

EFFECTIVENESS OF SLAG BEDS IN THE TREATMENT OF
ACID MINE DRAINAGE



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July 27, 2010

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INTRODUCTION

Water is a complex compound that is important and used in everyday life. It is integral to human survival because it is 70% of the human body (Patel, 2010, June 22). Water is used for daily functions; for example, people use it as a resource for hydration and cleaning. Not only is water important to humans, but it is also important to animals because it can be used as a habitat. Water is also used as a universal solvent, which means that it dissolves most substances. Since water is a precious resource, the water quality has to be monitored to make sure it is clean enough to be used.

Different methods used to test water quality are available. One method utilizes the existence of underwater communities. By assessing the presence of tolerant and intolerant species of insects in underwater communities, scientists can evaluate the water quality (Patel, 2010, June 22). Tolerant insects can survive harsh conditions, but intolerant species cannot. Therefore, the presence of one type over the other can serve as an indicator of the water quality. Another method used to test water quality is the analysis of chemical parameters such as pH, alkalinity, and iron and sulfate concentrations, which serve as indicators of water quality on a molecular level (Patel, 2010, June 22). When the chemical parameters change dramatically, it can indicate a problem such as pollution.

Pollution is a major factor in the reduction of clean, drinkable water from freshwater sources. A vast majority of pollution is anthropogenic, or caused by humans. The urbanization of areas near water sources causes chemicals, salt, and organic matter to run off nonabsorbent surfaces, such as asphalt, into the water. Pesticides and fertilizers used in agriculture as well as nitrates (NO_3^-) from animal defecation also run off into nearby water sources. Acidic water from inactive mines also washes into streams and rivers, causing a series of chemical reactions that

make the streams more acidic and give them a higher concentration of metals and sulfates (Patel, 2010, June 22).

Two major types of mining are surface and underground mining. Surface mining is the mining of coal and other minerals that are close to the surface of the earth (giving easier access to such minerals). Underground mining is used to access minerals deep down in the earth through tunnels made specifically to enter certain areas deep inside a mine (World Coal Institute, 2010). Mines that are currently being used are considered active, while closed mines are considered inactive. A major problem with inactive mines is that they are the leading cause of Acid Mine Drainage (AMD). When rain water (H₂O) enters the mine, it reacts with pyrite (FeS₂), and oxygen (O₂), causing the water to become acidic (Fig. 1).

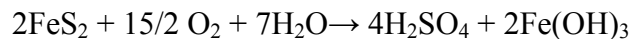


Fig.1- Overall reaction of Acid Mine Drainage (AMD)

In active mines, water is removed by pumps and deposited in a safe location where it will not form AMD that will run off into nearby bodies of water (World Coal Institute, 2010). In inactive mines, this precaution is not taken, so the water that fills up the mines and produces AMD is subsequently able to flow into nearby bodies of water. Ninety percent of AMD comes from inactive mines (Patel, 2010, June 22).

AMD is the drainage of acidic water from mines. Before mining, acid producing pyrite (FeS₂) is not exposed to water because it is located in the coal bed. When that land is mined, rainwater can fill the mine and interact with the pyrite. This water reacts with the pyrite to produce hydronium ions (H⁺), sulfate (SO₄²⁻), and ferrous ions (Fe²⁺), which is iron in its free form (Fig. 2). The ferrous ions and hydronium ions from the previous reaction react to produce

ferric ions (Fig. 3). In a subsequent reaction pyrite reacts with the ferric ions of the reaction, indicated in Figure 2, to produce more ferrous ions and sulfate (Fig. 4).

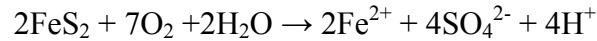


Fig. 2. – Reaction of pyrite (FeS_2) within the mine.

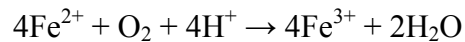


Fig. 3. – Reaction of ferrous ions (Fe^{2+}), oxygen, and hydronium (H^+) to produce ferric ions (Fe^{3+}).

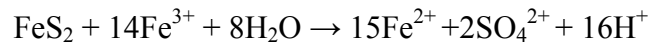


Fig. 4. – Reaction of ferrous ions and pyrite in the mine.

The water containing the hydronium ions, sulfate, ferrous and ferric ions, leaves the mine and drains into the stream as AMD, thereby decreasing the pH and increasing the levels of iron and sulfate in the stream. When the AMD reacts with the stream water of a higher pH (more basic), ferric hydroxide ($\text{Fe}(\text{OH})_3$), commonly known as yellowboy, precipitates out of the water (Fig. 5a). This is because at a pH of 3.0 or higher, ferric ions react with the water to produce hydronium ions and the precipitate ferric hydroxide. If the pH decreases below 3.0, then ferric hydroxide is dissolved and shown as iron in its free form (Fe^{3+}) (Fig. 5b). The ferrous ions produced in the mine that enter the stream continue to react with oxygen and the hydronium ions to produce water and more ferric ions (Fig. 3).

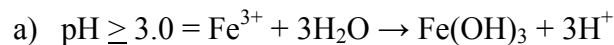


Fig. 5. – The precipitation of ferric hydroxide ($\text{Fe}(\text{OH})_3$) and the production of ferric ions (Fe^{3+}) depending on pH.

AMD adds sulfate, hydronium, and iron to the stream. Sulfate can be used as an indicator for AMD because it is a product of the reactions that take place in the mine (Fig. 1). The

production of hydronium ions decreases the pH, causing the stream to become acidic. This is because $\text{pH} = -\log [\text{H}^+]$, which means that pH and H^+ concentration are indirectly proportional. With the increased acidity, ferric hydroxide is able to dissolve in the water, increasing the level of iron (Fig. 5). The dissolved iron can be absorbed by the organisms in the water or by the animals that drink the water; iron in high amounts can cause them to become ill and die (Burns, 1995, April 25; Fripp, Ziemkiewicz, & Charkavorki, 2000, May).

Another impact of AMD is the depletion of the carbonate buffer (CO_3^{2-}). A healthy stream has a natural buffering system, which is used to keep the pH of the stream within a normal range. The measurement of the buffering system of a stream is called alkalinity and is gauged by the concentration of carbonate and bicarbonate (HCO_3^-) in the water. The negative charge on carbonate attracts the positive charge on the hydronium ions to produce bicarbonate and reduce the hydronium concentration. In the subsequent reaction, the negative charge on the bicarbonate attracts another hydronium ion to create carbonic acid (H_2CO_3) (Fig. 6). Reducing the hydronium concentration allows the pH to stay the same as it was before the introduction of acid because the hydronium is neutralized as soon as it enters the buffered area. If the carbonate and bicarbonate ions become saturated with the hydronium ions, the alkalinity depletes. When the buffer is depleted and rendered ineffective, even the slightest addition of acid can make pH decrease significantly.

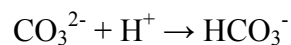


Fig. 6. – This shows the chemical equation of a carbonate/bicarbonate buffer.

AMD also affects the stream physically and ecologically. The precipitate ferric hydroxide adsorbs, or sticks to, the substrate, which is the bottom of the stream. When organisms attempt to

obtain nutrients from the substrate, they ingest iron instead. Also, the presence of ferric hydroxide in the water can reduce light penetration because the water is turbid, or murky. This decreasing light penetration is detrimental to plants because in order for plants to live and release oxygen for other organisms need sunlight for photosynthesis. While tolerant species may be able to survive the harsh conditions created by AMD such as lack of oxygen, extremely acidic pH, and high metal concentrations, sensitive species cannot survive and therefore will be eliminated.

Multiple treatments have been suggested to solve the problem of AMD, including non-limestone treatments and limestone treatments. Grout injections and wetlands are treatments that do not utilize limestone. A grout injection is the sealing of a mine with fly ash, which is a residue of coal combustion, and wet sealant. The mine is sealed so that water is not able to enter or exit through the mine portals. Pipes are also installed in the mine to direct runoff, carrying AMD, to a reservoir for treatment before it enters a stream (Fripp, Ziemkiewicz, & Charkavorki, 2000). Another type of non-limestone treatment utilizes wetlands. Wetlands use bacteria to initiate a chemical reaction that reduces sulfate into sulfide, forming a thio-metal complex that precipitates out of the water because it is insoluble (Fig. 7). Utilizing wetlands can prove to be beneficial in eliminating the effects of AMD because they can facilitate the precipitation of the metals dissolved in the water due to low pH.

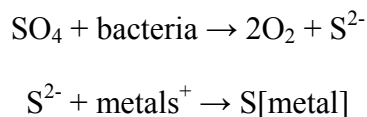


Fig. 7. –The reaction that takes place within wetlands to remove sulfate and metals from streams affected by AMD.

The AMD treatments that involve limestone are limestone dumping and limestone leach beds. Limestone dumping involves introducing massive amounts of limestone into a stream damaged by AMD in order to increase the buffer. This can cause a problem because the rapid

change in pH can shock the organisms living in the stream. Limestone leach beds consist of a human-made pond that is filled with limestone and water. The water comes from a water pipe or another clean water source. The limestone dissolves in the water to make it alkaline. Once the water is alkaline, a channel moves it from the leach bed to the stream, so the limestone treated water gradually enters the stream (Fripp, Ziemkiewicz, & Charkavorki, 2000, May). This method differs from limestone dumping in that it is gradual rather than immediate and therefore not as harmful. This gives organisms that live in the stream time to adjust to the changing pH.

The limestone, or calcium carbonate (CaCO_3), that is used to increase the pH of a stream affected by AMD adds to the natural buffer of a stream by adding calcium carbonate to the stream. This buffer helps increase pH because the negative charge on carbonate (CO_3^{2-}) and its conjugate acid, bicarbonate (HCO_3^-), attracts the hydronium ions to produce carbonic acid (H_2CO_3). This decreases the amount of free hydronium ions and thus increases the pH (Fig. 8) (Burns, 1996, April 25; Fripp, Ziemkiewicz, & Charkavorki, 2000, May).

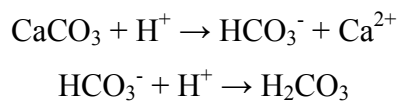


Fig. 8. – This is the equation for the CaCO_3 takes H^+ out of the stream

In extreme cases where the pH of the stream is found to be drastically low because of AMD, steel slag is used instead of limestone. Steel slag is also known as quicklime or calcium oxide (CaO). In the steel slag bed, the calcium oxide disassociates to produce calcium (Ca^{2+}) and oxygen (O^{2-}) ions. The oxygen ions react with the water in the slag bed to produce hydroxide (OH^-), which is a strong base. (Fig.9).

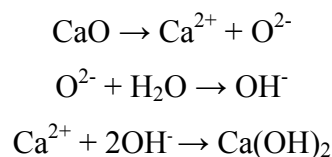


Fig. 9 – Mechanism of Steel Slag

Meanwhile, the calcium ions combine with some of the hydroxide (OH^-) to create calcium hydroxide $\text{Ca}(\text{OH})_2$, which is precipitated in the slag bed and then carried out into the stream. The slag is a mixture of the calcium hydroxide that forms and the remaining hydroxide ions.

Limestone leach beds contribute carbonate (CO_3^{2-}) to the affected water, thereby indirectly increasing the pH by increasing the alkalinity. Steel slag beds on the other hand, contribute hydroxide, a strong base, to the stream. The hydroxide (OH^-) is essential in performing three tasks. Primarily, the OH^- neutralizes the H^+ produced by AMD in the stream to produce neutral water. The increase in pH increases the alkalinity by reversing the reaction that creates H_2CO_3 , resulting in the formation of the conjugate base carbonate (Fig. 10). In an environment with a low pH, carbonate (CO_3^{2-}) exists in the form of carbonic acid (H_2CO_3) (Fig. 8). As the pH increases, H_2CO_3 separates into HCO_3^- and H^+ . As the pH continues to increase, the bicarbonate separates into hydronium ion and carbonate. These positive hydronium ions are captured by the free hydroxide ions in the stream and converted to water, leaving the carbonate to restore the alkalinity. After the two previous processes have come to completion, there are still hydroxide ions in the stream that makes the stream water alkaline, causing the metals to precipitate out of solution. This technique is being used to restore certain waters in the Chesapeake Bay Watershed.

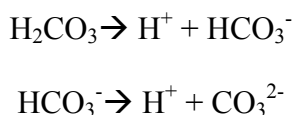


Fig. 10. – The chemical formula for the addition of the carbonate buffer

The Chesapeake Bay Watershed is one of the largest in the Mid-Atlantic Region and it is contaminated by AMD. One of the tributaries that contributes to the Chesapeake Bay is Georges Creek. According to the 1998 Clean Water Act, Georges Creek is classified as Priority I because it did not meet clean water requirements. The 2002 Maryland Water Quality Report recorded that

Georges Creek had poor underwater communities and low pH that can be attributed to AMD. Currently, several sites on Georges Creek are designated as AMD affected sites, and one of these sites is Matthew Run.

Matthew Run is located in Western Maryland, where there are many coal mines, both active and inactive. In the area around Matthew Run, there is an inactive coal mine that was poorly reclaimed in the late 1970s. There is still an exposed coal seam that leads the AMD produced in the mine to Matthew Run. This can be seen in Figure 11. The stream is negatively impacted by AMD. In an effort to restore the water quality back to its original condition, a steel slag bed was constructed on the north side of Matthew Run, which can be seen in Figure 11. This steel slag bed was constructed at that location to take the clean water from Neff Run and combines it with CaO to form Ca(OH)_2 and OH^- , which is then emptied into Matthew Run. The slag bed is designed to raise the pH, help restore alkalinity, precipitate heavy metals, and to return the stream's water quality back to that of Site 1 before it confluences with Neff Run.

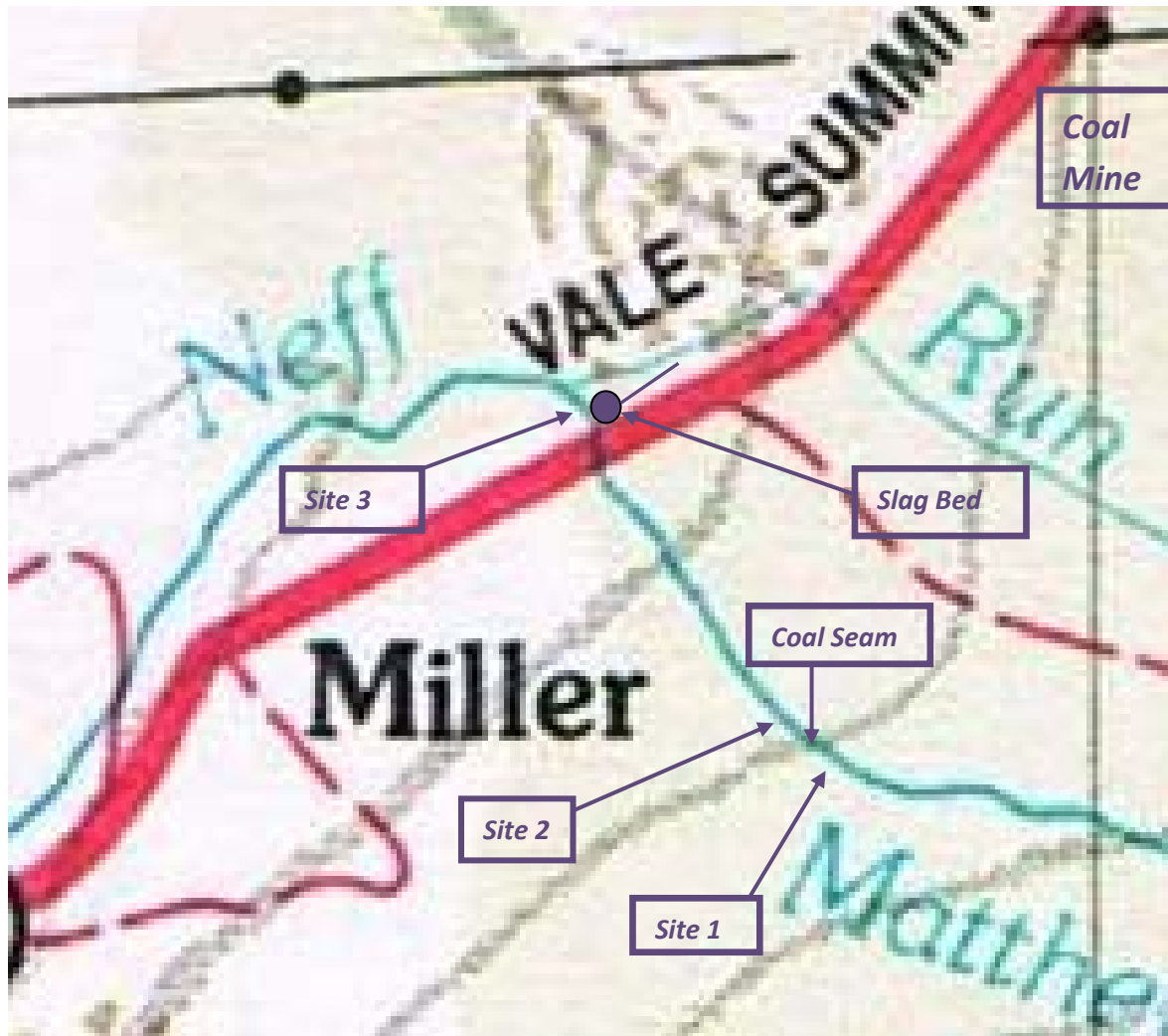


Fig.11.-Map of Testing Sites on Matthew Run

Matthew Run is an ideal site for our experiment due to the fact that it is a water source that has a control area not affected by AMD or the steel slag bed restoration, an acidic portion affected by AMD, and a portion that has been treated by a steel slag bed. The waters above the coal seam in Matthew Run are neither affected by AMD nor the steel slag bed. This situation makes Site 1 an optimal site as our control. Site 2 is located below the coal seam, where the AMD enters the stream. Site 3 is located downstream of the steel slag bed; this can be seen in Fig. 11. With Sites 1, 2, and 3 all coming from the same water source, it is possible to compare

the difference types of water without having extra disturbances in our data coming from different environments.

The purpose of this experiment is to evaluate the effectiveness of the steel slag bed on Matthew Run in returning the acidic water to its original condition. Four chemical parameters, which are pH, alkalinity, sulfates, and iron, will be tested and compared among the testing sites in order to determine the effectiveness of the steel slag bed. Two separate null hypotheses have been developed for this experiment: No significant differences will exist between the chemical parameters of pH, alkalinity, and iron for Site 1, the control site, and Site 2, the contaminated waters; no significant differences will exist between the chemical parameters of pH, alkalinity, and iron for Site 1, the control site, and Site 3, the treated waters. If the first null hypothesis is accepted, then the AMD does not effectively contribute to the deterioration of water quality for those parameters, and if it is rejected, then AMD is changing the water quality. If the first hypothesis is rejected and second hypothesis is accepted, then the steel slag bed is returning the contaminated water to its original condition. The sulfate concentration was not included in the hypothesis because the steel slag bed is not designed to precipitate the sulfate out of the stream.

METHODS

The experiment was conducted on July 5, 2010, in Midland, Maryland. We had three sites along Matthew Run. Our first site was located approximately 30m upstream from the coal seam, where the AMD enters the stream. Site 1 had a dense canopy cover, which means there were many plants and trees that blocked sunlight from entering the site. The stream had a moderate flow. In the streambed was a variety of sediment and different size of rocks. There

was also a steep bank in the stream. The water at Site 1 was not turbid, which means there was no indication of precipitate in the water.

Site 2 was 30m downstream from the coal seam and influx of AMD. Site 2 had a moderate level canopy cover, which means that there were parts of the site that allowed sunlight to penetrate. There was a house within eyesight. The stream also had steep banks from land erosion. Yellowboy was evident in the streambed. The sediment was comprised of tiny pebbles. The stream flow was moderate.

Site 3 was approximately 160m downstream of the AMD disturbance and 60m downstream of the slag bed. Yellowboy was visible and was adsorbed to the sediment, but there was not nearly as much as there was in Site 2. There were also larger rocks which are used as plunge pools. There was a steep slope on the bank. There was high level of canopy cover. The stream flow for site three was fast, much faster than that of Site 1 and Site 2

We had three sub-sites per site. At each sub-site, we tested the chemical parameters three times each. Each sub-site was located 10m apart. We took our tests at least 30m downstream from the disturbance of AMD and the steel slag bed. The placement of our sites was important because a chemical reaction had to take place so we could see the affects of AMD and the steel slag bed on the stream.

The pH was measured with a Hanna Instruments pH/EC/TDS Waterproof Family Probe (Model number HI73127). Alkalinity was measured using a LaMotte Alkalinity Test Kit (Model Code PHT-CM-DK-LT). Iron and sulfate were measured using an ICPE-9000 Inductively Coupled Plasma instrument. This instrument was located in a chemistry laboratory at Frostburg State University. We did not perform this test but rather gave the samples to a laboratory technician for testing.

We compared our data by using a t-test with a 95% confidence level. A t-test indicated if the two sets of data are significantly different. If the $p > .05$ there is more than a 5% probability that any difference in means of data is due to chance, which means that we must accept the null hypothesis. We will also construct column graphs to compare the range of the different parameter for their respective sites. In the confident intervals represents the average or mean of the data. In other words, we want to be 95% confident that the true mean lies within the range of our error. The error is calculated by dividing the standard deviation by the square root of population size (9) and multiplying that value by the critical t-value (which is 2.31 for 8 degrees of freedom). The pH is a logarithmic value and in order to determine the average pH, all of the pH data were first converted to hydronium ion concentrations. Then, hydronium concentrations was averaged, and then converted back to pH. The average hydronium ion concentration was used in the t-test.

RESULTS

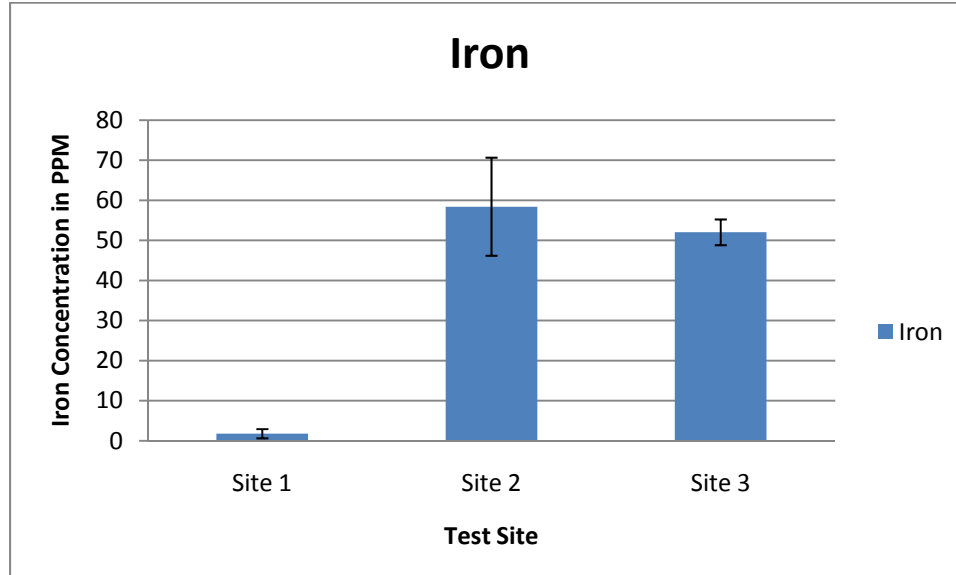


Fig. 12. – Iron concentration in parts-per-million among the three test sites with confidence intervals.

As shown in Figure 12, the iron concentration of Site 1 is much lower than the iron concentrations of Sites 2 and 3, with a t-test showing that Sites 1 and 2 were significantly different ($p=6.52E-06$; $n=9$), and Sites 1 and 3 were also significantly different ($p=8.65E-10$; $n=9$). The iron concentration of Sites 2 and 3 were not significantly different ($p=2.74E-01$; $n=9$). The average concentration of iron was 1.76 ppm at Site 1. The average concentration of iron increased to 58.40 ppm at Site 2, and the average concentration of iron at Site 3 was 50.02 ppm. The confidence intervals for Site 1 did not overlap with either the confidence intervals for Site 2 or Site 3, while the confidence intervals for Sites 2 and 3 did overlap, meaning there was less chance for a significant difference between those two values.

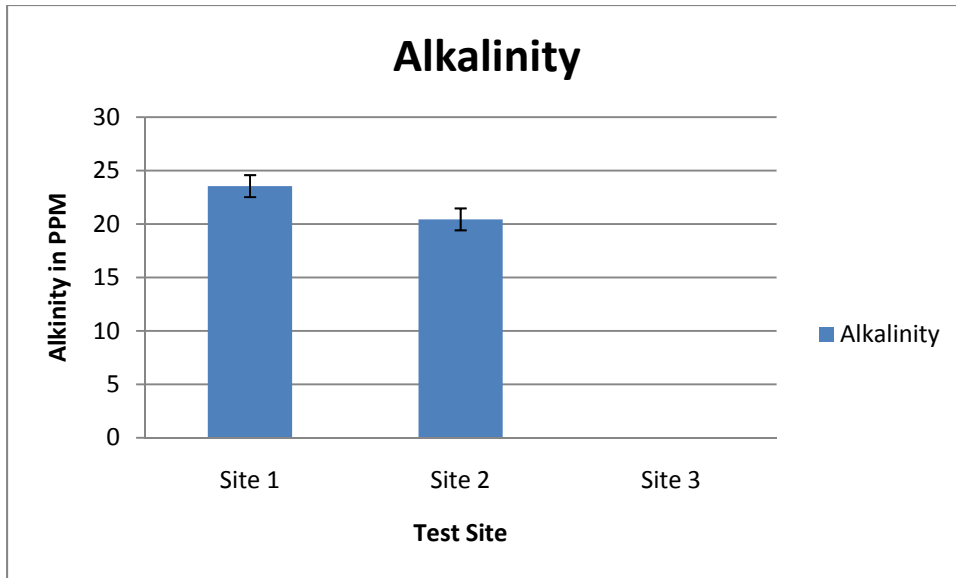


Fig. 13. – Alkalinity in parts-per-million among the three test sites with confidence intervals.

As can be shown in Figure 13, the alkalinity of the stream decreased as we went further downstream. A t-test showed a significant difference between the alkalinity of Site 1 and Site 2 ($p=7.36E-4$; $n=9$). Another t-test showed a significant difference between the alkalinity of Site 1 and Site 3 ($p=1.78E-11$; $n=9$). The t-test run between Sites 2 and 3 showed a significant difference ($p=5.51E-11$; $n=9$). The average alkalinity at Site 1 was 23.56 ppm. The alkalinity at Site 2 decreased to 20.44 ppm. The alkalinity at Site 3 decreased to 0.00 ppm. None of the three confidence intervals overlapped with one another, meaning there was a higher chance for significant differences among all three sites.

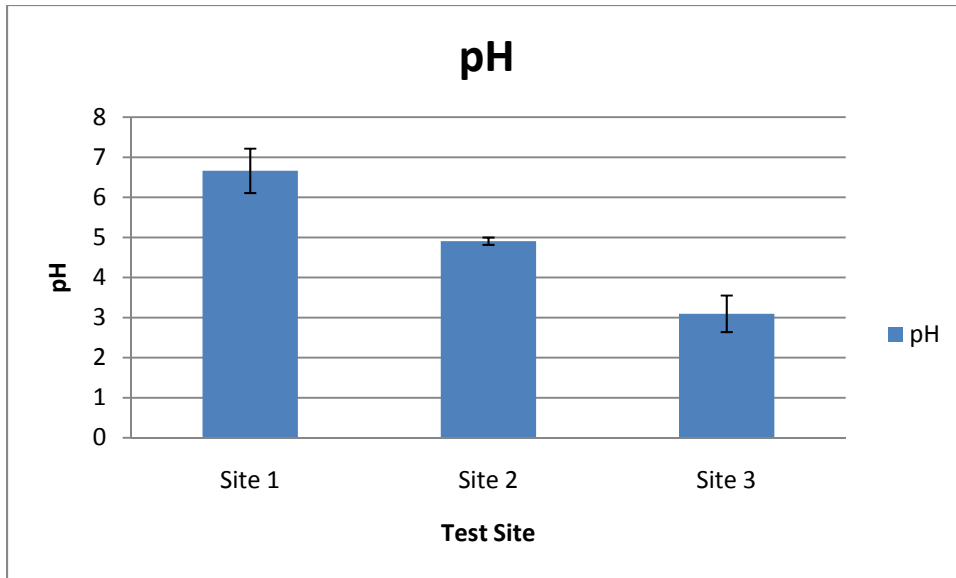


Fig. 14. – pH among the three test sites with confidence intervals.

As can be seen in Figure 14, the pH continued to decrease as we tested further downstream. A t-test showed a significant difference in pH between Site 1 and Site 2 ($p=2.2E-02$; $n=9$). Another t-test showed a significant difference in pH between Site 1 and Site 3 ($p=1.67E-4$; $n=9$). A significant difference was found between Sites 2 and 3 with a t-test ($p=1.84E-04$; $n=9$). In Figure 14, the pH of Site 1 was 6.66, the pH of Site 2 decreased to 4.91, and the pH of Site 3 was 3.10. None of the confidence intervals for the three sites overlapped, indicating a higher chance for significant differences.

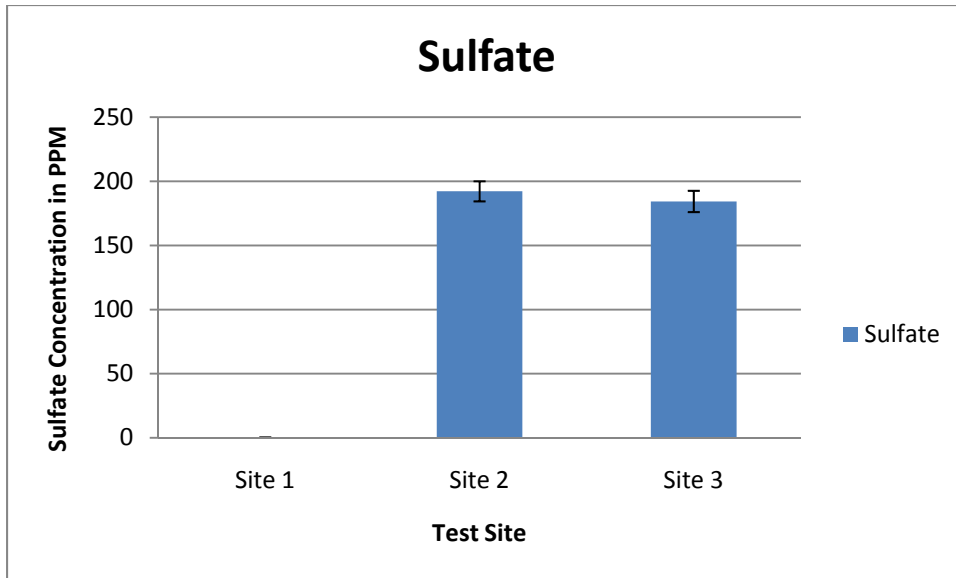


Fig. 15. – Sulfate concentration in parts-per-million among the three test sites with confidence intervals.

As shown in Figure 15, the sulfate concentration significantly increased between Sites 1 and 2 and between Sites 1 and 3, but stayed the same between Site 2 and Site 3. A t-test showed that there was a significant difference in sulfate concentration between Site 1 and Site 2 ($p=1.02E-11$; $n=9$), and another t-test showed that there was a significant difference between sulfate concentration of Site 1 and Site 3 ($2.3E-11$; $n=11$). There was no significant difference between the sulfate concentrations of Sites 2 and 3 ($p=1.3E-1$; $n=9$). The concentration of sulfate was 0.16 ppm at Site 1, and the sulfate concentration increased to 192.22 ppm at Site 2. The sulfate concentration was 184.33 ppm at Site 3. The confidence intervals for Sites 2 and 3 overlapped while the confidence intervals for Site 1 did not overlap with either of the other confidence intervals, indicating a higher chance for a significant difference in the comparison of sulfate concentration of Site 1 with Sites 2 and 3.

CONCLUSIONS AND DISCUSSION

The first hypothesis was that there will be no significant difference between the chemical parameters—iron, pH, and alkalinity—of Site 1 and Site 2. This hypothesis was to determine whether AMD is impacting the water quality of Matthew Run since Site 1 is upstream of where AMD enters the stream and Site 2 is downstream of the AMD impact. After performing the t-tests and finding a significant difference between all parameters of Site 1 and Site 2 (*Table 1*), we reject our hypothesis. We can say with 95% confidence that because there is a significant difference between Site 1 and Site 2, AMD is affecting Matthew Run.

The second hypothesis was that there will be no significant difference between the chemical parameters— iron, pH, and alkalinity—of Site 1 and Site 3. This was to determine whether the steel slag bed is returning Site 3 to the conditions of Site 1 because Site 3 is after treatment for AMD and Site 1 is not receiving treatment and is not being affected by AMD. The t-test showed a significant difference between all parameters of Site 1 and Site 3 (*Table 1*). We reject our hypothesis based on the results of the t-test and conclude that the steel slag bed is currently not returning to Matthew Run to Site 1 water quality conditions.

Table 1 – Table shows the p-values for each hypothesis and whether the hypothesis was accepted or rejected.

Hypothesis	Parameter	p-value	Accept/Reject
1	pH	2.19E-2	reject
2	pH	1.66E-4	reject
1	Alkalinity	7.35E-4	reject
2	Alkalinity	1.78E-11	reject
1	[Fe]	6.51E-6	reject
2	[Fe]	8.65E-10	reject

From Site 1 to Site 2, both iron and sulfate concentrations increased (Fig. 12 and 15) because they are products of AMD and were introduced above Site 2. Hydronium is also a product of AMD and was introduced above Site 2. The increase of hydronium caused the pH of the stream to decrease between Site 1 and Site 2 (Fig. 14). The alkalinity decreased between Site 1 and Site 2 (Fig. 13) because as the hydronium was introduced, the conjugate base of the buffer, carbonate (CO_3^{2-}), was reduced (Fig. 5), causing the buffer to be depleted.

From Site 2 to Site 3, the pH and alkalinity decreased while the iron and sulfate concentration stayed the same. The pH decreased between Site 2 and 3 the reaction shown in Figure 5 is producing more hydronium ions. The alkalinity decreased because the hydronium ions saturated the buffer as shown in the reaction in Figure 6. The iron concentration stayed the same because the iron that was formed was eventually precipitated out of the stream. The sulfate concentration stayed the same because the sulfate was not being produced in the chemical reactions in the stream as shown in Figures 2-4. The p-values that illustrate whether the parameters changed significantly between Site 2 and Site 3 can be found in Table 2.

Table 2. This table shows the T-test results for sites 2 and 3

T-tests between sites 2 and 3		
parameter	p-value	Difference
pH	1.84E-04	Significant
Alkalinity	5.51E-11	Significant
[Iron]	2.74E-01	Not significant
[Sulfate]	1.30E-01	Not significant

We concluded that the steel slag bed did not return the water of Site 3 back to its original condition, Site 1. This is important because the steel slag bed did not fulfill its purpose and AMD

is influencing the water quality downstream of the steel slag bed. After the experiment, we discovered that the steel slag bed was blocked with sediment from Neff Run and was not fixed due to lack of funding. It is reasonable to conclude that the steel slag bed was not treating Site 3 on Matthew Run as shown by the comparisons of Site 1 to Site 3 and of Site 2 to Site 3.

Our study had many limitations. These limitations include how many trials we did, the size of our sites, the preciseness of our pH probe and alkalinity kit, human error while using kits and time restraints. The size of our sites was small, which prevented us from having well spaced out testing sites. The pH probe only gave us a reading that was rounded to the nearest tenth, which made the result less precise. This was also a problem with the alkalinity test because we had to touch the tablet to place it in the water sample and the oil and chemicals that could have been on our fingers might have changed the results of the test. We also only collected data on one day and by doing that our data were more precise, but it did not show how natural elements could change our results only how they did on a hot, sunny day, which is not the usual weather of Frostburg, MD

Suggestions for further studies include using more precise equipment, researching the restoration efforts at the designated testing area before conducting the experiment, testing a greater area by utilizing more sub-sites, and testing on multiple days. If the group would have had more practice previous to the experiment, more accurate measurements could have been made while collecting samples in the sites. With more experience, the group would have used the equipment properly, which would minimize error. By using more precise equipment, the results of the data collected would be more precise and allow for the replication of the experiment. If we had researched the status of the restoration before the testing began, we would have known the steel slag bed's pipe was blocked with sediment from Neff Run and was not

working. By testing more sub-sites, the samples could give a better representation of the stream. This would yield more data and give us more accurate results. Testing on multiple days or months would give us an idea of how the weather contributes to the stream's water quality, so the AMD would be isolated as the cause of the pollution in the stream. Another suggestion would be to research the rate at which the AMD reactions occur in the stream water and in the mine. This would help the group take samples of the water to test for the products of AMD after the reactions finish.

Questions for further research were raised while conducting this experiment. The first question was why no animal life was present anywhere near the stream? Site 1 had only a few crayfish, and it appeared that Site 2 and 3 did not have crayfish. The lack of animal life was unexpected because there should have been some animal life at Site 1 (control site). It may be possible that the control site is affected by something else farther upstream that is killing off the animals in the stream. Another question is what happens to the vegetation on the stream banks of the AMD affected sites? The AMD that affected the stream might have affected the vegetation on the banks. This question leads to another question: how do the restoration efforts affect the environment? The use of a steel slag treatment may cause the release of the gases or chemicals like carbon dioxide (CO_2) into the air surrounding the treatment area. Another question raised was how long the remediation efforts would take place to reach a particular level of water quality. When streams have been restored by the treatments, would the treatments have to be continued for an amount of time or can the treatment be discontinued. The last question that came up was if cheaper, more efficient, eco-friendly remediation efforts exist? This could be a solution to spending less money on remediation projects, labor, and maintenance of some methods without having a negative effect on the environment.

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