a solid by the action of chemical reagents, temperature, pH, etc.

**pyrite** p. 25 A hard, heavy, shiny, yellow mineral, FeS<sub>2</sub> or iron disulfide, generally in cubic crystals. Also called iron pyrites, fool's gold, sulfur balls. Iron pyrite is the most common sulfide found in coal mines.

**reclamation** p. 21 Restoring the land to approximate pre-mining conditions or to other viable land use.

**refuse piles** p.28 Mounds of generally poor quality coal-like materials located where coal was prepared for market.

**reverberatory furnace** p. 4 A furnace with a shallow hearth, usually non-regenerative, having a roof that deflects the the flame and heat downwards toward the hearth or the surface of the charge so that the material to be smelted would not need to be mixed with the fuel which would result in impurities.

**riffle areas** p.38 A shoal, reef, or rocky obstruction in a stream, producing a ripple or a stretch of shallow, rapid, or choppy water.

**rock dust** p.18 Finely ground limestone applied to the walls, ceiling, and floor of a mine to suppress potential fires.

**roof bolt** p. 10 A long steel bolt driven into the roof of underground excavations to support the roof, preventing and limiting the extent of roof falls. The unit consists of the bolt (up to 4 feet long), steel plate, expansion shell, and nut. The use of roof bolts eliminates the need for timbering by fastening together, or "laminating," several weaker layers of roof strata to build a "beam."



**room and pillar method** p. 12

A method of mining flat-lying ore deposits in which the mined-out area, or rooms, are separated by pillars of approximately the same size.

**scrapers** p. 42 Aquatic organisms that have mouth parts specifically adapted for removing algae from rocks and vegetation.

**shredders** p. 42 Aquatic organisms that tear apart decaying plant material with powerful mouth parts.

**smelting** p. 4 A process in which molten metal or molten slag is produced by separating the pure metal from extraneous or impure substances with the use of heat.

**spent mushroom compost** p.48, 55  
Compost used by the mushroom industry consisting of hay, straw, horse and chicken manure, and gypsum that has been exhausted of the proper nutrients to grow mushrooms.

**spoiled** p.21 The act of removing overburden from its original location to gain access to the ore or mineral in surface mining.

**stripping shovel** p.22 A machine which is mounted on crawler tracks similar to a bulldozer and has an especially long boom with a bucket that shovels the overburden instead of dragging and scooping allowing it to reach further and pile higher.

**subsidence** p.13, 32 The gradual sinking, or sometimes abrupt collapse, of the rock and soil layers into an underground mine. Structures and surface features above the subsidence area can be affected.

**sulfuric acid** p. 26 A highly corrosive liquid ( $\text{H}_2\text{SO}_4$ ) which is formed upon weathering of pyrite.

**surface mining** p. 21 A mine in which the coal lies near the surface and can be extracted by removing the covering layers of rock and soil.

**Thomas Newcome** p. 15 (1663- 1729)  
A craftsman who built the first atmospheric steam engine which provided a continuous source of power to drive a pump.

**vertical flow system** p. 54 Vertical flow systems (VFS) consist of a treatment cell (pond) filled with limestone and sometimes topped with a layer of organic matter. Water travels vertically through the decaying matter and limestone removing oxygen and generating alkalinity, respectively.

**wetland** p. 46 Land that is permanently or periodically inundated with water sufficient to establish hydrophytic vegetation and anaerobic soil conditions.

**working face** p.13 Any place in a mine where material is extracted during a mining cycle.

**yellow boy** p. 41 An orange/red residue and staining which is iron in its solid form.

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## **Additional Resources**

The Pennsylvania Iron Industry - <http://explorepahistory.com/story.php?storyId=29>

Overview of the History of the Iron Industry - <http://www.history.com/topics/iron-and-steel-industry>

Mining Anthracite - <http://explorepahistory.com/story.php?storyId=11>

Mining Bituminous - <http://explorepahistory.com/story.php?storyId=30>

Coal Mining in Pittsburgh and Western PA (a list of good links) - <http://pittsburgh.about.com/cs/coal/>

McIntyre, Pennsylvania, The Everyday Life of a Coal Mining Company Town: 1910-1947  
photos, documents, memories of town residents - <http://www.mcintyrepa.com/frontpage.htm>

American Coal Foundation - <http://www.teachcoal.org/>

PBS (mountaintop removal mining) <http://www.pbs.org/independentlens/razingappalachia/mtop.html>

National Mining Association (info and stats about energy and coal) - <http://www.nma.org/>

Macroinvertebrate Key and Field Guide Links - <http://www.watersheded.dcnr.state.pa.us/what/macroslinks.html>

Virtual Museum of Coal Mining In Western Pennsylvania - <http://patheoldminer.rootsweb.ancestry.com>

Western Pennsylvania Coalfields - <http://www.coalcampusa.com/westpa/index.html>

Indiana University of Pennsylvania Coal Culture Projects - <http://www.iup.edu/archives/coal/default.aspx>

Passive Treatment Overview (variety of links to AMD, watersheds, laws and policies) -  
<http://www.amrclearinghouse.org/Sub/AMDtreatment/PassiveTreatment.htm>

Eastern Pennsylvania Coalition For Abandoned Mine Reclamation - <http://www.epcamr.org/>

Western Pennsylvania Coalition For Abandoned Mine Reclamation - <http://www.wpcamr.org/>

Pennsylvania Abandoned Mine Reclamation Annual Conference – <http://www.treatminewater.com/>

American Society of Mining and Reclamation - <http://www.asmr.us/>

National Association of Abandoned Mine Land Programs - <http://naamlp.net/>

U.S. Office of Surface Mining Reclamation and Enforcement - <http://www.osmre.gov/>

Handbook of Technologies for Avoidance and Remediation of Acid Mine Drainage  
<http://www.techtransfer.osmre.gov/NTTMainSite/Library/hbmanual/hbtechavoid/front.pdf>

International Mine Water Association - <http://www.imwa.info/>

Datashed (provides info and water quality data for specific mine drainage treatment projects <http://www.datashed.org/>

## **Lesson Plans**

Edible Coal Mining - <http://explorepahistory.com/viewLesson.php?id=91>

American Coal Foundation (variety of lesson plans) - <http://www.teachcoal.org/lessonplans/index.html>

Working Where the Sun Never Shines - <http://explorepahistory.com/viewLesson.php?id=92>

US Department of Energy NETL Lesson Plans - <http://www.netl.doe.gov/education/teachers.html#LESSONPLANS>

Lesson Planet (search engine for teachers with a huge library of coal related lesson plans) - <http://www.lessonplanet.com/search?keywords=coal&media=lesson>

Winnie Palmer Nature Reserve - <http://www.wpnr.org/>

Kentucky Coal Education - <http://www.coaleducation.org/lessons/primary.htm>

Schuylkill Intermediate Unit 29 Mining Resources - <http://www.iu29.org/Resources/CoalRegion.asp>

Franz Kline art project - <http://www.crayola.com/lesson-plans/detail/mine-the-work-of-franz-kline-lesson-plan/>

Danger at the Breaker - <http://www.lessonplanspage.com/LASSDangerAtTheBreaker-ComprehensionSkills-CoalMining24.htm>

Hot Chalk Lesson Plans Page (search engine for lesson plans) - <http://www.lessonplanspage.com/>

Coal Mining and Coal Towns in Western Pennsylvania - <http://www.lib.iup.edu/depts/speccol/Coal%20Culture/lessonplans/towns.pdf>

42 Explore Mining - <http://42explore.com/mining.htm>

Historical Society of Pennsylvania - <http://www.hsp.org/default.aspx>



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