Acid Mine Drainage Pollution in
the West Branch Schuylkill River and Upper Schuylkill River, Schuylkill County
Pennsylvania: A Case Study and Recommendations for the Future

Photo: Nanticoke Creek, Nanticoke PA
Source: Tara Sadak

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Abstract:

Acid mine drainage (AMD) is a huge environmental problem in Luzerne and Schuylkill Counties due to the mining of anthracite coal in the region. The Pennsylvania Department of Environmental Protection, through water quality data, has developed a Total Maximum Daily Load (TMDL) for all streams and rivers in the state. The West Branch Schuylkill River and the Upper Schuylkill River are two areas where AMD has had an effect on the water quality. For this study, I am using the data from PADEP to determine if the remediation actions have had an effect on the West Branch Schuylkill River and Upper Schuylkill River, or if it is too soon to tell. For both of these streams, data were collected by PADEP from 1996 through 2003; the data consist of the pH of the water, the concentration of iron, aluminum, and manganese expressed in milligrams per liter (mg/L), and the percent reduction needed to maintain good water quality standards. Through tables and graphs, the most affected sites along the rivers are made known, and these are the sites that are high priority for remediation. Recommendations are made for the sites along the rivers that are a high priority for remediation, mainly the mine discharges. If the sources of pollution are controlled, then future generations will not have to deal with the effects of AMD on the rivers and their environments.

1. Introduction:

Picture a river so polluted that the color of the water flowing downstream is bright orange, or imagine trying to catch a fish in a river only to find there are none due to pollution. These are the harsh realities found in northeastern Pennsylvania streams, rivers, and lakes due to acid mine drainage (AMD) from abandoned mines. Coal mining became a way of life for most people in the region and by 1914 employment had reached a record number of 180,000 men, women, and children. There are over 200 seams of coal in the region that have been mined historically and some that are still mined today. The fall of the coal industry, between 1950 and 1970, not only caused great economic hardship in the region, but it also left a legacy of environmental damage that is costing the government and other agencies millions of dollars in time and money (U.S. Department of Labor, 2007).

The abandonment of so many coal mines in the region has caused a great deal of pollution in the local streams, rivers, and lakes due to the acid mine drainage (AMD) that has resulted from the abandonment. AMD occurs when the pyritic material found in the walls of abandoned coal mines reacts with water and oxygen to produce sulfuric acid and iron hydroxide. The oxidation process lowers the pH of the water and this allows heavy metals such as copper, lead, mercury, and arsenic to dissolve and be discharged into the river's environment. The AMD not only affects the aesthetics of a river, but also impacts the flora and fauna, with many species unable to survive with the low pH conditions and the elevated concentrations of heavy metals (Bulusu, Aydilek, Petzrick, & Guynn, 2005; A. Sheoran, V. Sheoran, 2006; "Exploring the Environment, 2004). It is of great cause for concern in the region due to the large amount of heavy metals that are introduced into the watersheds on a daily basis through mine discharges.

Through funding from the EPA and other various organizations, the Pennsylvania Department of Environmental Protection (PADEP) has begun the long and tedious process of remediation of the streams and rivers, using a variety of techniques, in order to improve water quality. While some of the streams and rivers may never get funding to improve water quality, recent laws governing mining operations will hopefully prevent more AMD from occurring in the future. The West Branch Schuylkill River and the

Upper Schuylkill River are two projects underway for the remediation of the rivers and prevention of AMD in the future. If the PADEP can clean up these rivers in areas that were mined historically beginning in the early 1800s and still continuing today, then anything is possible for the future. AMD not only destroys the water quality, but it also devastates the rivers' environments for the local communities to enjoy.

2. Background Information

2.1 History of Coal Mining in Northeastern Pennsylvania

Anthracite coal was first discovered in Pennsylvania in 1775 near Wilkes Barre, Pennsylvania. As Fig. 1 below shows, anthracite coal is only found in the northeastern part of the state; mainly in Luzerne, Lackawanna, Schuylkill, Carbon, and Columbia Counties. Approximately 99 percent of the anthracite mined in the United States was mined in these counties. Arkansas, Colorado, Virginia, and New Mexico combined make up the other one percent of anthracite coal production. There are over 200 seams of anthracite coal in this region that were mined historically and some are still mined today. There are two types of mining, deep mining and surface mining. Deep mining is the extraction of coal at depths greater than 1,000 feet, and surface mining occurs when the rock and soil is taken off of the layer of minerals. Most of the anthracite coal mines are deep mines in which shafts and tunnels are used to extract the coal. In the 1800s and early 1900s anthracite coal mining was an important way of life for many families in these regions (U.S. Department of Labor, 2007; DiCiccio, 1996).

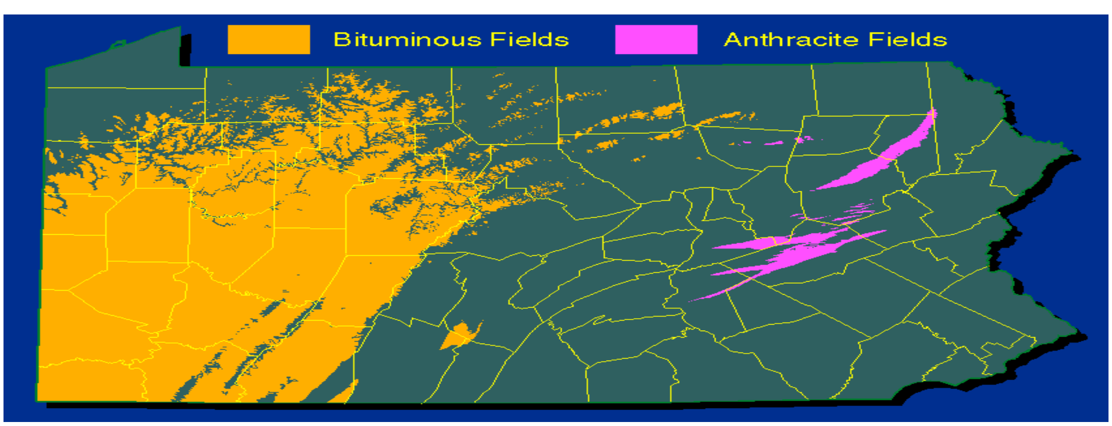


Fig. 1 Map of Bituminous and Anthracite Coal Fields in Pennsylvania.
Source: U.S. Geological Survey - pa.water.usgs.gov/projects/amd/

Being a coal miner in the 1800s and 1900s was not an easy way of life. Coal miners were under the complete control of the coal companies and mine bosses. Many of the towns in northeastern Pennsylvania were built and owned by the coal companies as well. The houses in these towns were not well maintained with a majority of the homes being built in the 1850s, and little to no maintenance was performed on them. The working conditions for the miners were both physically and emotionally draining. The mine bosses would often club those miners who were not working fast enough and the inequality between miners and the bosses and coal companies was huge. There were countless dangers that existed within the mine, including carbon monoxide poisoning, explosions, being crushed by heavy machinery and blasting mistakes to name a few. In the coal business an accident at work was most often fatal. According to Wallace (2003) in the late 1800s there was one death for every 49,174 tons extracted from the mine. That did not include those men who died later from their injuries. These men were risking their lives every day and their pay was usually less than one dollar per day. The coal companies and the mine bosses were getting rich, while the working class had to go to work everyday wondering if they would get out alive (Aurand, 2003; Wallace, 1987).

With the poor working conditions and pay, it was not long before labor unions became major players in the mining industry. There were many labor unions that started but were unable to compete with the power of the coal companies and lost their battles. The first union in northeastern Pennsylvania was the John Bates' Union formed in 1849. These union members staged a month long strike for higher wages and better working conditions, but their efforts were in vain and all the workers returned to work without a change in the working environment. There were similar smaller unions that also started, but they were not able to achieve any success. It wasn't until the Knights of Labor, which was established on December 9, 1869 in Philadelphia merged with Assembly No. 135 and the National Progressive Union of Miners and Mine Laborers that coal miners finally had a voice within the coal industry. By the end of the 1800s, the Union was able to guarantee an eight hour work day for the miners. By the mid 1900s, workers had bargaining rights and health and retirement benefits, which the workers had been fighting to achieve for generations. While the Union did its best to give the miners what they needed, it did not come without a price to pay; mining disasters and massacres were part of the job (United Mine Workers of America, 2008; DiCiccio, 1996)

The mining history in northeastern Pennsylvania is one of turmoil and death. There were many mining disasters, such as the Avondale Mine Disaster, which occurred on September 6, 1869. There were 108 men and boys who died that day due to a mine fire that they could not escape. It was the largest mining disaster in the region. On January 22, 1959 there was also the Knox Mine coal disaster which occurred when the Susquehanna River flooded the entire mine. The bodies of 12 men were never recovered and it was this event that is said to have ended deep coal mining in the northeastern region (U.S. Department of Labor, 2007).

The coal companies and mine bosses were very powerful people and in the late 1800s, the Molly Maguires found out how powerful these men actually were. The Molly Maguires were Irish-Catholic immigrants working in the coal fields in Schuylkill County. Through the work of the mine bosses and the Pinkerton detectives, these men were accused of committing 42 murders and 162 felonies. In the end, 20 Molly Maguires were hung for the crimes of speculation (DiCiccio, 1996; Wallace, 1987). The Lattimer Massacre was another unforgettable moment in mining history between the mine bosses and the miners. In the summer of 1897, 400 miners led a march through the coal towns in Luzerne County to the town of Lattimer. Here they were met by approximately 87 deputies who were told to use any means necessary to quell the uprising. The unarmed marchers were fired upon and 17 wound up dead. The massacre in this small town made national news and shocked a nation (Explore Pennsylvania History, 2003).

Coal mining is an important part of the history of Northeastern Pennsylvania and while there were a lot of hard times for these workers, it was the industry that held the region together. Fig. 3 shows Shenandoah, a once booming coal town that is now in a depression because of the closure of so many mines in the area. These depressed towns can now be seen all over the region since the fall of coal as a major resource for energy in the 1950s. Prior to 1950, there was an average of 100 million tons of anthracite coal production in the region and in 1950 that number decreased to 46 million. By 1970, the average anthracite coal production for Pennsylvania was only 9.2 million tons (U.S. Department of Labor, 2007). In addition to the economic hardship resulting from mine closure, there is a legacy of environmental damage including scarring of the landscape from surface and deep mining activities, subsidence from collapse of underground mines, and the focus of this paper, acid mine drainage.

Fig. 2 Photo of Shenandoah, Pennsylvania, a once booming coal town.
Source: Tara Sadak

2.2 What is Acid Mine Drainage (AMD)

Acid mine drainage, or AMD, is a huge problem worldwide for streams, rivers, and lakes in areas where abandoned coal mines exist. Pyrite, iron sulfide, in the walls of the abandoned coal mines reacts with water and oxygen to produce AMD. Oxidation of the mineral produces sulfuric acid and iron hydroxide in the series of reactions shown below. The formation of the iron hydroxide in steps three and four is what causes the yellowish-red coloration in the streams and rivers (Bulusu, Aydilek, Petzrick, & Guynn, 2005; A. Sheoran, V. Sheoran, 2006; "Exploring the Environment, 2004).

1. $2FeS_2 + 7O_2 + 2H_2O \text{ -> } 2FeSO_4 + 2H_2SO_4$
2. $2Fe^{2+} + 1/2\ O_2 + 2H^+ \text{ -> } 2Fe^{3+} + H_2O$
3. $Fe^{3+} + 3H_2O \text{ -> } Fe(OH)_3 + 3H^+$
4. $FeS_2\,(s) + 15/4\ O_2 + 7/2\ H_2O \text{ <--> } 4H^+ + 2SO_4^- + Fe(OH)_3\,(s)$

(Exploring the Environment, 2004)

The result of this oxidation process is a lowering of the pH of water draining from the mines. This low pH causes heavy metals such as copper, lead, mercury, and arsenic to dissolve and be discharged into the environment (Bulusu, Aydilek, Petzrick, & Guynn, 2005; A. Sheoran, V. Sheoran, 2006). The iron hydroxide that forms from the oxidization precipitates and accumulates as sediment along the river beds. The sediment causes the river to have a red, orange, or yellow coloring. Figure 3 shows the drastic coloration the iron compounds create (“Acid Mine Drainage, 2008).

Fig 3. Acid mine drainage pollution along the Lackawanna River, Wilkes Barre, Pennsylvania.
Source: Paul Lumia

The rate at which AMD occurs in an area depends on a number of factors. These factors include the amount of bacteria present, pH, surface area of pyritic material, amount of oxygen, microenvironments present, and temperature. Bacteria, especially *Thiobacillus ferroxidans*, are able to oxidize iron as an energy source if the ideal acidic and aerobic conditions are met. The favorable conditions for the bacteria are a pH of 2.0 to 3.0 at which they can perform at their best. By using the iron compounds for energy, less iron is introduced into the stream which helps to prevent AMD from occurring (Brady, Smith, & Schueck, 1998).

The pH of the water also has an effect on AMD generation. Waters with a pH between 4.0 and 7.0 will oxidize the pyritic material at a much slower rate, than water with a lower pH. If the pH is below 2.0, however, the bacteria then have ideal conditions for oxidation and can help to prevent AMD (Brady, Smith, & Schueck, 1998).

The surface area and amount of pyrite material contained in the rock can have an effect on the rate that AMD occurs. The greater the surface area of the rock and the more pyritic material it contains, the greater the rate of the oxidation process and release of iron into the river (Brady, Smith, & Schueck, 1998).

Oxygen also plays an important role in the rate at which AMD occurs. The main cause of AMD is when oxygen comes in contact with the pyrite; a river with higher levels of oxygen will produce acidic conditions at a quicker rate than those rivers that lack oxygen (Brady, Smith, & Schueck, 1998).

The microenvironment that can alter the rate of AMD occurrence refers to the pyritic material from the mines, also known as spoil. Water flows out of the abandoned mines at different rates depending on pore size and fractures in the material. Spoil that has high pyritic material content and small pores where water moves more slowly will tend to oxidize the iron more rapidly than areas where the water moves more quickly through larger pores (Brady, Smith, & Schueck, 1998).

Temperature is the final factor that affects the rate of AMD generation on a river. Oxidation occurs more rapidly at higher temperatures and therefore AMD will occur more frequently when temperatures increase in the summer (Brady, Smith, & Schueck, 1998).

AMD not only affects the aesthetics of the stream, such as the orange coloring and the sulfur smell, but also destroys aquatic plant and animal life along the polluted river ("Acid Mine Drainage," 2008). It is important to understand the process and rate determining factors of AMD generation in order to treat the polluted rivers and prevent more pollution in the future.

2.3 Effects of AMD

AMD has huge impacts on the river environment water quality and resident flora and fauna. Macroinvertebrates and fish are directly impacted by AMD. Good indicator species of pollution in a river are the benthic macroinvertebrates, such as mayflies, caddisflies, and stoneflies because they normally stay in a general area, and do not move around a lot, and they react to pollutants in different ways. Depending on how extreme the AMD is, the diversity and abundance of these species can be decreased. Mayflies can not tolerate AMD while stoneflies and caddisflies will be able to survive in a river with a slight acidity. Fish are not the best indicator for the pollution caused by AMD because they move around a lot and are harder to quantify (Brady, Smith, and Schueck, 1998).

The pH of the water plays an important role in the survival of the aquatic life within the river. Low pH can cause the most harm because it throws off the balance of sodium and chloride found in the blood of these insects and fish. A low pH also changes the plant life of a stream; many macroinvertebrates only feed on certain plants and therefore they will move to where the food is more available. Research done on Pennsylvania rivers and streams affected by AMD found that the survival rate of fish at a pH lower than 4.5 was nonexistent. Like the macroinvertebrates, the fish died because of the interruption in the balance of the sodium and chloride ions in their bloodstream. The gills of the fish were also impacted by the lower pH in the water (Brady, Smith, and Schueck, 1998).

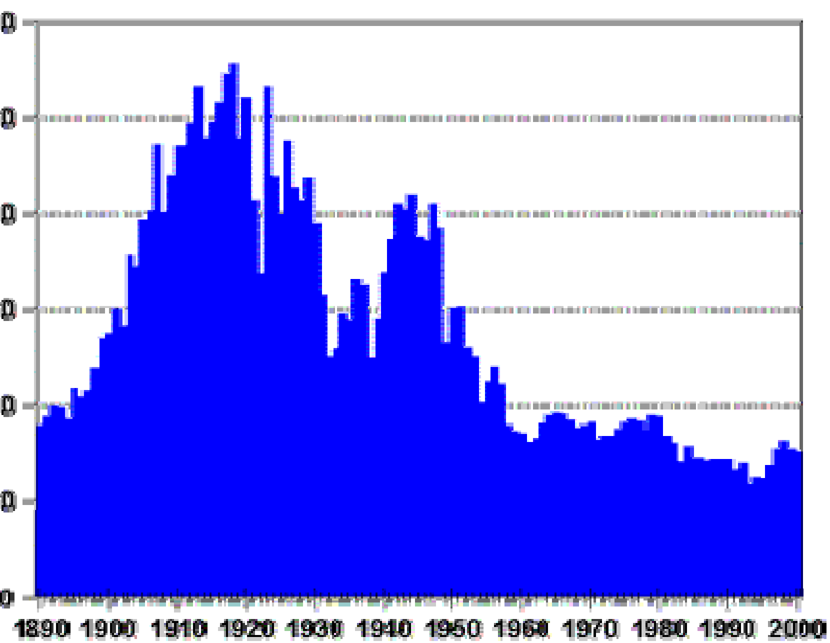
Heavy metals also play a role in the survival of the macroinvertebrates and fish. Some metals found in AMD contaminated rivers are iron, aluminum, manganese, zinc, cadmium, and copper. When these metals precipitate, they can do a variety of damage to the river and its inhabitants. There can be a decrease in oxygen, and the precipitate can collect on the fish and eggs making it impossible for the fish to breathe properly or the eggs to hatch. The precipitate can also adhere to the rocks and make it difficult for the macroinvertebrates to survive on the rocks in the river. AMD has a wide array of effects on the organisms living in the rivers and it is important to help maintain the proper balance of the pH of the water so that the organisms will be able to survive and maintain the proper environment (Brady, Smith, and Schueck, 1998).

AMD can also have an effect on the local drinking water systems. The taste of the water can be affected by higher concentrations of iron, sulfate, and manganese, and a lower pH. Other problems that can occur in areas were AMD is prevalent are the corrosion of the pipes and wells due to the lower pH, sulfides, and chlorides found in the contaminated streams. Incrustation is another problem that occurs with AMD. This occurs when precipitates from the heavy metals form around the pumps of wells and make it impossible for the well to function properly. AMD also has an effect on concrete structures, such as bridges that go across the contaminated rivers. The acid will slowly eat away at the concrete and cause damage to the structures (Brady, Smith, and Schueck, 1998). AMD affects everything from plant and animal life to everyday use of water and it is important to remediate the problem areas before more aquatic life loses its habitat and more impairment of drinking water supplies occurs.

2.4 Coal Production in Pennsylvania

AMD is a huge problem worldwide because coal is an important source of energy and is extensively mined. In the early 1900s, coal made up 55 percent of the total energy used worldwide. By 1997, that number dropped to 22 percent (Schobert, Song, 2002). In Pennsylvania, there were an estimated 22.8 billion tons of coal available for mining. Of that number, nearly 10.8 billion tons have already been mined and there are approximately 12 billion tons that can still be useful once mined (Edmunds, 2002). Graph 1 below shows the coal production in Pennsylvania from 1890 through 2000. The peak periods of coal production occurred in the early part of the 1900s. The extent of mining that has occurred in the past in Pennsylvania has left nearly 2,400 miles of polluted streams and rivers throughout the state. The Schuylkill River Watershed, which the West Branch Schuylkill River and Upper Schuylkill River are part of, is estimated to have 143 AMD discharges throughout (PADEP, 2007).

Historical Coal Production in Pennsylvania



Graph 1 – Coal Production in Pennslvania 1890-2000
Source: Energy Information Administration -
http://www.eia.doe.gov/cneaf/coal/statepro/imagemap/pa.htm

While the occurrence of abandoned mines in the United States has decreased over the years due to the Surface Mining Conservation and Reclamation Act of 1971, it has not been completely eliminated. This act required all persons who are involved in mining operations or those who wanted to extract more coal from a previously abandoned mine have measures put in place to prevent AMD from the site in the future. The Act provides tax incentives for those who remediate the land to prevent pollution to the environment (Brady, Smith, & Schueck, 1998). Northeast Pennsylvania has begun to take steps to improve the water quality of the local streams and rivers in the area including the West Branch Schuylkill River and the Upper Schuylkill River. Both of these areas have been heavily mined since the 1800s and continued to be mined today either through re-mining or ongoing coal mining production (PADEP, 2007). AMD needs to be taken care of at the source and PADEP, along with many other organizations, have been experimenting with different remediation techniques in order to prevent AMD from occurring in the future and also to improve the water quality of the streams, rivers, and lakes already affected.

3. Remediation Techniques for AMD

Remediation of the streams and rivers that are affected by AMD is the only way to correct with the existing problems and make these environments safe for the future. It is estimated that there are nearly 19,300 kilometers of streams and rivers and 72,000 hectares of lakes that have been polluted through mining operations worldwide (Johnson & Hallberg, 2005). There are many options for remediation including limestone drains, constructed wetlands, plants and microorganisms, coal combustion by-products (CCB), and remediation of the abandoned mine site. The character, positive features and drawbacks of each will be reviewed below.

3.1 Limestone Drains

Limestone drains neutralize AMD. Limestone is made up of calcium oxide and when the acidic water reacts with the compound it forms calcium hydroxide. The calcium hydroxide that is formed in the initial reaction then breaks down into calcium ions and hydroxide ions; this reaction is what allows the pH to increase to a more neutral level. The chemical equation for this process of neutralizing the acidic water is $CaO + H_2O \rightarrow Ca(OH)_2$. The calcium hydroxide than reacts to form ions in the equation of $Ca(OH)_2 \rightarrow Ca^{2+} + OH^-$. Any other metals present in the water during the reaction will also precipitate to form hydroxides as well (Johnson & Hallberg, 2005; Kalin, Fyson, & Wheeler, 2006; Robb & Robinson, 1995; Santomartino & Webb, 2007).

Limestone drains can be active or passive. Active limestone drains continually provide alkaline material with a machine, while passive drains rely on the flow of the stream to pass over the alkaline material. The passive system can work in both anoxic conditions, or conditions that lack oxygen, and are normally refered to as anoxic limestone drains (ALD), and oxic conditions. The treatments can use either crushed limestone or limestone gravel depending on the exact type of system (Santomartino, & Webb, 2007). Each of the different limestone drains uses the same type of chemistry in order to increase the pH of the water.

It is important to prevent the limestone drain from forming iron hydroxides because of the destructive nature the iron can have on the drains. The precipitates can inhibit the limestone drains by forming a layer of sediment over the alkaline material and thus prevent the water from reacting with it. In many cases, the sludge that forms from the precipitated material needs to be disposed of as a hazardous waste because it contains the precipitated heavy metals from the reactions (Johnson & Hallberg, 2005; Kalin, Fyson, & Wheeler, 2006; Robb & Robinson, 1995; Santomartino & Webb, 2007). Figure 4 below shows the basic layout of a limestone diversion well such as occur on the West Branch Schuylkill River in the area of study.

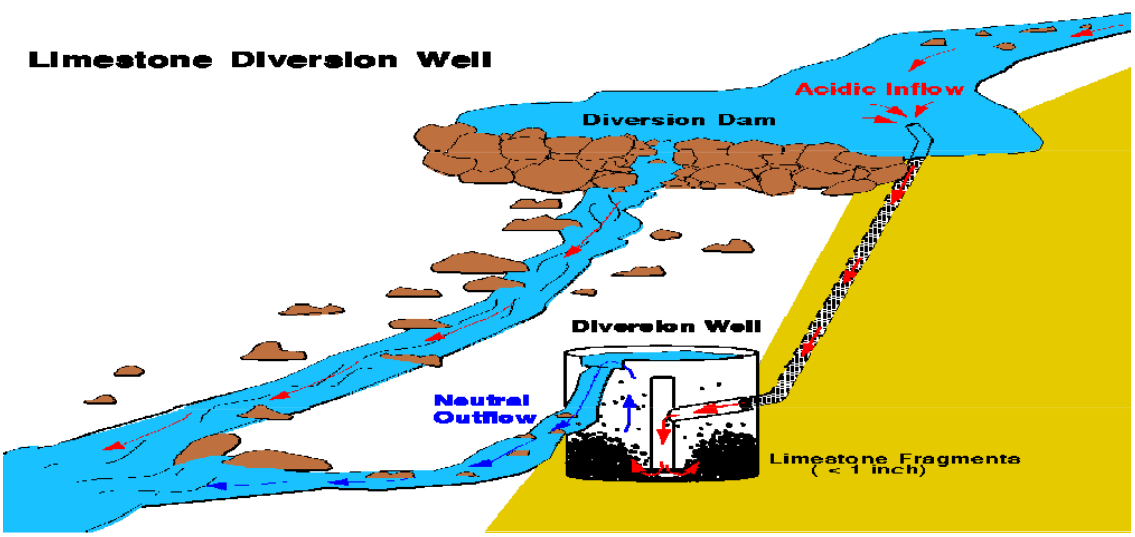


Fig. 4– Example of a Limestone Diversion Well
Source: USGS - pa.water.usgs.gov/projects/amd/div_well.gif

Using limestone drains as a means to remediate a river is very cost effective; however, it cannot be used in every environment. If these drains were used in an area that had high concentrations of iron or aluminum in the water, the treatment system would get a build up of the precipitates and would fail to function properly. Most of the time these drains are used in conjunction with constructed wetlands (Johnson & Hallberg, 2005).

3.2 Constructed Wetlands

Constructed wetlands are another way of reducing the acidity and heavy metals that travel downstream in an AMD contaminated river. Wetlands remove the heavy metals and reduce the pH of the water in three ways: through the soil, hydrology, and vegetation that exist within the environment. The wetlands can either be aerobic or anaerobic depending on the type of water that needs to be treated. Aerobic wetlands are best if used for rivers containing high levels of iron and manganese and anaerobic wetlands are best when the acidity of a river is greater than 300 mg/L (Hedin, 1996; Sheoran, 2006).

Aerobic wetlands use the oxygen present to oxidize the iron compounds found in the water. This oxidation results in an iron precipitate that settles to the bottom of the wetland. The reaction with iron and oxygen will reduce the pH of the wetland and can harm some plants that do not have a high tolerance level for changes in pH. The iron precipitate that consolidates in the sediment can be pumped out when needed and disposed of in a landfill. If the iron is not pumped out of the sediment, the wetland can reach its maximum holding capacity and then would no longer function properly. The best types of plants for an aerobic wetland are common cattail (*Typha latifolia*) and common reed (*Phragmites australis*) because of the ability to add oxygen to the soil through the root system which helps with the oxidation process (Hedin, 1996; Sheoran, 2006; Robinson, 1998).

Anaerobic wetlands use organic material and limestone to aid in the remediation of the river. Having organic material present in the wetland will encourage the growth of sulfate-reducing bacteria (*Desulfovibrio* sp.). The bacteria will consume the iron and reduce it to a sulfide. Through this process, bicarbonates are formed that will increase the pH of the water, and the sulfides will react with the heavy metals to form precipitates that will settle to the bottom of the wetland. Some of the organic material that has been used in the past is mushroom compost, manure, and sawdust. It is important to prevent plants from taking over the wetland in order for it to be effective. If there are a large number of plants present, then oxygen is introduced into the substrate and the anaerobic conditions will not exist. The removal of the precipitates is harder in an anaerobic wetland because the precipitates mix with the organic material and cannot be easily pumped out (Hedin, 1996; Robb & Robinson, 1995). Figure 5 shows the configuration of a typical constructed wetland for AMD. Many of these wetlands are used in conjunction with limestone drains as either a pre-treatment of the water or a post treatment after the water passes through the drain. The river water would enter the wetland and flow through the organic material and limestone before exiting the wetland back into the river at a neutral pH.

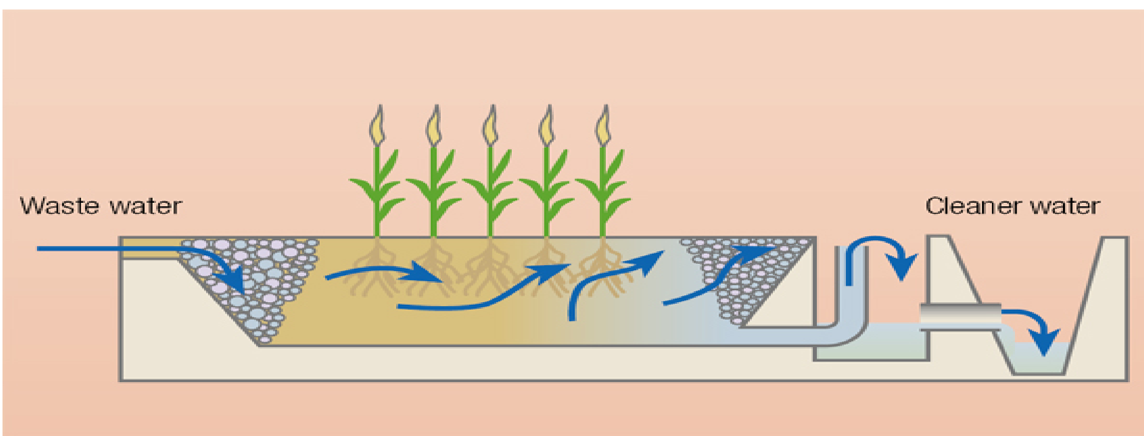


Fig. 5 – Example of a constructed wetland for AMD
Source: United Nations Environment Program
http://www.unep.org/geo/yearbook/yb2003/images/fresh_img_g_40.jpg

In order for the constructed wetlands to continue remediating environments affected by AMD there needs to be continual maintenance of the wetland. The precipitates that form need to be disposed of properly before the wetland reaches its maximum holding capacity and the plant life needs to be maintained to prevent overgrowth. However, these tasks are minimal compared to how much damage can be done if the rivers are not treated for AMD (Hedin, 1996).

Plants and microorganisms play an important role in the uptake of heavy metals, which normally occurs in the wetlands. Emergent plants and surface-floating plants have the best capacity to uptake the heavy metals that are present in the water from AMD. These plants can uptake the metals through their leaves and the roots whereas submerged plants mainly take up heavy metals from the sediment. Plants can uptake heavy metals at different rates depending on the growth cycle of the plant and the concentrations of the metals. The plants ultimately can hold 200,000 times the concentration of heavy metals found in the water. The reason the plants can hold such a great concentration of heavy metals is that they are stored in the cell walls of the plant. The best plants for the uptake of cadmium, copper, manganese, zinc, and lead are umbrella plant (*Cyperus alternifolius*) and erect marsh-flower (*Villarsia exaltata*). Emergent macrophytes such as southern cattail (*Typha angustata*) and munj sweetcane (*Saccharum bengalense*) can also hold a great deal of heavy metals without it disrupting the growth pattern of the plant (Sheoran, 2006). In Pennsylvania broadleaf cattail (*Typha latifolia*), great bulrush (*Scirpus validus*), spike rush (*Eleocharis obtuse*) and sedge grass (*Cyperus strigosus*) are some of the more common plants that are used in the constructed wetland (Chaplin, White, and Loper, 2006). It is important to incorporate plants into the wetlands that have a high tolerance rate for things like changes in pH, temperature, organic matter, and the chemistry of the system (Sheoran, 2006).

Microorganisms, like plants, can also help with the uptake of heavy metals in the water. The processes that microorganisms use occur naturally in the environment. The bacteria reduce iron and sulfates into precipitates that settle to the substrate of the wetland. The microorganisms have the ability to increase the uptake of heavy metals by more than half. In a study of wetlands, it was found the bacteria increased the uptake of chromium from 40% to 84%, copper from 36% to 88% and selenium to more than 95% (Sheoran, 2006). The limestone drains, wetlands, and plants and microorganisms provide effective measures for dealing with AMD that has already occurred in rivers, streams, and lakes. They are even more effective when they are combined together and with continuing research the perfect system will be designed to maximize the uptake of heavy metals and neutralize the water to prevent further damage from AMD.

3.3 Coal Combustion By-products

Coal Combustion By-products (CCBs) are a good way of preventing further damage to the streams and rivers by AMD. CCBs are the by-product of coal generation plants that produce electricity in the United States. The CCBs are mainly made up of Class F fly ash, flue desulfurization by-product, fluidized bed combustion by-product, and quicklime (Bulusu, Aydilek, Petzrick, and Guynn, 2005). Class F fly ash is the residue from coal combustion. Class F fly ash is considered low lime, whereas Class C fly ash is high lime. The fly ash, when combined with water makes good cement. Pennsylvania mainly produces Class F fly ash. Flue desulfurization by-product is the sludge that is produced through the process of removing sulfur dioxide. This by-product has high calcium sulfate and calcium sulfite contents. Fluidized bed combustion by-product is another type of fly ash that is produced from the fluidized bed combustion boiler and will contain more dust than Class F fly ash (U.S. Office of Surface Mining, 1998). There are other CCBs produced within the plants but they are not efficient for preventing AMD. Using CCBs to prevent AMD not only helps with pollution of the streams and rivers in the future, but it also helps the disposal problems that come about with CCBs. According to Canty and Everett (2001) the EPA estimated the amount of CCBs that were produced in the United States was almost 110 million tons annually. This provides many disposal challenges for plants; most often the waste would go to landfills and take up much needed space. CCBs contain heavy metals such as arsenic, selenium, boron, nickel, and zinc. Other uses for CCBs have been discovered, such as uses for road construction, structural fill, and agricultural needs, but it is still a small amount of the 110 million that is produced annually.

CCBs help to prevent AMD by producing a barrier where the pyritic material never comes in contact with water and oxygen. It has been used in the past to help prevent land subsidence around abandoned mines and through research, it has also been found to help with AMD. The CCBs are made into a grout mixture by combining the CCBs with quicklime; the grout mixture is then injected into the abandoned mine and forms a concrete seal that prevents collapses and also keeps water and oxygen from entering the mine. Research is still being done to figure out the best proportions of CCBs and quicklime for optimal results. The research has shown a decrease in the amount of heavy metals found downstream of abandoned coal mines that have been encapsulated with CCBs (Bulusu, Aydilek, Petzrick, Guynn, 2005). Using CCBs cannot fix the AMD problems that already exist, but by using this method it will prevent more metals from destroying the rivers and streams in the future. There is controversy in using CCBs for AMD because of the heavy metals such as arsenic, selenium, and boron that are contained in the by-products. A study done by Canty and Everett (2004) has found that nickel, zinc, arsenic, and boron levels were all below federal standards for these metals in streams. Selenium, however, was found at a higher rate than is allowable by the federal government which can cause problems to the environment in the future. In areas where drinking water aquifers are present, the use of CCBs may be a problem unless a way to prevent the selenium from leaching out can be established. In a study done by Bulusu, Aydilek, Petzrick, and Guynn (2005) found that water testing done eight years after the CCB grout mixture was injected into the mines did not show any increase in trace elements in the water. The grout mixture did not have a negative impact on the groundwater or drinking water either. The use of CCBs will remain a controverial until it can be guaranteed that the heavy metals will stay in the grout mixture and not be leached out into the water that is used for everyday use.

3.4 Reclamation of Abandoned Mines Sites

Coal is an important and an inexpensive source of energy, but with that there comes a price; the price of the energy being the environmental degradation that occurs in order to extract the coal from the fields. It may be difficult to remediate some of the lands due to the extensive mining that has occurred, but it is important to try to get some plant and animal life in the areas, not only for aesthetic reasons, but also to help prevent AMD in the future. The most efficient way for abandoned mine reclamation is through re-mining. Although it may seem that re-mining an area would cause more damage, any active mining company is required to reclaim any land that they have disturbed. Re-mining of an area would guarantee that the mine site would not be left abandoned (Schuylkill Conservation District, 2005). Most often the sites are remediated through forestry and agriculture. Forestry is best used in areas where steep slopes limit planting of other species of plants. Planting trees in the area of the abandoned mine provides future economic assistance once the trees are old enough to use as lumber. The types of trees and shrubs that are planted in a given area depend on a number of factors including climate, location, and availability. It is important to plant species that are native to the area so that the area looks as similar to before it was mined as possible. Agriculture is another option for abandoned coal mine sites. Agriculture refers to cropland, pasture, and rangeland (Mudroch, Stottmeister, Kennedy, and Klapper, 2002). Most of the remediated sites in Northeastern Pennsylvania are of the rangeland type. Biosolids are used on many of these sites in order to help with the growth of the grasses that are planted on the abandoned mine sites. Biosolids are collected from a municipal wastewater treatment plant. These are the solids that settle out during wastewater treatment. Once the biosolids are collected in a basin, they are treated to destroy any pathogens that might be present and then are used as a fertilizer. Biosolids are used more in mining reclamation than manure because they contain more nutrients that are needed for plants to grow. Many times these abandoned areas lack the needed nutrients for plant growth. Figure 6 shows the amount of nutrients that are found in biosolids. They are made up of a lot of organic material along with phosphorus and nitrogen which are important in plant growth (National Park Services, 2001).

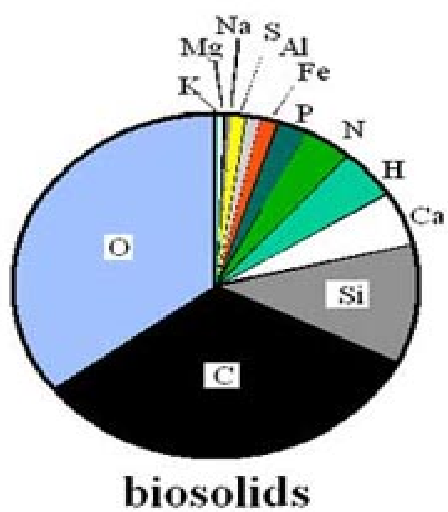


Fig. 6 – Nutrients found in biosolids
Source: Nation Park Services – http://www.nps.gov/plants/restore/pubs/biosolids/why.htm

While biosolids provide the needed nutrients to sustain plants and help with the aesthetics of the land, many communities are opposed to this method of fertilization. People complain about the odor that is sometimes present on sites that use biosolids, and the EPA does not have regulations for the odor. Many people are also uninformed about the processes of collection of the biosolids and using them and they feel that their health would be in danger if a site was to use this application. These oppositions to the use of biosolids will continue until the EPA can make it clear to the public how important they are for mining reclamation (National Park Services, 2001). Heavy metals and pathogens are actually not a major problem when they are applied to sites. Wastewater treatment plants now have very high standards for heavy metals and pathogens set forth by the EPA. Most of the heavy metals are treated on site and so the amount of heavy metals found in the biosolids are below the federal standards. Pathogens are also removed at the site, and those pathogens that may remain in the biosolids would not be able to survive the harsh conditions of sunlight, air, and rain to have an effect on humans (Nutriblend, 2004). Without the use of this organic material, many sites would not be able to grow grass and become a rangeland again, instead of an abandoned mine site. Figures 7 and 8 illustrate what an abandoned mine would look like before and after the application of biosolids. Figure 7 depicts what much of Northeastern Pennsylvania looks like. Over time, some trees begin to grow out of the coal and rock that has been left behind from years of mining. Figure 8 shows what a site would look like after it has been graded back to its original state and biosolids were applied to help with the growth of the grass. It is much nicer to ride through Northeastern Pennsylvania and see a site with grass than it is to see the abandoned mines.

Fig. 7 – Abandoned coal mining site before remediation using biosolids; Rattler Mountain, Tioga County Pennsylvania.
Source: Garvy Resources, Inc. -www.garveyresources.com/readarticle.php?id=15

Figure 8 – An abandoned mine site reclaimed using biosolids; Rattler Mountain, Tioga County, Pennsylvania.
Source: Garvy Resources, Inc. -www.garveyresources.com/readarticle.php?id=15

3.5 Summary of Remediation Techniques

Table 1 below shows a brief summary of the five different remediation techniques for AMD through either helping with the existing problem or preventing it from occurring in the future.

Technique	Pros	Cons	Examples
Limestone Drains	Cost effective and materials are readily available	Maintenance must be performed in order to keep the drains working properly and cannot be used in all environments	Dyer Run, Minersville, Pa, Silverbrook Diversion Wells, McAdoo, Pa
Wetlands	Provides a habitat for plant and animal life	Continuous maintenance and prevention of plants from taking over the area	Minersville Wetland, Norwegian Township, Pa, Tamaqua Dry Dam, Tamaqua, Pa
Plants and Microorganisms	Aesthetically pleasing and effective at reducing the amount of heavy metal in the water	Have to use the right plants and microorganisms for the maximum amount of uptake of metals	Minersville Wetland
CCBs	Creates an outlet for the 110 million tons produced annually	Contain heavy metals that may be able to leach into the surface and groundwater	Pottsville, Pa
Reclamation	Aesthetically pleasing and prevents future AMD. Also brings native species of plants back to an area	Need permission from owner of land. Biosolids are frequently used which have a strong odor	Mahanoy City, Pa and Palmerton, Pa, Sharp Mountain, Pottsville, Pa

4. Methods

For this study, I am using data from PADEP to determine if the remediation actions have had an effect on the West Branch Schuylkill River and Upper Schuylkill River. For both of these streams, data were collected from 1996 through 2003; the data consist of the pH of the water, the concentration of iron, aluminum, and manganese expressed in milligrams per liter (mg/L), and the percent reduction needed to maintain good water quality standards. With this water quality data, the PADEP developed a Total Maximum Daily Load (TMDL) for the affected sections of the stream. These TMDL's are required by the Clean Water Act on all streams affected by pollution, in this case from AMD. The EPA (2007) defines a TMDL study as "a calculation of the greatest amount of a pollutant that a water body can receive without violating water quality standards, and assigns the amount of pollution that can be contributed by the pollutant sources". The study allocates a "numeric endpoint" for the amount of pollutants. The TMDL data show on average the amount of metals that are being released in the stream on a daily basis and what the allowable limit of the metals is. The data are expressed in pounds per day (lbs/day) since it is an average. The computing of the TMDL data is statistical and is based on the assumption that the ideal water quality would be met 99% of the time. The Monte Carlo simulation is used to assess the allowable amounts of heavy metals and pH for the stream. The percentage reduction, which is the percentage needed to have good water quality 99% of the time, was calculated using the Risk Analysis and Simulation Add-in for Microsoft Excel. The actual amount of heavy metals present was based on a yearly average (Capacasa, 2007). All of these calculations were performed by the PADEP and I am using the data to decipher whether or not there has been an improvement in water quality or if it is too soon to tell. Recommendations are also made for the sites along the river that are a high priority for remediation. Along with pictures of the streams, I have taken pictures of the limestone diversion wells and the wetlands to include in the project.

5. TMDL Study

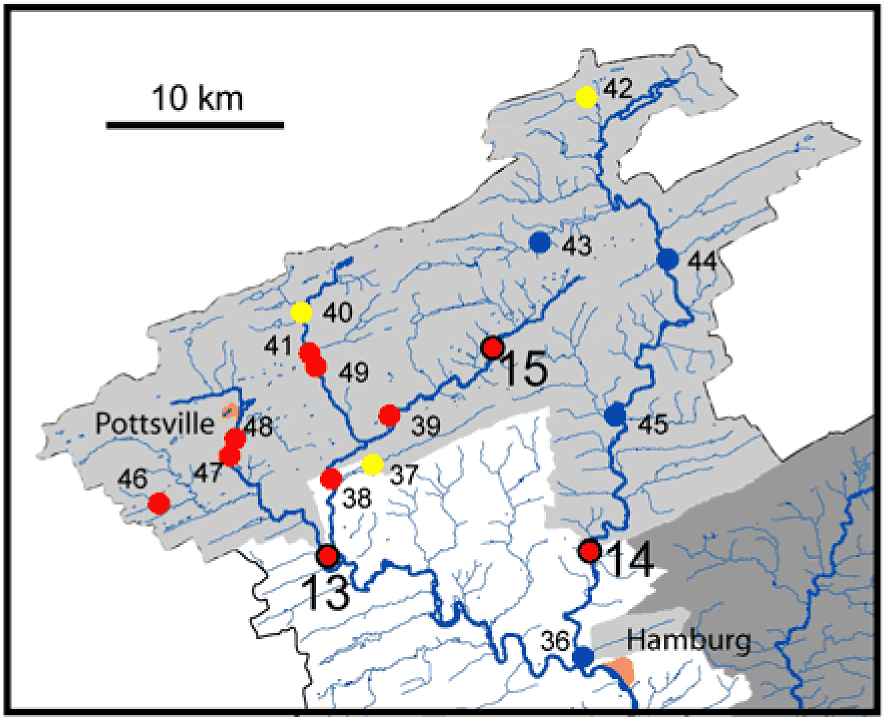
Section 303(d) of the Clean Water Act requires that every state, territory, and tribe assess the water quality for the area. The water quality data are then used to determine which waters in the area, which includes streams, rivers, and lakes, are polluted. The polluted streams are the ones that need a TMDL study. The states are required to rank their polluted streams based on how severely polluted the stream is. The states develop a TMDL for the area which gives water quality and options for improving the water quality and submits this information to the EPA. The EPA can approve or disapprove the submitted TMDL depending on whether or not they feel the stream is in need of restoration or if the data are not sufficient to approve the TMDL at the current time (PADEP, 2005). According to the EPA (2005), there are seven steps that are used to determine a TMDL.

- Collection of pre-existing data on the watershed to be used for the study
- Calculations of the allowable and existing pollutants in the water
- Finding the sources of pollution
- Verifying how important the stream is compared to other polluted streams
- Public acknowledgement of the situation
- TMDL data are submitted to the regional EPA
- EPA either approves or rejects TMDL data

6. Background on the West Branch Schuylkill River and the Upper Schuylkill River.

The PADEP does much of the background research on these streams in order to have complete TMDL data. It is important to decipher the cause of the pollution in each of the streams in order to have accurate data available.

The Little Schuylkill River (LSR) is an important tributary of the Schuylkill River that runs through Philadelphia. The LSR headwaters are located in Haddock and continue downstream to Port Clinton where it merges with the Schuylkill River. A history of coal mining in the area has caused a great deal of pollution along the LSR. Fig. 9 shows a map of the LSR, with number 13 being the West Branch and number 14 being the Little Schuylkill River and number 15 being the Mainstem Schuylkill River. Fig. 10 shows the water quality of streams and rivers of the Schuylkill River Basin. The data collected show the water quality of the LSR to be poor when compared with the Macroinvertebrate Aggregated Index for Streams (MAIS). This system quantifies the amount of macroinvertebrates in the water to determine the pollution level of a stream (Stroud Water Research Center, 2006). All three branches of the LSR are rated as poor with this system.



Water Quality:	good	fair	poor

Fig. 9 Map of Little Schuylkill River Watershed
Source: Stroud Water Research Center – http://www.stroudcenter.org/schuylkill/interpretation.htm

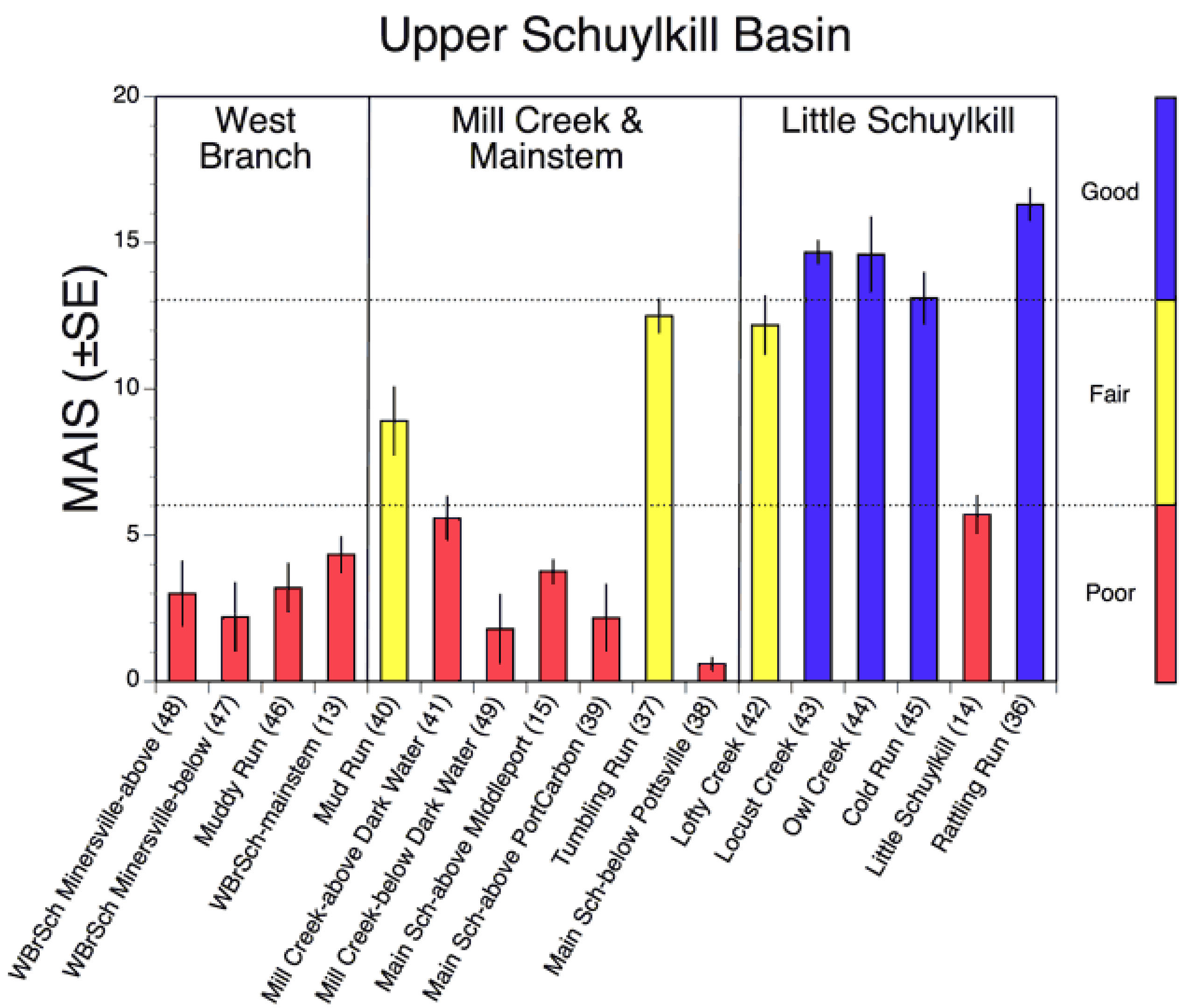


Fig. 10 – MAIS index of Schuylkill River Basin
Source: Stroud Water Research Center - http://www.stroudcenter.org/schuylkill/interpretation.htm

The Pennsylvania Department of Environmental Protection (PADEP) has begun numerous projects in order to help clean up the LSR. The focus of the paper is to determine if PADEP is having success in improving water quality on the West Branch and the Upper Schuylkill River using a variety of remediation techniques.

7. West Branch Schuylkill River

7.1 Background Information

The West Branch Schuylkill River is located in Schuylkill County and has a watershed that is approximately 21 square miles from Heckscherville to Cressona. It flows through the towns of Minersville, Pottsville, and Cressona in an east-southeast direction. The West Branch is in an area that has been heavily mined since the 1800s. It is found in the Anthracite Upland Section of the Ridge and Valley Province. The deep mining that occurred in the area normally went below the water table so there were many abandoned mines that have been collecting water for years. Along with AMD in this stream, there is also the problem of raw sewage being introduced into the stream from Minersville and Pottsville. There are six sampling sites along the stream and these different sampling sites can be seen in Figure 11 below. WB1 is a discharge from the Oak Hill/Pine Knot Tunnel, WB2 through WB4 and WB6 are sites along the stream, WB5 is a water sample from below the West-west Branch Schuylkill River tributary, and RWS001 is from the discharge of the active mine owned by RS & W Coal Company. Two abandoned mines are the cause of AMD along this stream; those mines are the Oak Hill/Pine Knot Tunnel and the Oak Hill Boreholes. The Pine Knot Tunnel discharges approximately 30,000 gallons per minute. Re-mining in the area is occurring on two sites along the stream. The RS & W Coal Company has a permit to discharge a certain amount of water into the stream and this is taken into consideration with the TMDL data. The Dyer Run Diversion Well and the Minersville Wetland are also located along this stream. The wells were completed in June 2001 and the wetland in 2002. The wetland is a passive wetland and consists of an intake, settling pond, treatment cell, water level control, and an outfall back into the river. The main goal of the wetland is to provide a sink for the iron hydroxide to settle out. *Typha latifolia*, or broadleaf cattail, is used in the wetland along with mushroom compost. The wetlands have not been in operation for that long of a time but hopefully they are having an impact on the levels of iron in the stream (Schuylkill Conservation District, 2005; PADEP, 2005).

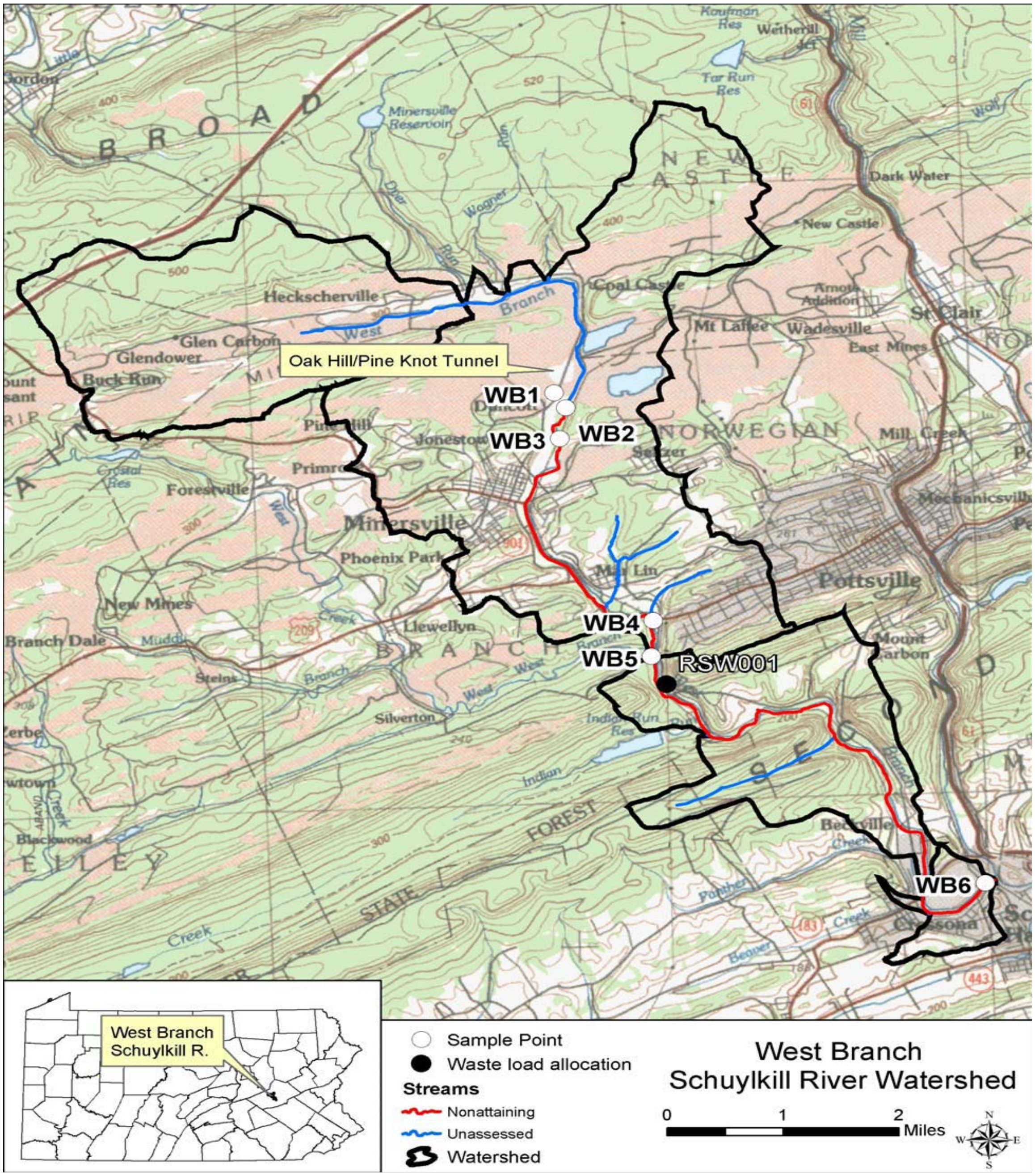


Fig. 11 – Shows the different water sampling sites along the West Branch Schuylkill River.
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Figure 12 shows the same map except without the geography and roads to get a clearer look at the sampling points along the stream.

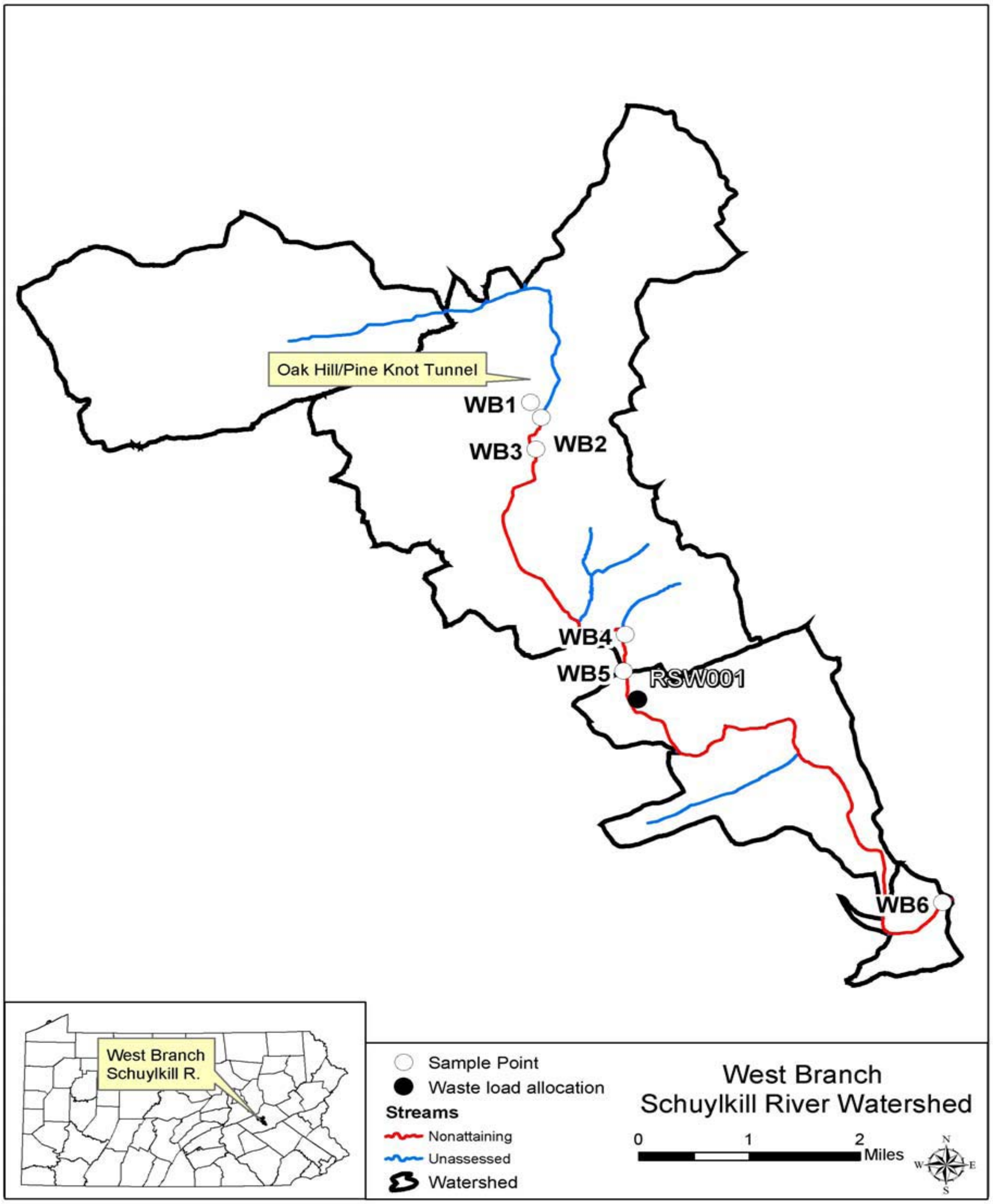


Fig. 12 – Sampling points along the West Branch Schuylkill River
Source: Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

7.2 Water Quality and TMDL Data and Discussion

PADEP has collected water quality data on the West Branch Schuylkill River and the Upper Schuylkill River from 1997 through 2003 and from 1997 through 2006 respectively. The water quality data were used to create the TMDL for both regions. The EPA (2007) defines a TMDL study as "a calculation of the greatest amount of a pollutant that a water body can receive without violating water quality standards, and assigns the amount of pollution that can be contributed by the pollutant sources". The study allocates a "numeric endpoint" for the amount of pollutants. The TMDL data show, on average, the amount of metals that are being released in the stream on a daily basis and what the allowable limit of the metals is. The data are expressed in pounds per day (lbs/day) since it is an average. The computing of the TMDL data is statistical and is based on the assumption that the normal water quality would be met 99% of the time. According to the EPA (2007) there are certain criteria that a body of water must meet in order for the water quality to be deemed normal 99% of the time. These criteria include chemical, biological, nutrient, and sediment. The chemical criterion is the amount of pollutants that can be introduced into the body of water without affecting the water quality. Biological criterion states that a body should have a certain amount of aquatic life present at any given time, nutrient criterion suggests a set amount of nutrients present, and sediment criterion describes conditions for avoiding unfavorable effects on the sediment.

The water quality data for the West Branch Schuylkill River are broken down by the sampling sites. The PADEP tested for pH, aluminum, iron, and manganese and the sampling sites can be seen in Figures 11 and 12 above. The data present are for a particular day; the DEP then used that daily data to formulate averages for the TMDL. The EPA has recommended ranges for pH and concentrations heavy metals that can be found in a river. The concentrations of heavy metals are different for rivers depending on the heavy metal and also the flow of a river. A larger river will be able to handle a greater concentration of heavy metals than a much smaller river. The West Branch Schuylkill River and the Upper Schuylkill River have the can handle the same amount of heavy metals.

The EPA recommended concentrations are:

- pH – 6.0 – 9.0
- Aluminum – 0.75 mg/L
- Iron – 1.50 mg/L
- Manganese – 1.00 mg/L
- Aluminum, iron, and manganese should not exceed these limits.

Table 2 – Sampling Site WB1 – Oak Hill/Pine Knot Tunnel

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
7/22/1997	6.2	1.1	6.6	3.4
8/29/1997	5.8	1.8	8.2	4.5
9/30/1997	6.0	1.7	8.8	6.3
12/3/1997	6.1	1.4	8.3	4.0
1/7/1998	5.9	1.4	7.4	4.0
2/5/1998	5.7	1.8	6.6	4.1
3/11/1998	5.6	2.2	5.4	3.5
4/9/1998	5.8	1.5	5.4	3.3
5/14/1998	5.3	3.4	3.2	3.2
6/10/1998	6.1	1.1	5.4	3.3
8/19/1998	6.2	0.9	6.8	4.0
10/29/1998	6.4	1.2	10.8	5.6
11/24/1998	6.3	0.8	9.7	4.9
12/22/1998	6.3	0.8	9.9	4.8
2/25/1999	6.1	1.4	7.4	4.4
3/25/1999	5.7	2.1	6.7	3.8
4/29/1999	6.0	1.2	6.1	3.7
5/20/2003	6.2	0.8	6.3	2.9
6/27/2003	5.9	1.3	5.6	2.7

Table 2 – Water Quality Data for sampling site WB1
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Table 3 – Sampling Site WB2 – Near Duncott, Pa

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
9/5/2002	4.6	6.6	10.1	9.9
10/9/2002	6.4	1.7	10.1	5.4
11/5/2002	5.1	0.5	No Data	0.2
12/23/2002	5.0	0.6	No Data	0.2
3/17/2003	5.1	1.0	No Data	0.3
4/21/2003	6.0	0.6	No Data	0.5
5/20/2003	5.7	0.7	No Data	0.4
6/27/2003	6.1	0.5	No Data	0.2

Table 3 – Water Quality Data for sampling site WB2
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Table 4 – Sampling Site WB3 – Below Oakhill Boreholes

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
9/5/2002	6.7	1.1	4.6	4.6
10/9/2002	6.5	1.2	4.3	4.3
11/5/2002	6.3	1.2	6.5	2.7
12/23/2002	6.3	1.3	5.9	2.3
3/17/2003	6.2	1.5	1.7	1.7
4/21/2003	6.5	0.9	6.2	2.4
5/20/2003	6.4	0.8	8.7	3.0
6/27/2003	6.2	1.0	5.7	2.1

Table 4 – Water Quality Data for sampling site WB3
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Table 5 – Sampling Site WB4 – Below Tributaries

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
9/5/2002	6.9	0.9	4.2	4.2
10/9/2002	6.7	1.1	3.6	3.6
11/5/2002	6.4	1.0	4.2	2.1
12/23/2002	6.6	1.3	4.5	1.9
3/17/2003	6.5	1.7	5.7	1.6
4/21/2003	6.7	0.9	4.8	2.2
5/20/2003	6.6	0.7	5.4	2.7
6/27/2003	6.4	1.0	4.7	2.0

Table 5 – Water Quality Data for sampling site WB4
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Table 6 – Sampling Site WB5 – Near Mouth of West West Branch Schuylkill River

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
9/5/2002	7.4	No Data	0.2	0.2
10/9/2002	7.2	No Data	0.4	0.4
11/5/2002	6.6	No Data	No Data	0.6
12/23/2002	6.9	No Data	0.8	0.5
3/17/2003	6.7	0.7	2.6	0.5
4/21/2003	6.9	No Data	0.7	0.8
5/20/2003	6.7	No Data	0.3	0.8
6/27/2003	6.7	No Data	0.9	0.7

Table 6 – Water Quality Data for sampling site WB5
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Table 7 – Sampling Site WB6 – Mouth of West Branch Schuylkill River

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
9/5/2002	7.5	0.5	1.2	1.2
10/9/2002	7.1	0.5	1.9	1.9
11/5/2002	6.6	0.5	1.6	1.6
12/23/2002	7.0	0.8	1.3	1.3
3/17/2003	6.8	1.4	5.1	0.9
4/21/2003	7.0	0.6	2.4	1.6
5/20/2003	7.0	0.5	2.1	1.8
6/27/2003	6.7	0.7	2.4	1.3

Table 7 – Water Quality Data for sampling site WB6
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Table 8 – Average Concentrations for All Sampling Sites

Sampling Site	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
WB1	6.0	1.5	7.1	4.0
WB2	5.5	1.5	10.1	2.1
WB3	6.4	1.1	5.5	2.9
WB4	6.6	1.1	4.6	2.5
WB5	6.8	0.7	0.8	0.6
WB6	7.0	0.7	2.3	1.5

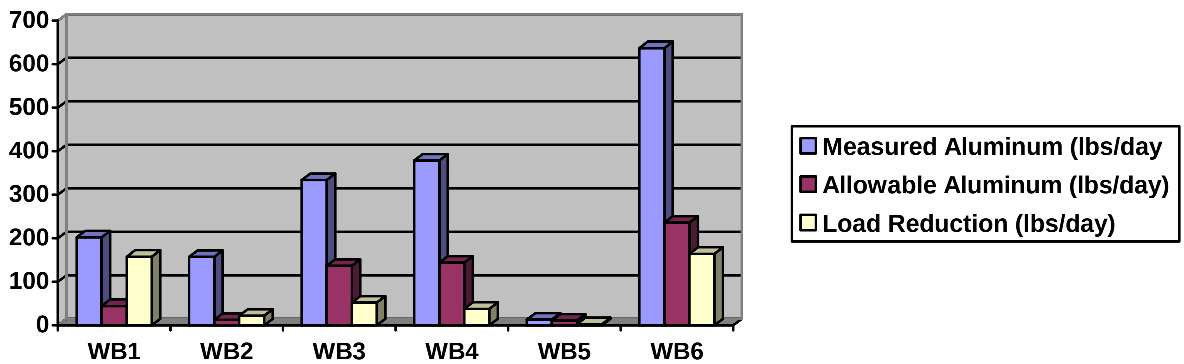
Table8 – Average concentrations for all sampling sites along the West Branch Schuylkill River
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

The water quality data in Tables 2 through 7 show some trends in the concentration of heavy metals present in the water at the different sampling sites. Table 8 provides average concentrations for all sampling sites. The average pH of the water remained consistent throughout the sampling dates and falls into the EPA's recommended range of between 6.0 and 9.0. The average concentration of aluminum at WB1, WB2, WB3, and WB4 exceeds the EPA's recommended value of .75 mg/L. The average concentration of iron exceeds the EPA's recommended value of 1.50 mg/L at all sampling sites except WB5. The same is true of the average concentration of manganese which exceeds the EPA's recommended value of 1.00mg/L at all sites except WB5.

The average concentrations of aluminum, iron, and manganese are higher at sampling sites WB1, WB2, and WB3 than at other sampling sites due to the location of the sites. WB1 is found downstream of the Oak Hill/Pine Knot Tunnel which discharges 3860 gallons per minute (gpm) of contaminated mine water into the river and the WB3 sampling site is where the Oakhill Boreholes discharge into the river. WB2 is affected by the Oak Hill/Pine Knot Tunnel discharge as well because it is found slightly downstream. There is not enough flow in the river to decrease the heavy metals before being sampled at WB2. This contaminated water causes the heavy metals to have higher concentrations at these sites along the river. The average concentrations of heavy metals at the other sampling sites are not as elevated because of the mixing with the water and other tributaries flowing into the West Branch Schuylkill River. There are dates where the concentrations of the heavy metals are either much greater or much less than the previous sampling date. This may be due to a large rainfall or snowmelt that would have added more water into the stream than normally flows. Along with that extra water, heavy metals from runoff could have entered the stream causing the data to fluctuate. Table 8 compares the average pH and concentrations of heavy metals for all the sampling sites. Iron has the greatest concentrations and is cause for concern along the river (PADEP, 2005).

The following graphs represent the TMDL data for the West Branch Schuylkill River that was compiled using the water quality data in the tables above. The TMDL data shows the pollution along the stream and where the most attention needs to be placed for stream remediation. The graphs below show the loads of aluminum, iron, and manganese found at the different sampling sites along the West Branch Schuylkill River. The load reduction is what the heavy metals would have to be reduced to in order to reach a normal water quality. This number, represented in pounds per day (lbs/day), takes into consideration the heavy metals that are entering the river at different points along the sampling sites so this number is sometimes negative if there is no pollution of a specific heavy metal in the sampling area. With the load reduction information, the DEP using a statistical analysis develops a Percent Reduction for the sampling sites. This number gives the percentage of a particular heavy metal that would need to be removed in order for the river to meet water quality standards. It expresses the load reduction as a percentage instead of lbs/day, taking into consideration the mechanisms of the river as part of the equation.

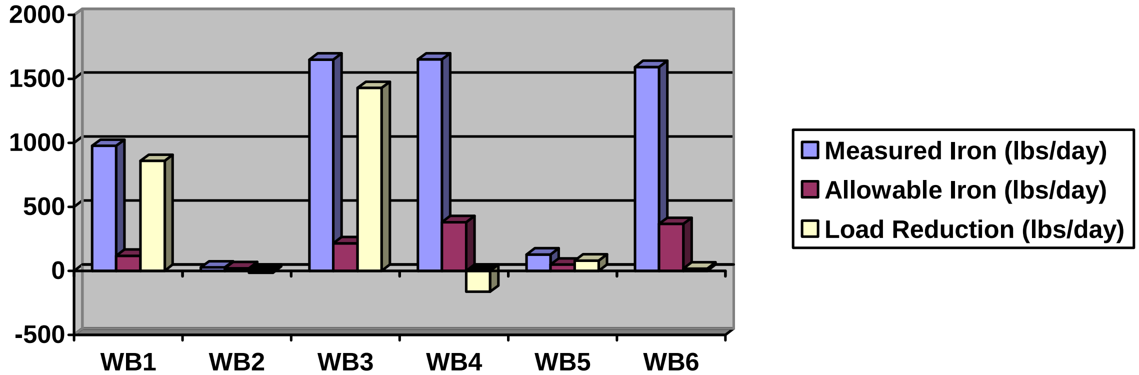
Graph 2 – Measured and Allowable Aluminum Loads for All Sampling Sites



Graph 2 – Measured and allowable Aluminum loads at sampling sites.

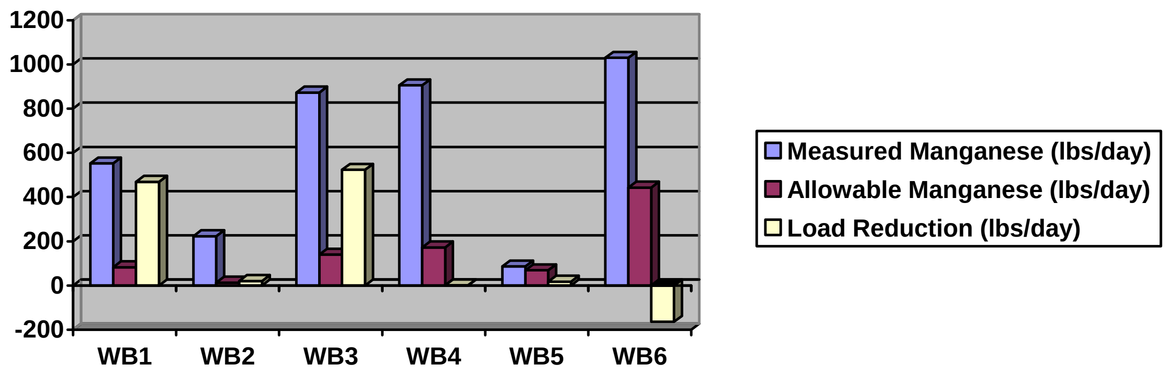
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Graph 3 – Measured and Allowable Iron Loads for All Sampling Sites



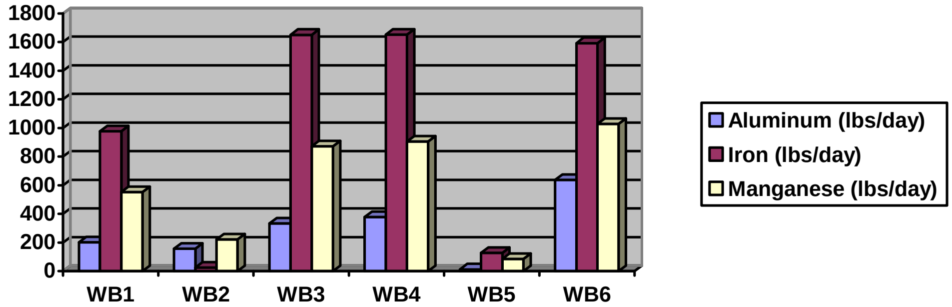
Graph 3 – Measured and allowable iron loads.
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Graph 4 – Measured and Allowable Manganese Loads for All Sampling Sites



Graph 4 – Measured and allowable manganese loads.
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

Graph 5 – Average Loads for All Sampling Sites



Graph 5 – Average loads for all sampling sites.
Source: Pennsylvania Department of Environmental Protection
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/WestBranchSchuylkillRiver_TMDL.pdf

The TMDL data for Graph 2 show high aluminum loads at sampling sites WB3, WB4, and WB6. While the three sites show a high influx of aluminum, only sampling sites WB1, WB2 and WB6 have a high load reduction in order to help with the water quality of the river. The load reduction of WB1 is 157.7 lbs/day with a percent reduction of 78%. WB2 only has a load reduction of 22.0 lbs/day, but the percentage reduction is 64% so this sampling site would be high priority to remediate for aluminum. WB6 has a load reduction of 164.2 lbs/day with a percent reduction of 41%. The other sampling sites percent reductions are less than 25% because if you remediate the sources of the problem, it will alleviate the heavy metals from traveling downstream.

Graph 3 shows the iron load that is discharged into the stream. WB1, WB3, WB4, and WB6 have the highest iron loads. WB1 and WB3 are found at discharges, WB4 is below the Muddy Branch tributary, and WB6 is the mouth of the river. According to the load reductions, remediating WB1 and WB3 would alleviate the iron problem, since both of these sites are at discharges. Preventing the iron from ever entering the stream would cause the levels downstream to drop. The load reduction and percent reduction for these sampling sites are 859.2 lbs/day and 88% and 1428.8 lbs/day and 87%, respectively. The percent reductions for sampling sites WB2, WB4, and WB6 are all less than 5%. The percent reduction for sampling sites WB5 is higher at 62%, but it not as high a priority as sites WB1 and WB3.

Graph 4 shows the manganese load for all the sampling sites. Again, sampling sites WB1, WB2, WB4, and WB6 show high load allocations for this heavy metal. Sampling sites WB1, WB2, and WB3 have the highest load reductions for this heavy metal. The manganese is entering the river through the mine discharges and so it is not imperative to remediate the sites below WB3 for this heavy metal. The percent reductions for these sampling sites are all at or above 79%. The downstream sampling sites have 0% or close to that as a percent reduction.

Graph 5 shows the average loads of heavy metals for all sampling sites. It is shown that iron and manganese are the major problems for the river. WB1, WB3, WB4, and WB6 have the highest loads and it is important to remediate these areas in order to prevent future pollution of the river.

The PADEP has plans set in place to improve the water quality of the West Branch Schuylkill River. These plans include the reclamation of the abandoned mines in the area and making sure all active mining sites are permitted. The Oak Hill Mine which discharges into the West Branch Schuylkill River has been put on the high priority list for reclamation. This area did have diversion wells, but there was not enough funding to keep up with the maintenance of the project and sludge has since taken over the limestone wells. Land reclamation above the discharge will help with the amount of heavy metals that are introduced into the river and small wetlands will help with the impact. The Pine Knot Tunnel, which also discharges into the West Branch, is on the high priority list. This area is a little more complicated to reclaim than the Oak Hill Mine because of the amount of water that exists and is added to the mine pool. A team of engineers has been hired to decide the best way to remediate this large area; the Pine Knot Tunnel discharges 30,000 gpm into the river and has high iron and aluminum concentrations which make this remediation project very costly. The Sharp Mount Mine Subsidence also discharges water into the West Branch. This mining site had been so extensively mined in the past that the mountain is starting to cave in on itself. The subsidence that occurs along this mountain collects acidic water and discharges it into the river. This is another costly project to stop the subsidence from occurring and preventing more contaminated water from entering the river; it will take years to complete (Schuylkill Conservation District, 2005).

8. Upper Schuylkill River

8.1 Background Information

The Upper Schuylkill River runs through Pottsville, Schuylkill Haven, and Port Clinton in central Schuylkill County, Pennsylvania. It has a watershed measuring 49.4 square miles and flows east-southeast. The headwaters are located in Tuscarora and join the Little Schuylkill River in Port Clinton. The watershed is located in a part of the Southern Anthracite Coal Field which is within the Anthracite Upland Section. This region is the largest coal field out of the four that exist within the Upland Section of the Valley and Ridge Province. Like the watershed of the West Branch Schuylkill River this area has been extensively mined since the 1800s. It was a great area for mining because the river provided access to places like Reading and Philadelphia. There are 10 active permits for mining along the river still today. These permits are either active mining operations or reclamation sites. There is also raw sewage being introduced into the river in a few places. There are 21 sampling sites along the Upper Schuylkill River where water quality data were collected to formulate the TMDL. Figures 13 and 14 below show where the sampling sites are located along the river. Many of the sampling sites are located at discharges along the river (PADEP, 2007).

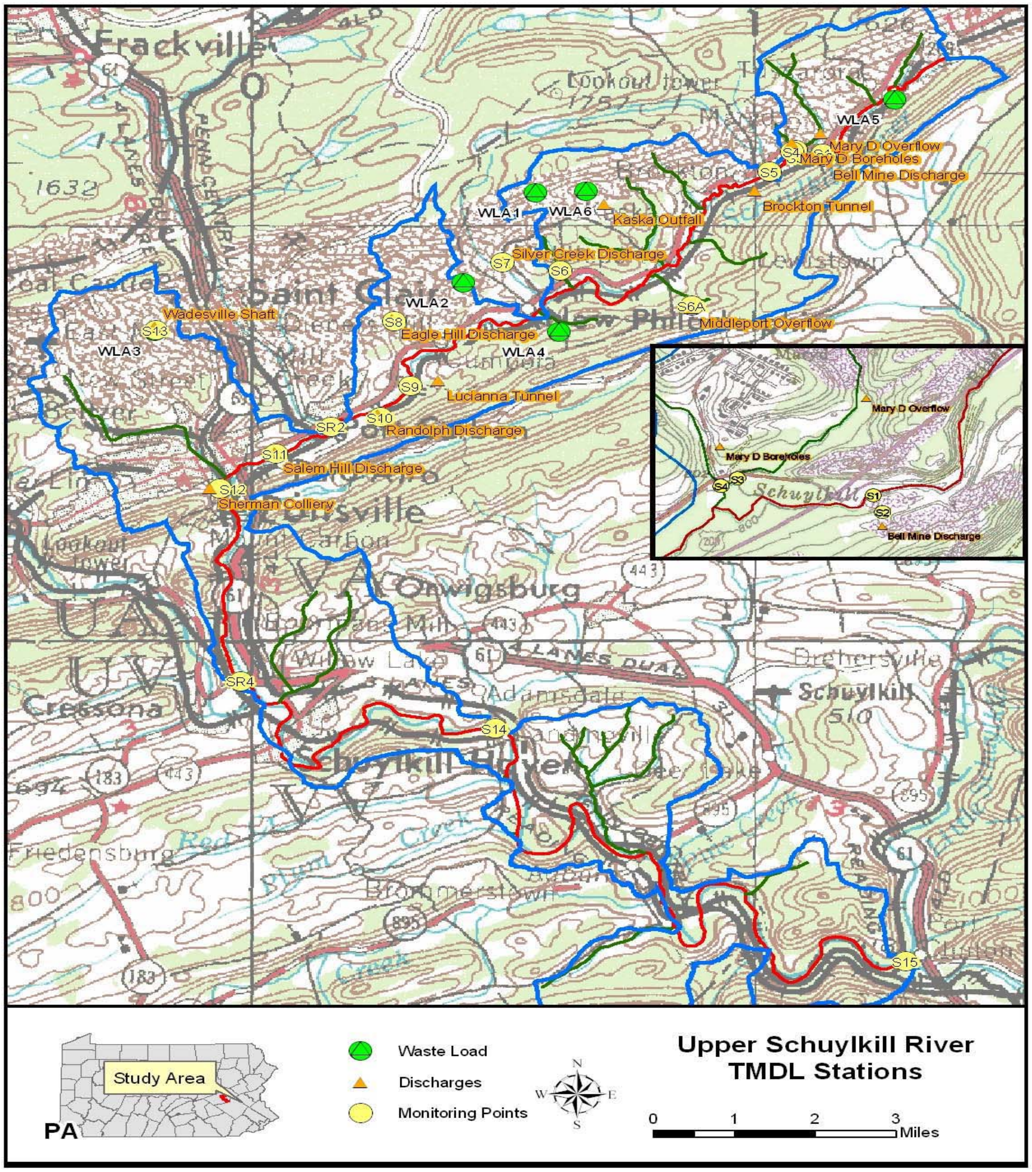


Fig. 13 – Sampling Points along the Upper Schuylkill River
Source: Pennsylvania Department of Environmental Protection – http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

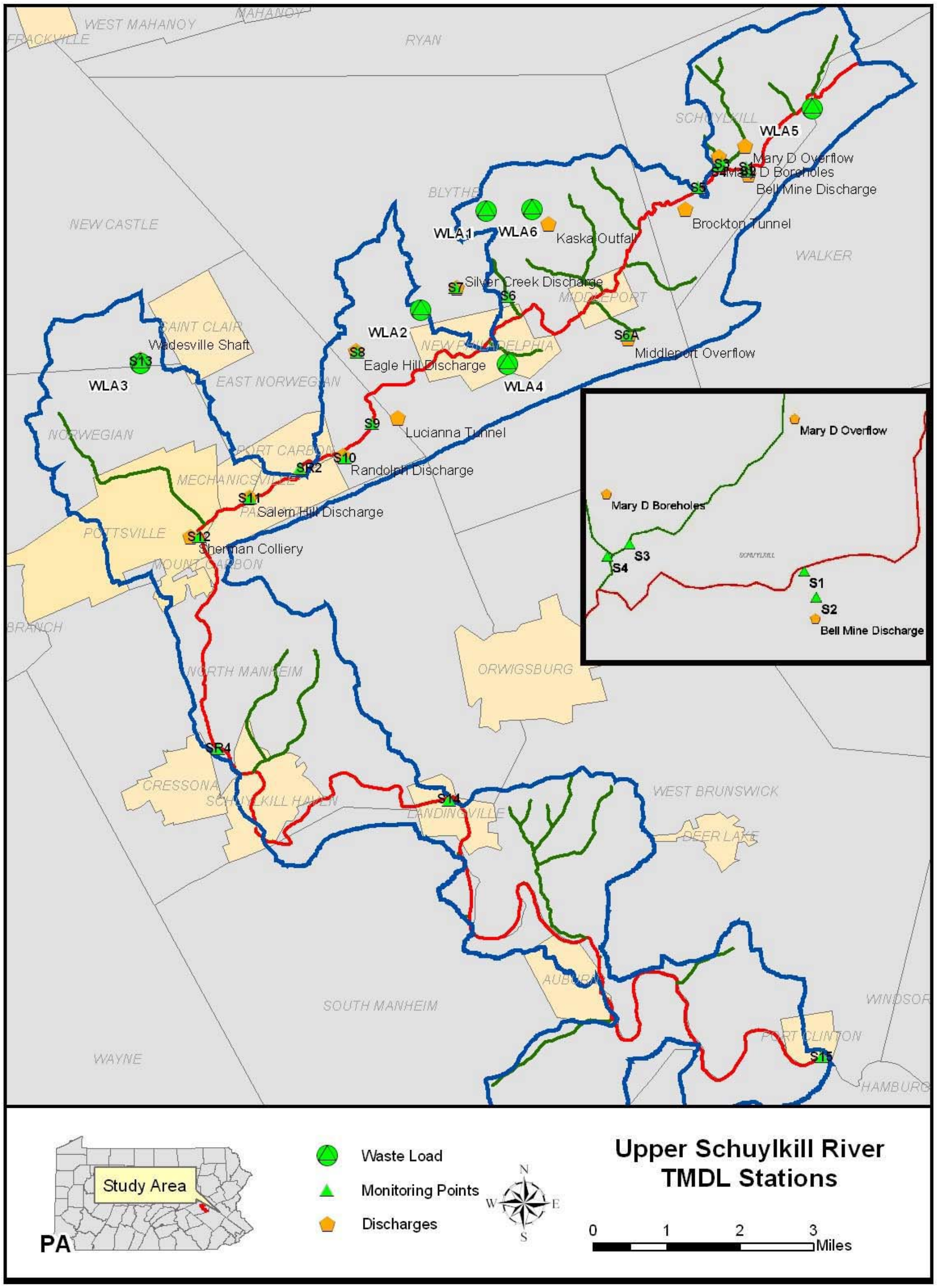


Fig. 14 - Sampling Points along the Upper Schuylkill River
Source: Pennsylvania Department of Environmental Protection – http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

8.2 Water Quality and TMDL Data and Discussion

Like the West Branch Schuylkill River, the PADEP did water quality testing along the Upper Schuylkill River. The tests were for aluminum, iron, manganese, and pH and that information was used to create the TMDL data for the river. There are 8 sampling sites along the river, 10 sampling sites at discharges, one sampling site where Big Creek flows into the Upper Schuylkill River, and 10 areas where there are permitted discharges into the river from coal companies. All of these sampling sites can be seen in Figures 13 and 14. For the purpose of this study, the sampling sites that will be looked at along the river will be S1, SRM, SRNP, SR2, SR4, S14, and S15. Three mine discharge sampling sites will also be looked at; those sites are S2, S7, and S10. The tables below show the water quality data of these sampling sites that were used to formulate the TMDL.

The water quality data for the Upper Schuylkill River are broken down by the sampling sites. The PADEP tested for pH, aluminum, iron, and manganese and the sampling sites can be seen in Figures 13 and 14 above. The data present are for a particular day; the DEP then used that daily data to formulate averages for the TMDL. The EPA has recommended ranges for pH and concentrations heavy metals that can be found in a river. The concentrations of heavy metals are different for rivers depending on the heavy metal and also the flow of a river. A larger river will be able to handle a greater concentration of heavy metals than a much smaller river. The West Branch Schuylkill River and the Upper Schuylkill River can handle the same amount of heavy metals. The EPA recommended concentrations are:

- pH – 6.0 – 9.0
- Aluminum – 0.75 mg/L
- Iron – 1.50 mg/L
- Manganese – 1.00 mg/L
- Aluminum, iron, and manganese should not exceed these limits.

Table 8 – S1 – Headwaters of Schuylkill River

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
11/7/2002	6.2	1.0	0.5	1.0
12/30/2002	5.5	1.3	0.7	1.1
3/19/2003	6.5	1.0	0.8	0.6
4/24/2003	5.6	1.5	0.6	1.3
5/21/2003	5.7	1.2	0.8	1.5
6/30/2003	5.8	1.2	0.6	1.0
10/16/2003	6.3	0.8	0.5	0.9
4/15/2004	5.9	0.8	0.7	1.0

Table 8 – Water quality data for sampling site S1
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 9 – SRM – Schuylkill River in Middleport

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
5/10/2005	6.9	No Data	0.8	0.9
6/30/2005	6.7	No Data	0.9	1.6
9/9/2005	6.4	No Data	0.0	0.6
4/26/2006	6.6	No Data	1.1	0.8
6/7/2006	6.3	No Data	0.3	0.8

Table 9 – Water quality data for sampling site SRM
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 10 – SRNP – Schuylkill River in New Philadelphia

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
5/10/2005	No Data	No Data	No Data	No Data
6/30/2005	6.7	No Data	2.3	1.4
9/9/2005	6.5	No Data	1.3	0.9
4/26/2006	6.5	No Data	2.0	0.8
6/7/2006	6.2	No Data	1.8	1.0

Table 10 – Water quality data for sampling site SRNP
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 11 – SR2 – Schuylkill River in Port Carbon above Mill Creek Confluence

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
5/10/2005	6.6	0.0	1.7	1.1
6/30/2005	6.9	0.7	3.1	1.5
9/9/2005	6.6	0.0	1.5	1.1
4/26/2006	6.3	0.0	2.3	0.9
6/7/2006	6.4	0.0	1.5	1.1

Table 11 – Water quality data for sampling site SR2
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 12 – SR4 – Schuylkill River in Cressona

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
5/6/2005	7.6	0.0	1.0	1.2
6/30/2005	7.9	0.8	2.8	1.0
9/9/2005	8.2	0.0	0.5	0.5
4/26/2006	6.4	0.0	1.6	0.6
6/7/2006	6.5	0.0	1.0	0.9

Table 12 – Water quality data for sampling site SR4
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 13 – S15 – Schuylkill River before joining the Little Schuylkill River

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
11/14/2002	7.0	0.0	0.0	0.3
12/30/2002	7.0	0.0	0.4	0.8
3/19/2003	7.6	0.0	0.9	0.4
4/23/2003	7.1	0.0	0.4	0.9
5/21/2003	6.4	0.0	0.4	0.5
6/30/2003	7.2	0.0	0.0	0.8
10/16/2003	7.1	0.0	1.0	0.4
4/16/2004	7.7	1.1	1.0	0.4

Table 13 – Water quality data for sampling site S15
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 14 – S2 – Bell Tunnel Discharge

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
4/21/1975	3.6	No Data	2.0	No Data
11/1/1991	5.0	No Data	12.0	1.5
8/12/1997	3.9	1.2	2.9	1.4
10/16/1997	3.9	1.3	4.5	1.6
7/2/2002	4.0	0.7	2.3	1.1
9/10/2002	3.9	0.6	6.0	1.3
10/23/2002	4.0	0.9	7.5	1.7
11/7/2002	4.1	0.9	9.5	1.8
12/17/2002	4.2	0.9	4.2	0.9
3/5/2003	3.7	1.0	3.6	1.6
4/28/2003	4.4	1.3	2.1	1.5
6/30/2003	4.0	1.5	2.8	1.6
8/27/2003	3.9	1.3	2.7	1.7
10/6/2003	4.1	1.2	3.3	1.6
12/16/2003	4.3	No Data	No Data	No Data
4/15/2004	3.9	1.0	3.1	1.4

Table 14 – Water quality data for sampling site S2
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 15 – S7 – Silver Creek Discharge

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
4/22/1975	4.5	No Data	20.0	No Data
11/7/1991	6.0	No Data	27.0	3.5
8/9/1995	5.6	1.9	31.3	4.3
4/16/1997	5.8	1.0	17.0	2.9
6/12/1997	5.8	1.5	23.0	3.3
7/8/1997	5.9	1.3	20.5	3.2
11/7/2002	6.1	1.2	26.2	3.6
12/30/2002	6.1	1.6	23.2	3.4
3/19/2003	6.0	2.2	24.1	3.4
4/24/2003	5.8	1.9	20.1	3.3
5/21/2003	5.7	1.6	21.1	3.3
6/30/2003	6.1	2.4	18.1	3.1
10/16/2003	6.1	1.5	21.1	3.2
4/15/2004	5.8	1.5	19.7	2.9

Table 15 – Water quality data for sampling site S7
Source: Pennsylvania Department of Environmental Protection -
http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 16 – S10 – Randolph Discharge 100 meters downstream

Date	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
11/7/2002	6.8	0.0	14.3	2.3
12/30/2002	6.8	0.0	14.3	2.1
3/19/2003	6.6	0.0	16.2	2.2
4/24/2003	6.7	0.0	13.2	2.3
5/21/2003	6.3	0.0	12.9	2.1
6/30/2003	6.6	0.0	12.0	2.2
10/16/2003	6.7	0.0	17.5	2.7
4/16/2004	7.0	0.0	17.6	2.8

Table 16 – Water quality data for sampling site S10
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Table 17 – Average Concentrations for All Sampling Sites

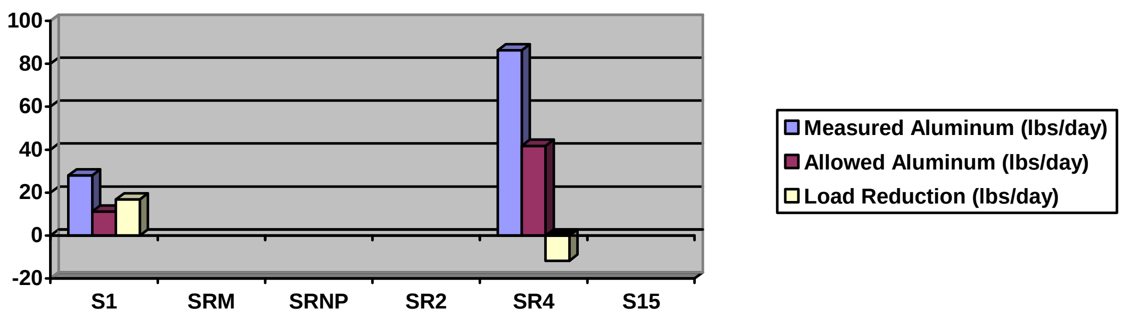
Sampling Site	pH	Aluminum (mg/L)	Iron (mg/L)	Manganese (mg/L)
S1	5.9	1.1	0.7	1.1
SRM	6.6	No Data	0.6	0.6
SRNP	6.5	No Data	1.9	1.0
SR2	6.6	0.7	2.0	1.1
SR4	7.3	0.8	1.4	0.8
S15	7.1	1.1	0.5	0.6
S2	4.1	1.1	4.6	1.5
S7	5.8	1.4	22.3	3.3
S10	6.7	0.0	14.8	2.3

Table 17 – Water quality data for sampling all sampling sites
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

The water quality data and TMDL graphs show that the Upper Schuylkill River is also suffering from pollution due to AMD from the abandoned mines. The water quality data shown in Tables 8-10 show the pH normally falls between the ranges of 6.0-9.0, which is considered normal for a stream. At sampling site S2, however, the average pH is more acidic than at other sampling sites along the stream due to the tunnel discharge that is located there. Throughout the stream, aluminum, iron, and manganese have the highest concentrations at the sampling sites located at or near the mine discharges (S2, S7, and S10), which would be expected because the water entering the river at these points is directly from the mines. The heavy metal concentrations are not as high at some other sampling sites because of the mixing that occurs from other tributaries and the river itself. Table 17 show average concentrations for all the sampling sites. The discharges have the greatest concentrations compared to all the other areas of the stream. The iron concentrations are especially high at sampling sites S7 and S10 due to the mine discharge. There are some areas where no data were collected for some of the heavy metals. This could be due to human error or a low flow in the river and it is not specifically stated in the data (PADEP, 2007).

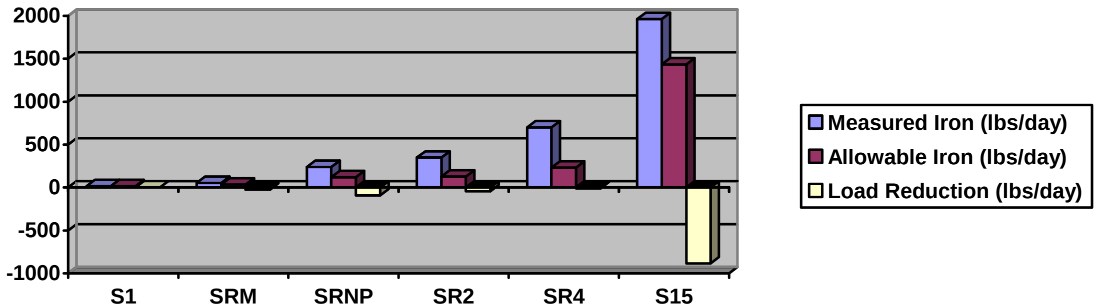
The following graphs show the TMDL data that were compiled using the water quality data from the different sampling sites. The TMDL data express the heavy metals in pounds per day (lbs/day) and they also give a load reduction figure, which is the amount of heavy metals that would need to be reduced in order for the stream to meet water quality standards 99% of the time.

Graph 6 – Measured and Allowable Aluminum Loads for Sampling Sites Along the Stream



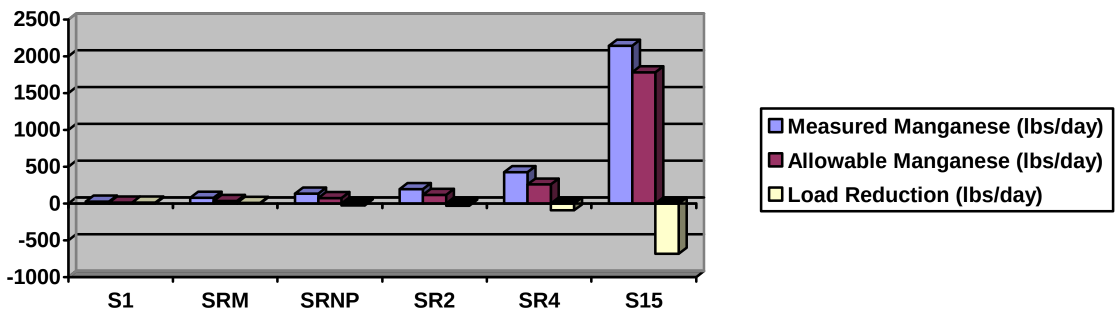
Graph 6 – Measured and allowable loads of Aluminum
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Graph 7 – Measured and Allowable Iron Loads for Sampling Sites Along the Stream



Graph 7 – Measured and allowable loads of Iron
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

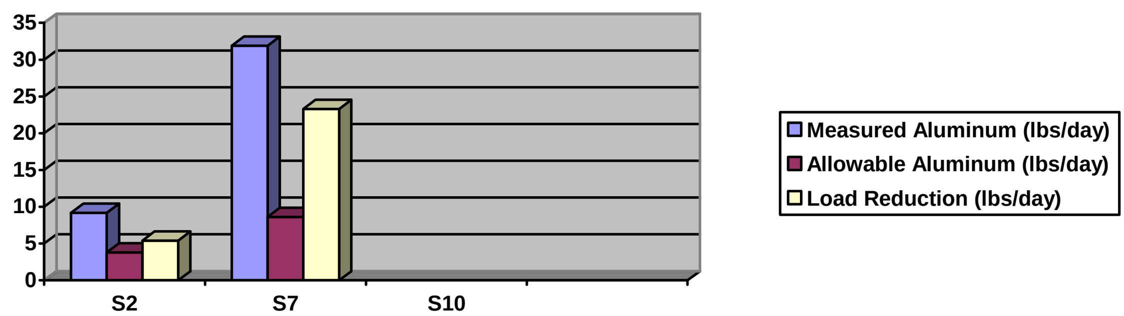
Graph 8 – Measured and Allowable Manganese Loads for Sampling Sites Along the Stream



Graph 8 – Measured and allowable loads of Manganese
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

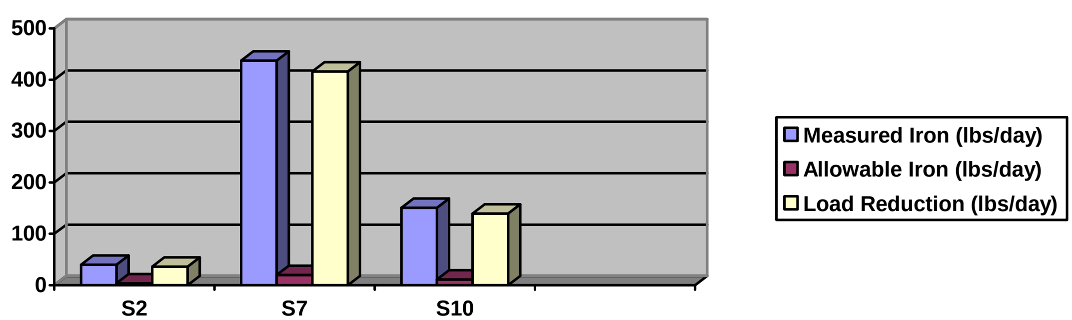
Graphs 9-11 show the TMDL data for the mine discharges along the river.

Graph 9 – Measured and Allowable Aluminum Loads at Discharges



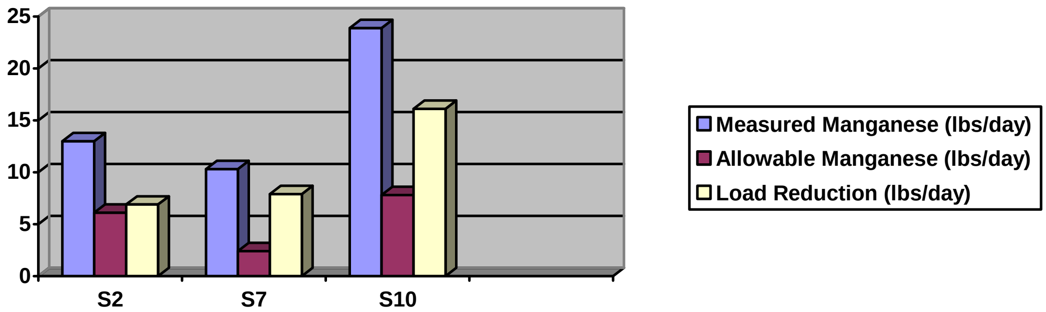
Graph 9 – Measured and allowable loads of Aluminum
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Graph 10 – Measured and Allowable Iron Loads at Discharges



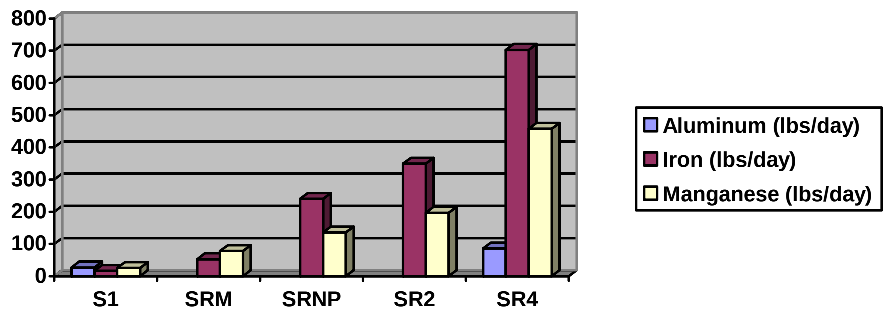
Graph 10 – Measured and allowable loads of Iron
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Graph 11 – Measured and Allowable Manganese Loads at Discharges



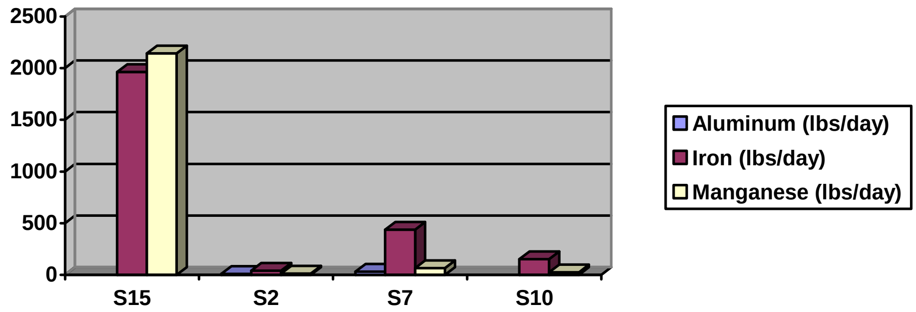
Graph 11 – Measured and allowable loads of Manganese
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Graph 12 - Average Loads for Sampling Sites



Graph 12 – Average loads for sampling sites
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Graph 13 – Average Loads for Sampling Sites (continued)



Graph 13 – Average loads for sampling sites
Source: Pennsylvania Department of Environmental Protection - http://www.dep.state.pa.us/dep/deputate/watermgt/wqp/wqstandards/tmdl/Upper%20Schuylkill%20River%20TMDL%20Final032807.pdf

Graph 6 shows the heavy metal load for aluminum for the sampling sites along the river. Only sites S1 and SR4 show any amount of heavy metals present. This can be due to a low flow in the river or human error. S1 however is the only site that has a load reduction of 16.8 lbs/day, with a percent reduction of 60%.

The TMDL data for Graph 7 for iron and Graph 8 for manganese show that S15 has the highest load for each heavy metal. The load reduction for iron and manganese is a negative number for S15 because the iron and manganese are introduced at the mine discharges and so once the mines are remediated the heavy metals would not be a problem at the mouth of the river. The sampling site S15 is located at the mouth of the river so if sites above this are remediated, then this site would not have to deal with the load allocations of the heavy metals.

Graphs 9 through 11 show the loads for aluminum, iron, and manganese that are found at mine discharges along the river. For aluminum S2 and S7 have the highest loads, with S10 TMDL data not detectible. The load reduction for S2 is 5.37 lbs/day with a percent reduction of 58% and for site S7 it is 23.3 lbs/day and 73% respectively. Each sampling site for iron and manganese would need load reductions in order for the river's water quality to be considered normal by EPA standards.

Graphs 12 and 13 show the average loads of each heavy metal that is being discharged into the Upper Schuylkill River. Iron and manganese are the biggest cause for concern in this river and need to be taken care of at the source, which would be at the mine discharges. The Upper Schuylkill River has many more sampling sites than the ones shown and they all express the same data. The river has higher than normal concentrations of heavy metals and remediation in the near future will help this river's water quality for the future.

There are plans for the remediation of the Upper Schuylkill River that have been discussed for the areas that are considered high priority. Some of these plans include the remediation of the Mary D Mine Outflow. This outflow has high iron concentrations and the recommended means for remediation would be a wetland because of the inconsistency in flow rates throughout the year. The Randolph Discharge is another high priority site for the river. This site discharges 851 gpm of water into the river. The proposed remediation for this site includes settling ponds and a passive wetland system. There are many other areas that may need future remediation, but further water sampling must be completed before those sites can be assessed (Schuylkill Conservation District, 2005).

9. Recommendations

The water quality data and the TMDL data demonstrate that the West Branch Schuylkill River and the Upper Schuylkill River suffer from pollution caused by AMD from the abandoned mines throughout the watersheds. In order for these rivers to have any improvement in water quality, a variety of steps needs to be taken to ensure the future of these environments.

- Funding – an increase in funding for remediation projects must occur in order to complete and maintain the various remediation techniques that would be in place throughout the rivers. It is expensive to start these projects and the cost continues through monitoring and maintaining the remediated sites. Funding comes from a variety of sources, such as the EPA, U.S. Army Corps of Engineers, PA Bureau of Abandoned Mines, and the PADEP to name a few.
- Landowner Cooperation – in order for the PADEP to complete any remediation projects, they must have the permission of the person who owns the land. It is important for the community and landowners to

support the PADEP's efforts because without their help the work cannot be completed.

- Best Remediation Techniques – Limestone diversion wells and wetlands seem to be the best techniques to improve water quality of the rivers. While limestone diversion wells and wetlands cannot be used at all the sites, they are the most easily maintained and cost effective as long as the PADEP keeps up with the maintenance of the sites. Using CCBs as a means to remediate the mines is also a good technique, but until the public approves of this technique there will be a lot of red tape to go through before being able to do this.
- Re-mining and Land Reclamation – re-mining of the various abandoned mines not only provides jobs for the area and coal, but it also guarantees that the land will be reclaimed to close to its original grade after the mining operations cease. Even if the company goes bankrupt there is money in a bond to complete the projects and AMD will not be a problem in this area.

The recommendations listed above will help with the problem of AMD, but it is a long process. It takes a while to design and build the limestone diversion wells and wetlands and it can be years until any real progress is shown in the water quality data. The sooner the TMDL data is approved by the EPA, the sooner these projects can get funding and construction can begin (PADEP 2005; PADEP 2007; Schuylkill Conservation District, 2005).

10. Future Remediation Projects

There are many remediation projects that are already underway or are waiting approval throughout Pennsylvania. The Nanticoke Creek Assessment and Restoration Project is one project in Luzerne County, Pennsylvania. This project is estimated to cost approximately $5 million dollars and includes the construction of wetlands and extensive water quality data collection. The Lackawanna River Tributary Stream Restoration is not focusing on the source of AMD, but what mining did to the river. The widespread mining that occurred along the river has changed the morphology of the river and has caused areas to flood on a regular basis. This project, with estimated costs of $500,000 will focus on preventing flooding in the future by restoring the tributaries and riparian buffers in the area. The Butler Mine Tunnel is a $10 million project that has been in the works since 1985 and flows into the Susquehanna River. The EPA has been monitoring this site and it has been discussed that a pipeline be put in place to carry the heavy metals to the water treatment facility and bypass the river all together. The Little Nescopeck Creek Restoration Project is another $10 million project in Luzerne County. The Jeddo Mine Tunnel discharges 50,000 gpm into the stream, which is the largest discharge in Northeastern Pennsylvania, and continues today (PA Heritage). These are only a very few of the many remediation projects that are in Pennsylvania for AMD. Just from the few listed it is evident why funding is so important. The main sources of funding for mine reclamation come from federal grants through the Title IV of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). The grants go to certain mine sites depending on their rank. The SMCRA program defines the ranking system as:

- Emergencies – mine site is life-threatening
- Priority 1 – protection from extreme danger
- Priority 2 – protection from adverse affects of coal mining including AMD
- Forfeited Reclamation Bonds – any company that has failed to reclaim the mine site will lose all bonds associated with the site

The Federal Government obtains there money through the coal companies. The companies must pay the Government 35-cents-per-ton for each ton of surface-mined coal and 15-cents-per-ton of deep mined coal. On average, Pennsylvania receives approximately $20 million in grants for mine reclamation. It is estimated that it will take 50 years to reclaim only the high priority sites; this will leave thousands of sites untouched due to lack of funding (Lehigh University, 2004). Without help from the EPA, U.S. Army Corps of Engineers, PA Bureau of Abandoned Mines, etc. these projects would never be possible and AMD would continue to destroy the local watersheds.

11. Conclusion

AMD is a huge environmental problem throughout Northeastern Pennsylvania and it will continue to be a problem until the sources of the pollution can be remediated.

Coal mining throughout the area has caused many of the streams, rivers, and lakes in the area to be polluted with heavy metals. It has caused problems for the flora and fauna that rely on the rivers for their habitat and has caused the orange color that many of the rivers have which is not aesthetically pleasing. The PADEP through funding has begun the slow process of trying to remediate the rivers and bring the water quality back to a suitable standard, but this process is long and arduous. The rivers in the area must first be prioritized by the degree of pollution and then the high priority areas of the stream should be the first to be remediated. To prioritize the rivers in Pennsylvania, the PADEP used water quality data to formulate a Total Maximum Daily Load (TMDL). The TMDL data identifies the sampling sites that have the greatest amount of heavy metals present and these sites become high priority for remediation. Most often the high priority sites are located at mine discharges. If the DEP can take care of the problem at the source of pollution, then the heavy metals will not be a problem downstream. While the process of remediation is slow, Pennsylvania has made great strides in the reclamation of abandoned mines. According to the PADEP (2007) "Pennsylvania reclaimed 54 acres of gob piles, 73 acres of mine pits, 2,500 acres of spoil areas, 7,658 feet of highwall, and treated 94,465 gallons of mine drainage under their environmental program." While these numbers are an improvement it is estimated that there are 3,000 miles of polluted rivers in Pennsylvania that are affected by AMD and it will cost between $5 billion and $15 billion to remediate all these areas. Pennsylvania has begun to take the right steps toward improving the water quality of the rivers affected by AMD and hopefully the remediation techniques will create watersheds where plants and animals flourish and future generations will not know what an orange stream is (U.S. Geological Survey, 2007; PADEP, 2007).

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Photos:

All photos were taken by Tara Sadak

Figure 15: AMD along the West Branch Schuylkill River

Figure 16: AMD at a different site along the West Branch Schuylkill River

Figure 17: Minersville Wetland Project, Minersville, Pennsylvania


Figure 18: Small scale diversion wells at Dyer's Run. The limestone is contained in the hoppers and the river is diverted over the limestone.


Figure 19: Another view of the Dyer Run Diversion Wells


Figure 20: Inside of the limestone hopper that needs to be filled

Figure 21: A mine site in the process of being re-mined in Glen Lyon, Pennsylvania

Figure 22: An area of the same mine site that has been reclaimed back to its original grade

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