Abandoned Mine Drainage: An Epic Tale

Join a Cast of Watershed All-Stars in this entertaining, educational film about:
How Abandoned Mine Drainage is formed,
The damage it causes, and
The ways you can help with the solution to the problem

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DVD
Contaminated water seeping from abandoned coal mine areas (commonly known as abandoned mine drainage or AMD) is the most severe water pollution problem in the coal fields of the Appalachian mountains of the eastern United States and certainly in the bituminous and anthracite coal fields of Pennsylvania." (Daymut, 2010)

Water pollution is a problem that affects each one of us in our daily lives whether we are aware of it or not, especially those that live in mining impacted areas. You drink water don’t you? Cook and wash dishes? Even washing your car requires clean water to start with. In order to do something about this pollution problem we still have to know a few more specifics about AMD pollution and where it comes from.

The Mine

Mining is the removal of a natural resource from the earth. In this instance the resource mined is coal which was laid down in the Carboniferous Period of Geologic Time. Carboniferous, meaning "contains coal", is a geologic time period that extends from the end of the Devonian Period, about 360 million years ago, to the beginning of the Permian Period, about 300 million years ago, abbreviated mya. This period in North America is further broken down into 2 sub-periods: the younger (more recent) being the Pennsylvanian (~300-320 mya) and the older being the Mississippian (~320-360 mya). It was a time of moving glaciers, low sea level, mountain building, and included a minor marine life extinction event in the middle of the period.

Many coal beds were created globally during this period, hence the name. (Carboniferous, 2010)

Why is coal mined?

The Carboniferous coal beds provided much of the fuel for power generation during the Industrial Revolution and are still of great economic importance today. Approximately 56% of Pennsylvania’s energy is produced from burning coal.

Coal can be...

- burned to produce electricity,
- used in producing iron and steel,
- transformed into hundreds of useful compounds like makeup, pencil graphite and soda water

![Image of coal formation](https://example.com/coal_formation.png)
How is coal mined?

Underground

“Room and Pillar” Mining - leaves about 50% of the coal behind to support the mine roof
Longwall Mining - removes all coal from a “panel” (hundreds of acres) & causes subsidence

Surface Mining
Removes all earth above a coal seam (overburden) to get to the coal… laws now require that the land be returned to the approximate original landscape after mining.

Abandoned Mine Drainage (AMD) problems result when surface water touches abandoned waste rock and other earthen materials pulled from the mine that now lay on the surface of the ground. It can also happen when groundwater seeps into empty spaces or voids in an underground mine where it comes in contact with remaining coal or rock strata. If the water becomes acidic, it is referred to as “acid mine drainage”. Just about every mine produces a different mix of mine drainage based on many different geochemical reactions that take place in the mine or mine spoil. Carboniferous rocks in eastern North America are largely made up of repeated layers of limestone, sandstone, shale and coal beds. As these layers were disturbed through mining, water soaked into them and mixed with minerals that had been buried for millions of years. In North America, the early Carboniferous rock stratum is largely marine limestone, which accounts for added alkalinity in some mine drainage. (Carboniferous, 2010)

The vast majority of this kind of pollution is caused by old mining operations that were abandoned after the coal was removed. In some cases, the AMD is from very old mining operations dating from the late 1800’s. Prior to 1977, the laws governing coal mining operations were less strict about protecting the environment. It was very common to simply abandon mine sites after the coal reserves were used up, and then the company would declare bankruptcy. This allowed the mining operators to walk away from liabilities, including environmental devastation. **Thousands of old underground mines, un-reclaimed strip mines, and coal refuse piles are all active AMD pollution factories on duty 24/7.**

The Extent of Damage

Just how severe is this AMD problem?

Approximately 6% (over 5,000 miles) of streams in Pennsylvania are damaged by AMD. The pollution starts in coal mines in the anthracite and bituminous coal regions in northeastern and western Pennsylvania. However, water flows downstream and impacts ecosystems far outside of the coal region.

Although mining-related stream pollution occurs throughout the Appalachian Mountains, the most damaging drainage occurs when coal was mined from coal seams from the Pennsylvanian geologic age. (Dulong, 2002)
Mine drainage is prevalent in many streams in western and northeastern Pennsylvania, and northern and south central West Virginia. Mine drainage also pollutes streams in southwestern Virginia, southeastern Ohio, southeastern Kentucky, and western Maryland within the northern Appalachian Mountain Region. While mine drainage impacts are wide spread in bituminous coal regions, the mountain building forces that formed ridges and valleys concentrated mine drainage impacts to about a 10 county area in northeastern PA, known as the Anthracite Region. Underground mining methods with few government regulations created large polluted aquifers or underground lakes, known as mine pools, which are under river and stream valleys. One discharge, the Old Forge Borehole, spews between 50 and 100 Million Gallons of AMD per day into the Lackawanna River, near Scranton, PA.

Unfortunately, damaging effects on our ecosystems are not the only drawbacks to AMD. Trout Unlimited recently completed a study to show how an AMD polluted stream negatively affects our economy. The study showed that the more than 1,200 miles of AMD polluted streams kept towns and communities from earning an estimated $22.3 Million from fishing and recreation in the West Branch of the Susquehanna River Watershed (an area that covers about 1/7 of Pennsylvania) in just one year. If the AMD problem was cleaned up, jobs would be created, property values would go up and more money would be spent on recreational activities like camping, swimming and boating. Also, there would be more clean drinking water at a lower price. (Down Stream Strategies LLC., 2008)

The Polluted Stream

The make-up of AMD contamination varies greatly from site to site, as its formation is dependent on a lot of factors. AMD lowers water quality, hurts aquatic life (fish/frogs) and usually contains one of these four major ingredients:

1. **Low pH** (high acid content or acidity),
2. **High metal concentrations** (iron is the most common),
3. **Increased sulfate levels**, (what’s that smell…rotten eggs? Nope, sulfur.)
4. **Build up of silt or suspended solids**, (logged streams & flash flooding)

These “ingredients” are also known as nonpoint source (NPS) pollutants. Point source pollution, such as a discharge from a chemical factory, is easy to locate because comes from an exact location. Nonpoint source pollution may originate from many different sources without one specific solution to fix the problem, making it difficult to identify like water runoff from city streets after a storm.
Let's explain those components in more detail:

**Low pH**

Acidic mine drainage can kill fish and the bugs they eat, slow down plant growth, wear away metal structures and raise water purification costs. Pyrite or “fool's gold”, commonly found in mine rocks is the leading source of acidity, or low pH. When exposed to oxygen in the air, ordinary rainwater or ground water can react with pyrite to form sulfuric acid (or battery acid) and iron compounds. Acid levels in AMD can be more than 10,000 times higher than drinking water.

In addition, it can create a “snowball effect” as it breaks down surrounding rocks, clays and soils to release metals and other compounds, causing more contamination to creeks, rivers, and ground water.

**High Metal Concentrations**

Overburden, or layers of rock above the coal removed during mining, often contains traces of iron, manganese, aluminum and other heavy metals. These metals can be dissolved at mining sites by acid runoff (as explained above) or can be washed into streams covering the riverbed with rusty orange, yellow, black, gray or white sediment. Many metals, though common in the soil, can be toxic to fish and other aquatic life when they are present in the water. Dissolved iron and iron precipitates settle out on rocks and smother the fish’s food, thus reducing or wiping out the overall fish population. This sludge is often called “yellow boy” or a pigment called ochre. Invisible in acidic water, dissolved aluminum in levels as low as 2 drops out of 1 million (parts per million) can begin to coat fish gills, used to breathe, depriving them of oxygen and eventually leading to their death.

**Increased Sulfate Levels**

As pyrite is chemically broken down by water and oxygen, a sulfur gas is given off which smells like rotten eggs. Sulfates can bond with water molecules to form sulfuric acid. Sulfur can react with calcium to form gypsum, a very soft gray mineral used in drywall and to make tofu (soy bean curd). AMD from bituminous coal commonly contains higher sulfate levels than drainage from anthracite coal.

**Build up of Silt or Suspended Solids**

Most people think the largest problem with AMD is the chemical pollution, but the biggest threat to water quality and aquatic life comes from soil erosion at mine sites, which clogs streams, can cause flooding and is often accompanied by illegally dumped trash. Tiny fly nymphs (insect larvae) and other water bugs that form the base of aquatic food chains, can be wiped out by heavy build up of soil and mine waste that wash into streams after rain events.
Suspended silt particles can also clog the fish gills and smother their eggs on the stream bottom.

Clogged streams can cause flash flooding for nearby residents as the streams find different channels to flow, which sometimes means through back yards, down streets or even through our homes.

**The Lab**

“A significant amount of scientific research has been conducted to determine the chemical reactions that create acidity and lead to the precipitation of dissolved metals, but despite improvements in prediction and prevention methods, acid mine drainage problems persist. The rate of pyrite oxidation depends on the following: reactive surface area of the pyrite, the oxygen concentration and pH of the water, the forms of pyrite, and the presence of iron oxidizing bacteria (Thiobacillus ferroxidans).” (U.S. Geological Survey, 2010)

The majority of AMD problems come from the reaction of pyrite with water and oxygen. A pyrite molecule is made up of one atom of iron and two atoms of sulfur (FeS₂, also known as iron sulfide). While in actuality a series of chemical reactions occur to form the contaminated water, the complex reactions can be summed up here:

\[
\text{pyrite + water + oxygen} = \text{sulfuric acid + iron oxide (yellow boy) + sulfur gas (rotten egg smell)}
\]

**The pyrite reaction is a complex 3 step process and this is what it looks like to a chemist:**

**(Step 1)** Pyrite (iron sulfide) reacts with water and oxygen and is oxidized, forming a dissolved ferrous iron (iron(II)), sulfate and acidity.

\[
2\text{FeS}_2(s) + 7\text{O}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{Fe}^{2+}(aq) + 4\text{SO}_4^{2-}(aq) + 4\text{H}^+(aq)
\]

Often, this is the only reaction that has occurred as the AMD surfaces from underground (if oxygen and pH levels are low)

**(Step 2)** Ferrous iron (iron(II)) is oxidized to ferric iron (iron(III)) and water

\[
4\text{Fe}^{2+}(aq) + \text{O}_2(g) + 4\text{H}^+(aq) \rightarrow 4\text{Fe}^{3+}(aq) + 2\text{H}_2\text{O}(l)
\]

Constructed sedimentation ponds and aerobic wetlands promote this reaction by spreading out the water

**(Step 3)** Ferric iron is hydrolyzed to an insoluble iron hydroxide precipitate (yellow boy)

\[
4\text{Fe}^{3+}(aq) + 12\text{H}_2\text{O}(l) \rightarrow 4\text{Fe(OH)}_3(s) + 12\text{H}^+(aq)
\]

This reaction happens very quickly after Step 2. Sedimentation ponds and aerobic wetlands provide space for the solid iron hydroxide to be settled out and collected.

**Net reaction**

\[
4\text{FeS}_2(s) + 15\text{O}_2(g) + 14\text{H}_2\text{O}(l) \rightarrow 4\text{Fe(OH)}_3(s) + 8\text{SO}_4^{2-}(aq) + 16\text{H}^+(aq)
\]

The specifics of where and how these reactions occur depend on the geology, or composition of the rocks, and hydrology, or water flow patterns, of the particular site. No two AMD discharges are exactly alike. In fact, we prefer the term Abandoned Mine Drainage over Acid Mine Drainage, because discharges can be very different chemically. In general, drainage from mines is net acidic with a pH below 7, but the drainage from some mines is net alkaline, and have more neutral pH near 7. The individual impacts and the options for treating discharges have much variability and must be determined on a site by site basis.
The Wetlands

Fortunately, at some sites, the mineral limestone may also be present in the geologic strata. As contaminated water comes in contact with limestone, a beneficial reaction sometimes occurs. The limestone contains calcite, also known as calcium carbonate (CaCO$_3$), which counteracts or neutralizes the acidity generated by the pyrite reaction. The AMD may actually become alkaline or have high pH above 7. While it may still carry a variety of other contaminants, the impacts are not as far reaching as if the acidity were present.

All treatment strategies have two common elements:
  If acidity is present, neutralize it.
  If metals are present, capture and retain them.

One of the most effective, inexpensive, and widely employed methods to treat AMD are the addition of limestone and the use of constructed wetlands. These elements are often the basis of best management practices known as passive treatment. Some AMD discharges are so severely polluted or have such high flows that active or chemical treatment is required.

The Refuse Pile – Reclaimed

Reclamation of the surface features and re-mining of an abandoned coal mine can also aide in treatment as it removes the source of the AMD production. Reclamation will often consist of the removal of surface waste coal piles containing pyrite and other heavy metals compounds. Other reclamation projects fill abandoned strip pits or reroute streams away from underground mines, removing water and oxygen from the chemical equation. The process of re-mining, also known as “day lighting”, consists of digging up an abandoned underground mine, removing the leftover coal pillars and backfilling the voids.

Today, mining companies mine smarter. Predicting and preventing acid mine drainage from occurring is preferable to having to perform remedial treatment once the problem has occurred. Current mining practices can predict the potential for a site to produce mine drainage and prevent it from happening by placing the rock strata, or overburden back in such a way that the acidity is neutralized. Both static and kinetic chemical tests have been developed to aid in acid-base accounting of the overburden, which measures the neutralization potential vs. the maximum potential acidity of rock strata. (U.S. Geological Survey, 2010)

How you can help:
  Get involved with environmental issues.
  Get educated about the problems and possible solutions.
  Spread the word about the existing problem and what could happen if it was cleaned up.
  Join your local watershed or community organization to brainstorm treatment possibilities.
Glossary

abandoned – a site where mining stopped prior to 1977 and the passage of the Surface Mining Control and Reclamation Act.

anthracite – a hard, compact variety of coal that has a high luster, highest carbon content and the fewest impurities; found in Northeastern PA.

Appalachian - a vast system of mountains in eastern North America.

aquifer - a wet underground layer of water-bearing permeable rock or unconsolidated materials from which groundwater can be extracted using a well

bituminous - relatively soft coal containing a tarlike substance called bitumen; higher quality than lignite but of poorer quality than anthracite.

Carboniferous – a period of geologic time where coal beds were laid down globally starting after the Devonian (~300 mya) and ending before the Permian (~360 mya); made up of 2 sub periods: Pennsylvanian (~300-320 mya) & Mississippian (~320-360 mya)

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carbide – a hard form of coal containing impurities

carbonic acid – a weak acid in water and soil

carboniferous – a period of geologic time when plants were abundant and laid down layers of peat that are now compressed into coal

coal bed – a layer, seam or vein of coal normally found compressed between layers of rock

ecosystem - all the organisms in a given area, along with the nonliving (abiotic) factors with which they interact

extinction - the end of a group of organisms; generally considered to be the death of the last individual of the group

geochemical reactions - chemical processes and reactions that govern the composition of rocks, water, and soils

Industrial Revolution - a period from the 18th to the 19th century where major changes in agriculture, manufacturing, mining, transport, and technology had a profound effect on the socioeconomic and cultural conditions starting in the United Kingdom, then subsequently spreading throughout Europe, North America, and eventually the world.

precipitation - the formation of a solid in a liquid; the solid formed is called the precipitate

reclaim / reclamtion - the process of creating useful landscapes that meet a variety of goals, typically creating productive ecosystems (or sometimes industrial or municipal land) from mined land.

remediate / remediation - the removal of pollution or contaminants from environmental media such as soil, groundwater, sediment, or surface water for the general protection of human health and the environment
rock stratum - a layer of rock or soil with internally consistent characteristics that distinguish it from other layers.

overburden - the material that lies above an area interest in mining; most commonly the rock, soil and ecosystem that lies above a coal seam or ore body. Also known as ‘waste’ or ‘spoil’ when removed.

subsidence - the motion of a surface as it shifts downward usually caused by collapsing of voids found in karst terrains or by removal of a subsurface natural resource such as coal or gas.

silt – a material of a grain size between sand and clay derived from soil or rock. Silt may occur as a soil or as suspended sediment in a surface water body. It may also exist as soil deposited at the bottom of a water body.

Works Cited


Disclaimer:

EPCAMR and WPCAMR are separate 501(c)3 non-profit organizations consisting of conservation district, community group and industry representatives from 14 counties in Pennsylvania’s Anthracite Coal Region and 24 counties in Pennsylvania’s Bituminous Coal Fields, respectively. The PA DEP 319 Program funds a majority of the work of the EPCAMR and WPCAMR Staff. The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. EPA, PA DEP of any of their sub-agencies.