Market Exploration for AMD Sludge

Environmental Science Project Management Academy Cluster
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Forward to
Market Exploration for AMD Sludge
By Westminster College Environmental Project Management Academy (EPMA)
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The Market Exploration for AMD Sludge feasibility study was completed as part of a project-based learning experience at Westminster College during the Spring 2019 semester. The project was completed as part of a "cluster course," a requirement of the Liberal Studies curriculum at Westminster, in which two linked courses are taught by at least two faculty members from different disciplines to the same group of students. This cluster course was an interdisciplinary integration of ES 170 Project-Based Environmental Science, taught by Helen Boylan, Professor of Chemistry and Environmental Science; BA 250 Principles and Practices of Project Management, taught by Brian Petrus, Assistant Professor of Business; and an embedded Leadership Seminar, taught by Alison DuBois, Associate Professor of Counseling.

Through the EPMA program, students collaborated with community stakeholders as they integrated knowledge of environmental science, project management, and soft skills with project work on environmental issues relevant to the region. With this cohort, Year 2 of a National Science Foundation funded program, 21 Westminster College business and STEM majors worked with Slippery Rock Watershed Coalition stakeholders to study the market feasibility of extracting minerals from AMD sludge for commercial use. The culmination of their work is contained within this document.

The magnitude of this project should be underscored by the fact that this cohort of 21 undergraduate students had little project-management experience and AMD knowledge prior to this semester. As a result, a project of this undertaking was not possible without the support of many dedicated professionals. We acknowledge Cliff Denholm, environmental scientist with Biomost, who served as our main collaborator on this project. We acknowledge the many guest speakers who visited our classroom and provided expertise on the topic: Dr. Peter Smith, Professor of Chemistry at Westminster College; Mr. Ben Nelson, Vice President and Senior Credit Officer at Moody's; Dr. Paul Ziemkiewicz, Director of the West Virginia Water Research Institute; and Dr. Robert Hedin, President of Hedin Environmental. We are grateful to the Western Pennsylvania Coalition of Abandoned Mine Reclamation (WPCAMR) organization for their willingness to locate their spring quarterly meeting at Westminster College and to serve as a receptive audience for the EPMA student presentation. Ms. Ann Puskaric, Mr. Randy Cain, Mr. Michael Gross, and Dr. Jeremy Lynch have been valuable advisory board members, and Dr. Sandra Webster has provided critical expertise for the assessment and evaluation of this program. We are appreciative of the administration and our colleagues at Westminster who have been tremendously supportive of our work. This project and associated educational initiatives are supported by the National Science Foundation under Grant No. 1712028, Improving Undergraduate STEM Education (IUSE) Program.

The feasibility study contained herein represents the collective work of the EPMA students, with editorial guidance only, provided by course professors. The students, professors, and Westminster College (collectively, Consultant) do not make and hereby disclaim any representations or warranties, which may arise out of or in connection with this Project or the performance by any of the parties above. In no event shall Consultant be liable for indirect, special or consequential damages suffered by the Slippery Rock Watershed Coalition and its stakeholders in connection, directly or indirectly, with the action or inaction of Consultant, under or in relation to this Project. All recommendations contained herein should be verified by a qualified professional.

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Executive Summary

To remediate the detrimental effects of abandoned mine drainage (AMD) in western Pennsylvania, the Slippery Rock Watershed Coalition (SRWC) utilizes passive treatment systems to treat over 1.5 billion gallons of water annually. Passive treatment systems rely on natural processes to improve the quality of affected water and precipitate a sludge by-product. The sludge by-product consists of high concentrations of precipitated iron and manganese metals. By utilizing interdisciplinary research and collaboration, students in the EPMA cluster course have analyzed the environmental effects, marketability, and economic value of the sludge. A complete feasibility study has been done to assess the costs associated with removal and marketing minerals present in the sludge.

Comprehensive results of this feasibility study are being presented as a recommendation to the SRWC, as well as similar stakeholders, for further consideration. The goal is to shed light on the possibility of economic gain from the sale of the sludge by-product associated with passive treatment systems and to evaluate the environmental dangers associated with AMD. After a lab analysis of the AMD sludge, results indicated a significant amount of iron oxide was present and used to determine the feasibility of entering various markets. After conducting a market and cost analysis, it was determined that the expenses of extracting the sludge currently outweigh the potential revenue that could be produced from selling the sludge. It is believed, however, that through additional cost mitigation and synergistic partnership strategies, niche market exposure may be economically viable in the future.

Introduction

Overview on Environmental Project Management Academy (EPMA) Cluster

Environmental Project Management Academy (EPMA) is an interdisciplinary course combining two core courses, ES 170 Project-based Environmental Science and BA 250 Principles and Practices of Project Management, with an embedded Leadership Seminar component. EPMA is a National Science Foundation funded project that creates an interdisciplinary environment for science and business students alike. Project-based Environmental Science focuses on bringing attention to major environmental issues while teaching students scientific literacy. Principles and Practices of Project Management (BA 250) embodies the skills and expertise needed to adequately manage projects and their associated team members. BA 250 teaches the effective use of team member communication, project scope, expected cost projections, and how to properly function in a project team setting. Students have the opportunity to participate in meetings structured to mimic workplace management meetings. Students also learn to give and receive feedback in a professional manner. The leadership seminar allows EPMA students to experience many different methods of handling conflict and develops students' intangible skills vital to project team communication. Students have the opportunity to learn about various leadership styles while molding themselves to a style that best fits their character.

The EPMA course begins with nine weeks of content related to project management and environmental science and directly ties to completion of project work. Project work is divided into small, interdisciplinary teams where students hone their communication and leadership skills by rotating into four different positions on a weekly basis. These positions include a team lead, team recorder, communication liaison, and a feedback coordinator. EPMA students incorporate their knowledge of project management, environmental science, and leadership skills into project work as they relate to a particular environmental issue. EPMA students also have the opportunity to interact with multiple external advisors and industry-experienced professionals. A main focal point of this course is to create a professional and unique interdisciplinary environment. Students are encouraged to step out of their comfort zones while growing as a project team member and as a leader. EPMA creates a workplace environment for its students; they gain firsthand experience in the difficulties experienced with team projects and how those difficulties ultimately affect the project's scope and completion.

Community Partner

Slippery Rock Watershed Coalition has spent years working in the Slippery Rock Creek Study Area, a 27 square mile drainage basin. "The goal of the Slippery Rock Watershed Coalition is to not only restore the Slippery Rock Creek to a viable fishery but also to provide educational opportunities to students of all ages and the general public" (SRWC document (accepting the challenge), page 67). SRWC is a non-profit organization in constant need of continuous funding due to the high cost of constructing and maintaining the various passive treatment sites across western Pennsylvania. The goal of the class project was to explore markets in which SRWC could sustainably maintain a profit from the process of extracting sludge from the AMD passive treatment sites.

Purpose for Study

This study aims to explore sustainable and profitable uses for the AMD sludge that collects throughout the treatment process. The 2019 program objective was to investigate the recovery and marketability of minerals from passive treatment sites and make a recommendation to the SRWC based on various analyses. The project managers worked to ultimately answer the question "how can SRWC generate revenue from AMD treatment related byproducts, in order to continue operation and maintenance of passive treatment sites?"

Overview of Approach, Procedure & Methods

This project used various research elements from both business and scientific backgrounds, combining the benefits of both areas into this marketable and sustainable project. Extensive background research was done on AMD and the various passive treatment systems applied to affected streams. To gain more insight on the process of passive treatment systems, the class visited the Jennings Environmental Education Center in Butler County, PA, for an integrated tour and hands-on testing of the water at the treatment site. The class broke into separate teams to research various locations within the Slippery Rock Creek Watershed to collect water and sludge samples for laboratory tests and to analyze alkalinity, pH, iron content, and oxidation reduction potential (ORP) in the field. The sites tested included: BC16, De Sale I, De Sale II and McIntire. The samples were analyzed using digestion and Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES). Research on potential markets was performed to analyze the opportunities, risks, and various financial factors and implications.

Overview of AMD

Abandoned mine drainage is a devastating form of water pollution. It is currently a main pollutant of surface water. AMD impacts over 4,600 miles of freshwater streams throughout the state of Pennsylvania (SRWC, p. 26). AMD is a byproduct of mining that was completed years ago, allowing water and oxygen to react with metals to form a highly-acidic form of water (SRWC, p. 25-26). It has characteristically low pH, low alkalinity, and high manganese and iron content.

This highly acidic water dissolves minerals such as iron and manganese. The acidic composition of AMD disrupts naturally flowing streams, resulting in a depletion of vegetation and aquatic life (SRWC, p. 26). AMD is also visualually unappealing and can have a foul smell. Iron gives the sludge left behind by the AMD a rusty orange color, as seen in Figure 1 below. Manganese leaves the AMD sludge with a black or dark gray color as seen in Figure 2 below. There are ways that environmentalist groups such as the SRWC are combating AMD. These methods are called passive and active treatment sites, which are two innovative ways of repairing affected streams.

Figure 1. Fe sludge from McIntire.

Figure 2. Mn sludge (Photo from of B. Slupe)

Overview of Active Treatment

Active treatment is a labor-intensive approach to AMD stream reclamation. While passive treatment uses natural products such as limestone to precipitate out metals, active treatment often requires large equipment, maintenance, and a constant flow of energy to allow the system to run properly. “Pumps are often used to convey the water to the plant and between various components of the system, power is usually needed to meter additives to the water such as neutralising chemicals, flocculants, and coagulants, and power is necessary for mixing and oxidation of the water” (Trumm, 2010, p. 195). The main purpose of both treatment types is to lower acidity and toxic metal concentrations, raise pH, and often lower sulphate concentrations and salinity. Active treatment is best used in currently active mine sites because it is more suitable with smaller areas of land and has the personnel to run the system (Taylor, Pape, & Murphy, 2005). An example of an active treatment site can be seen in Figure 3 below.

There are a variety of methods that are considered active, the most used one in AMD is DAOS. Dosing with Alkali (DA) is typically the first step followed by oxidation (O) and sedimentation (S). Although effective, active treatment systems generally incur high capital and operational costs. Although more costly than passive treatment systems in the long term, active treatment systems for AMD are often appropriate at active mine sites due to their small footprint compared to passive treatment systems which have the ability to address drainage chemistry and flow rates that can change as mining proceeds (Taylor, Pape, & Murphy, 2005). In 1980, Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), which gave the U.S. Environmental Protection Agency (EPA) power to regulate hazardous substances at contaminated waste sites, including abandoned mines, nationwide. CERCLA imposes a fine of $25,000 per day for failure to comply with any order

(Acid Mine Drainage). As a result, most active mine companies are proactive in engaging private companies or watershed organizations to maintain the health of the water.

Figure 3. A photo from a watershed organization installed an active treatment site to clean up a stream. (Grant, 2014).

Overview of Passive Treatment

A more natural, cost-effective alternative for treating AMD can be the utilization and implementation of a passive treatment system. Locally, due to its characteristics and success, the SRWC utilizes over 20 passive treatment sites, treating over 1.5 billion gallons of water each year (2019). A detailed map of the SRWC's passive treatment sites within Butler and Mercer county in Western Pennsylvania is shown below in Figure 4. EPMA students visited sites throughout the SRWC.

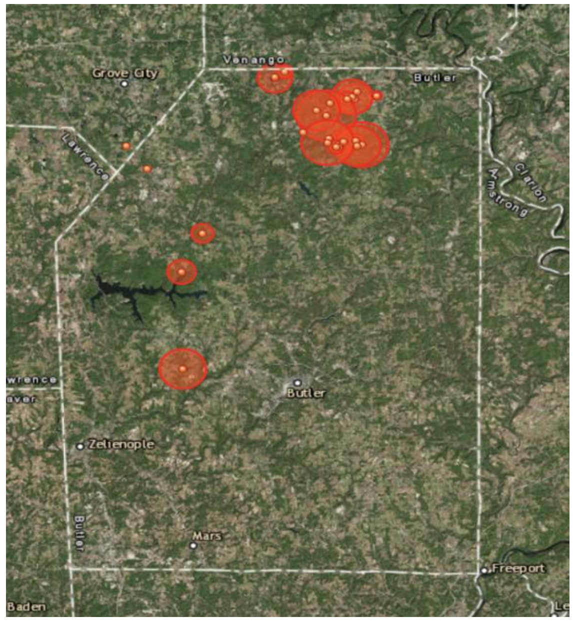

Figure 4. Map of passive treatment sites with the Slippery Rock Watershed Coalition (Datashed.org)

Although passive and active treatment both treat AMD, their approaches differ with passive treatment relying heavily upon natural processes to treat AMD. There are four main stages with the typical passive treatment process: anoxic limestone bed, vertical flow pond, constructed wetlands, and settling ponds. Anoxic Limestone beds contain buried cells of limestone aggregate, and works similarly to the open limestone channel. The major difference is that the term anoxic means that it occurs in the absence of oxygen which ensures that the metals will not oxidize, precipitate out and armor (prohibit it from working) the limestone (Slippery Rock Watershed Coalition, 2001). Vertical flow ponds combine the effectiveness of an anoxic limestone drain with the benefits of a constructed wetland. These are typically installed in areas that do not have the space required for an effective wetland, or if the AMD is highly acidic. The vertical flow utilizes gravity to force the water down through organic material that contains limestone (Slippery Rock Watershed Coalition, 2001). Slows the flow of water, allowing suspending solids to settle to the bottom. The large surface area of these wetlands ensures the all of the AMD will be exposed to oxygen. This allows for some of the metals present in the AMD to oxidize and precipitate out (Slippery Rock Watershed Coalition, 2001). Settling ponds are typically the last section of the passive treatment process. Settling ponds primarily serve as a collection point for all metals that are precipitated out of AMD (Slippery Rock Watershed Coalition, 2001). Shown below, Figure 5 represents a schematic of the order and implementation of passive treatment processes at the Jennings Passive Treatment Site.

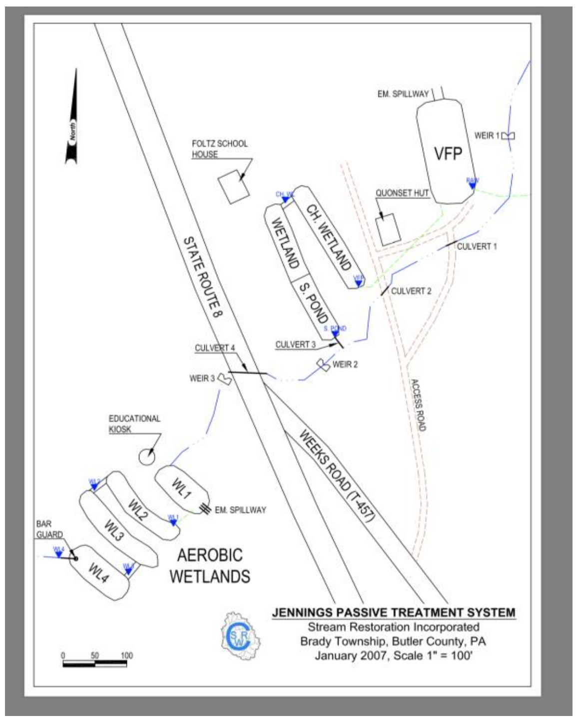

Figure 5. Schematic of Jennings Passive Treatment System (Datashed.org)

Due to the natural processes associated with passive treatment, costs are significantly lower than other alternatives. A passive treatment site can be a self-sustaining alternative due to its low maintenance and labor requirements, creating an advantage to nonprofits and organizations in which funding is scarce. However, expensive initial investments for passive treatment system construction can be a barrier in the absence of appropriate funding. These construction costs can be mitigated via state and federal grants or through private donations. In addition to low maintenance costs, electricity, toxic and costly chemicals, heavy equipment and buildings are not needed in order for a passive treatment site to function properly (Ford, 2003). Although passive treatment is an effective method of treating AMD, it does leave behind a by-product.

Previous Research

Two groups are currently researching the profitable uses of these metals– West Virginia University (WVU) Energy Institute, in their Rare Earth Extraction Facility, and Hedin Environmental. These two groups have looked into both passive and active treatment, as active is easier to extract rare earth metals. Both groups have helped the class to gain a better knowledge on the subject as well.

Paul Ziemkiewicz is one of the researchers at the WVU Rare Earth Extraction Facility. He visited with the class and shared his knowledge on AMD treatment and metal extraction. WVU has established a two-step process to extract the rare earth metals. The process is called Acid Leaching and Solvent Extraction (ASLX). After the process is completed, the rare earth metals are precipitated out as solids from the liquid sludge. The final product is able to be sold to technology companies to produce hardware and other parts for computers and phones. To put into perspective how long this process takes the facilities goal is to be able to produce three grams of rare earths per hour. Ziemkiewicz and his team have found that a kilogram of the metals will be worth $15,000 (WVU Today). Any byproduct of the extraction is returned to acid mine drainage treatment sites for disposal as well. This process has no negative or positive environmental impact (WVU Today).

Dr. Hedin also came to speak to the class about his work with abandoned mine drainage. He spoke on his company, Hedin Environmental, a consulting agency that specializes designing and maintenance of acid mine drainage sites and extracting sludge from passive treatment. Much of their focus is on treatment facilities, spanning across not only Pennsylvania, but throughout the world. Hedin Environmental extracts the iron oxide from the sludge by natural, passive treatment techniques. The iron oxide is then removed from the water and is set to dry for a period of time before it is then transported to a warehouse where it is dried further and awaits being sold to pigment companies. The iron oxide from AMD sludge is used to color products such as paint, wood stain finishes for hardwood flooring, and also a color of crayons (Hedin).

Some other research includes studies done by the Journal of Environmental Management, The University of Colorado at Boulder, The American Society of Mining and Reclamation, and several others across the world. The rare earth extraction is more tedious and costly for the passive treatment sites that the class is looking at and has visited. On the contrary, Hedin's research and process can prove to be applicable to the sites in the Slippery Rock Watershed Coalition. With more research and lab work completed, the EPMA class will be able to determine the best market for the metals within the sludge of the SWRC.

RESEARCH

Field Trips To Passive Treatment Sites

During the early months of the semester, between late February and early March, students visited numerous passive treatment sites within the Slippery Rock Watershed Coalition. The purpose of these trips was to collect samples for analysis, conduct field tests of the water, and observe the sludge by-product created by the passive treatment process. Each group collected water and sludge samples from their sites and compiled data regarding the field test analysis conducted at the site.

To become familiar with the different sites, research was done on each unique passive treatment site before the trip. Sample locations were determined during this time and based off of previous sampling locations recorded on www.datashed.org. LaMotte Field Test kits and Combo by Hanna pH/ORP probes were used at the site for analysis. Water samples were obtained from each location on the site (~250 mL) to analyze the presence of dissolved metals using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES). Sludge samples (~15 mL) were taken at locations where a significant amount of the product was visible to be analyzed by ICP-OES and laser induced breakdown spectroscopy (LIBS). The class was divided into five teams, with each team designated a passive treatment site, as indicated in Table 1 below.

Table 1. Team distribution and site designation.

Team	**Members**	**Site**
Team 1	Brice Bokesch Ben Gard Brianna Papp Blaine Sorrick	De Sale Phase II
Team 2	Braden Hogue Maria Wahal Emmitt Willis Emily Wilson	De Sale Phase I
Team 3	David Durbin Kaitlyn Fast Breanna Ferguson Yiannoula Katsadas Michael Stevens	McIntire (top half)
Team 4	Shae Cogley Brett Henderson Travis Lawrence Erin Ward	BC16
Team 5	Maura Belding Nick Burks Ian Miller Evan Vent	McIntire (bottom half)

Table 2. Basic water quality parameters of each site.

		pH (field)	*Alkalinity (mg/L, field)*	*Total Fe (mg/L, lab)*	*Total Mn (mg/L, lab)*
BC16	Influent	6.23	215	47.4	9.44
	Effluent	6.57	127.5	ND	4.25
De Sale I	Influent	4.20	ND	45.10	26.70
	Effluent	5.87	30	0.99	8.29
De Sale II	Influent	3.68	ND	2.94	13.27
	Effluent	5.24	2	1.55	11.65
McIntire	Influent	3.15	ND	98.03	32.33
	Effluent	7.15	131	ND	ND

Summary of Site Water Quality Parameters

The water quality tests shown above in Table 2 were conducted in order to determine if the components of the passive treatment system were working properly. Sampling points from the beginning, middle, and end of each site were tested to prove this to be true. The results of the data analysis conclude that the four sites are running efficiently. At every site, pH and alkalinity increased, and iron and manganese concentrations decreased significantly. BC16 was the only site that had a good pH level at the start of the passive treatment site. De Sale I and De Sale II did not have a high alkalinity level by the time the water had gone through the treatment system. McIntire proved to be working properly due to the increase in pH throughout the system, and the decrease in iron and manganese content at the final point. The comprehensive water sample results are located in Appendix A and B.

Summary of Sludge Results

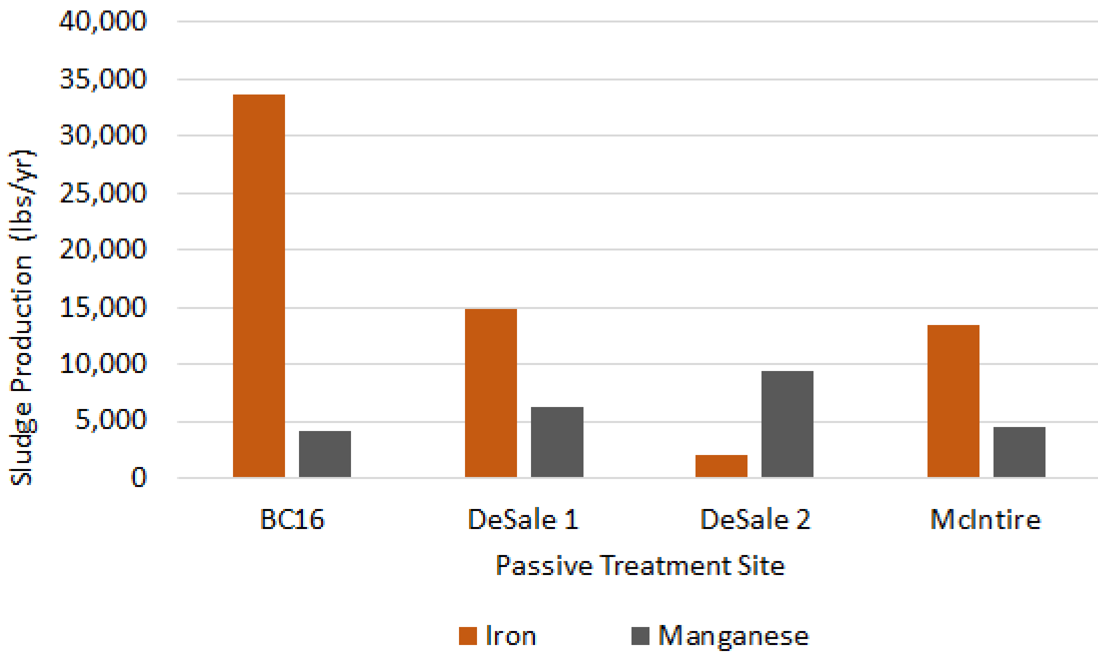

Figure 6. Projected annual metal sludge production at each site.

Table 3. Location of greatest sludge production at each site.

	Fe Recovery Location	**Mn Recovery Location**
BC16	Wetland	HFLB
De Sale 1	Wetland	VFPN
De Sale 2	Wetland	Forebay East
McIntire	902-OPC	902-WL

Based on the respective amount of gallons of water treated per year, retrieved from Datashed.org, the pounds of sludge produced per year was calculated for each site. From Figure 6 shown above, the greatest amount of iron can be found at the BC16 site, while De Sale II yields the highest concentration of manganese. After analyzing all water samples, the location with the greatest recovery of iron and manganese were determined and shown in Table 3 above. Also, detectable levels of some rare earth metals were found in De Sale II. Comprehensive laboratory results can be found in Appendix B.

MARKET ANALYSIS

Markets that use Iron Oxide

Iron and Steel Industry

Sludge from acid mine drainage (AMD) has high iron content along with a low cost and is used as raw material for the iron and steel industry. Iron ores are mostly iron oxides, but also contain magnetite, hematite, limonite, and others, and can be transformed into many different types of iron (Shatokha, 2016). Pig iron is a potentially marketable form of iron, but it has limited uses, only usable for producing steel and pure iron. Most of the iron is sent to a steel mill where it is converted into various types of steel. To produce steel, iron and other metals like chromium, nickel, manganese, molybdenum, and tungsten, are combined (Shatokha, 2016). Green iron and steel manufacturing using sustainable practices are becoming a popular trend and there are breakthrough technologies being introduced to these processes.

Cosmetic and Beauty Industry

Pigments from iron oxide and other metals are added to cosmetics. These pigments are inorganic and usually yellow, red, and black oxides of iron. Sepia melanin, black pigment, is used in cosmetics just like black iron oxide (Zheng, 2013). Typically, the pigments are used in foundations (liquid and solid) or powders, when pigment is necessary to match the skin color. These pigments are not found in skin or cleansing creams since they are meant to sink into the skin without changing the color an individual’s skin. There is a higher concentration of iron oxide in solid-type foundations than in liquid foundations (Zheng, 2013).

Paint Industry

The paint industry and iron oxides recovered from acid mine drainage (AMD) sludge go hand in hand. A specialty pigment called micaceous iron oxide (MIO) is used worldwide as a primer for heavy duty steel structures, like bridges, cars, and boat coatings (Cornell & Schwertmann, 2013, p. 513). There is even MIO on the Eiffel Tower in Paris. Metallic browns are used for these purposes, along with heat resistant enamels, specifically in the United States (Cornell & Schwertmann, 2013, p. 513). Iron oxide pigments can be used in both water- and organic-based paints (Cornell & Schwertmann, 2013, p. 511). Due to iron oxides strong ultraviolet absorbers, paints with iron oxide are less likely to degrade and corrode (Cornell & Schwertmann, 2013, p. 511). These are all reasons why iron oxide is extremely valuable for the paint industry.

Brick and Cement Industry

Iron oxides have been utilized in brick and cement manufacturing. It has been tested that bricks containing 15% sludge (with As and Fe) combined with clay, cured at a high temperature- about 1000 ºC, have a higher compressive strength than normal clay bricks (Rakotonimaro et al., 2017). Another benefit to utilizing the red pigment is the ability to withstand and resist up to 1200 ºC (Cornell & Schwertmann, 2013, p. 511). These natural iron oxides are also used to dye concrete and clay bricks, paving stones, roof tiles, and in mortar, usually with the red pigment. Swedish houses are known to use iron oxide based paints, especially red, for their cement floors and wall tiles (Cornell & Schwertmann, 2013, p. 513).

Dye and Pigment Industry

For thousands of years, iron oxides have been used as pigment agents. But, over the past few years, the global iron oxide pigment market has grown due to the demand in construction, paint, and plastic industries. Another positive impact for this industry is from government regulations moving incentivizing environmentally friendly products. Two pigments that can be made from acid mine drainage sludge are goethite and hematite. Goethite is raw iron oxide which is considered a yellow color and Hematite is the high temperature treated raw iron oxide which is a red color (“Grand View Research”, 2016). These iron oxide pigments, especially red, are widely used in the plastic and paint industries. The pigments are used in a wide range of plastic products including food packaging, vinyl siding, home computers, auto parts, soda bottles and toys ("Grand View Research", 2016). Coloring concrete bricks and pavement is also a popular approach with the natural red pigments. Lastly, the pigments are most often used for wood staining (Hedin, 2016).

Sorbent and Catalysts Industry

Iron oxide recovered from acid mine drainage (AMD) has a high surface area and absorption properties (Hedin, 2016). These mineral particles have potential to be a low-cost renewable materials that could be exchanged for reagent-grade chemicals in the creation of goethite, ferrihydrite, and magnetite with reasonably high purity (Flores et al., 2012). Iron oxides can also act as both an adsorbent to remove dyes from water and as a catalyst for heterogeneous Fenton reaction (Flores et al., 2012). The quality and purity of iron oxides recovered from AMD can be compared to those of analytical-grade reagents and synthetic iron oxides (Flores et al., 2012). Lastly, it has been found that iron oxide can be used in the absorption of phosphorus from dairy manure (Hedin, 2016).

Market Size

Total revenue data for industries in the United States of America was collected from IBISWorld for 2018 or 2019, based on the most recently updated information. These specific markets were chosen based on their demand for iron and manganese, the metals of highest concentration found in the sludge samples through ICP-OES analysis. Most of the markets in the chart are buyers of iron, with the exception of the battery industry, because iron is more primarily used than manganese. From the data, Figure 7 shown below was created to compare the industry size of the possible market opportunities.

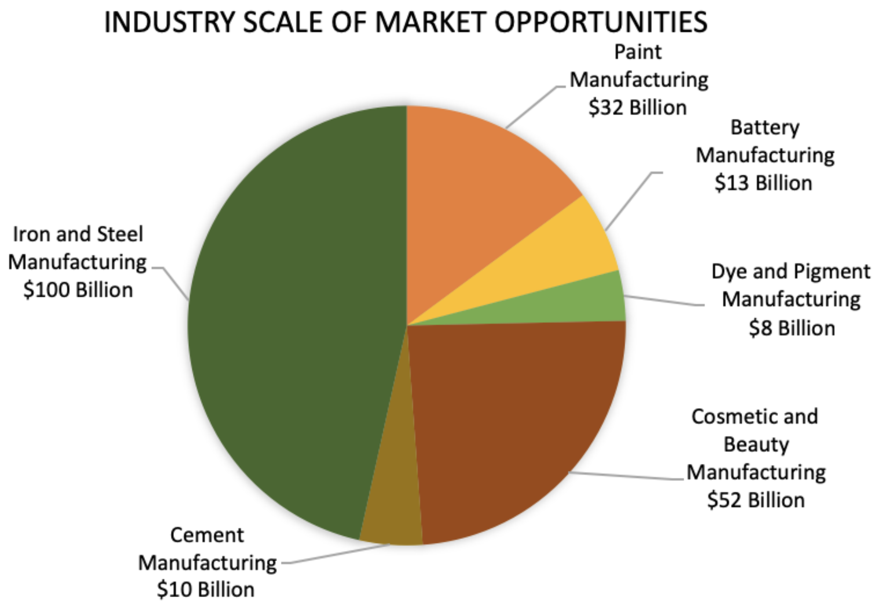

Figure 7. Annual revenue of specific markets from 2018 and 2019

As shown above in Figure 7, the iron and steel manufacturing industry had the largest total annual revenue, and the dye and pigment manufacturing industry had the smallest total annual revenue. The dye and pigment industry's annual growth over the past five years (2013-2018) has declined by 4.1%. However, as the construction industry grows and more infrastructures are built, this annual growth can become positive (IBIS, n.d.). According to a report on Grand View Research, the construction market is expected to grow over the next eight years due to an increase in Asia Pacific and the Middle East within their construction industries (Iron Oxide, 2016). If this industry begins to grow internationally, the growth may pick up domestically here in the United States of America.

Growth in the construction industry positively affects the dye and pigment industry as the demand for their supplies will increase. Utilizing iron oxide pigment primarily in concrete blocks, the construction industry was "the largest application segment in 2015" (Iron Oxide, 2016). Most industries, along with construction, value iron oxide highly for their coloration and film strength in paints (Iron Oxide, 2016).

Displayed in Figure 8 below, from the report on Grand View Research, displays the annual revenue of synthetic and natural pigments of iron oxide in the United States of America from 2014-2024. Synthetic pigments are typically favored over natural pigments for their purity and quality. Depending upon the market, natural pigments must undergo a purifying process and satisfy a specific particle size (Iron Oxide, 2016).

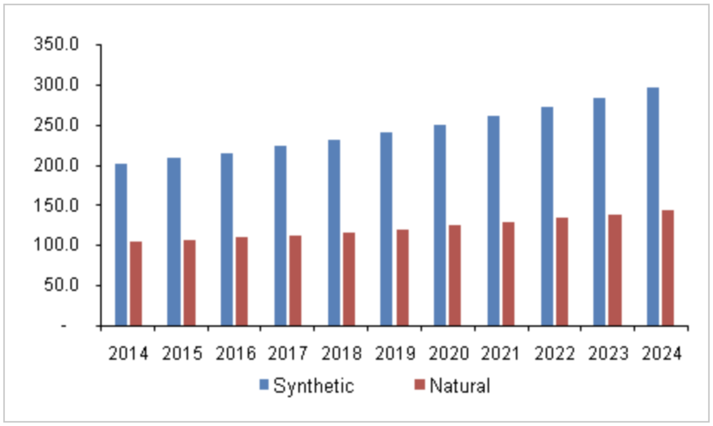

Figure 8. Annual revenue of synthetic and natural pigments of iron oxide from 2014-2020

While the annual revenue for synthetic pigment has a more significant increase of about 100 million USD versus natural pigment with an increase of about 25 million USD, the annual revenue for natural pigment gradually increases starting in 2019. According to the report, between the years of 2016-2024 the construction industry is expected to grow. Since 2019 is in the middle phase of this growth, the natural pigment industry is portrayed as having a steadier increase starting in 2019. As environmentally friendly business practices become increasingly widespread, natural pigment sales should rise. Along with the attractiveness of being environmentally friendly, natural pigments are associated with lower costs and high amounts of product available for sale (Iron Oxide, 2016).

Another market that possesses a demand for pigment is the pottery industry. According to IBISWorld the total revenue of ceramics manufacturing in the United States of America in 2018 was $3 billion, and the market had a 1.3% annual growth from 2013-2018 (IBIS, n.d.). The primary market researched in the ceramics industry was pottery, but the industry also consists of plumbing fixtures and other ceramic bathroom accessories, porcelain kitchenware, earthenware and pottery products, advanced ceramics and other pottery" (IBIS, n.d.). Based upon the concentrations of iron oxide found at the four passive treatment sites, the pottery market was of high intrigue. The size of this industry does not compare to the other market opportunities. However, the demand for iron oxide meets the supply at the treatment sites as expressed below.

Currently, the Slippery Rock Watershed Coalition has 100,000 lbs. of sludge that was collected over eight years from one vertical flow pond. Among the four sites where samples were analyzed, there are five vertical flow ponds in total. Meaning that over eight years, roughly 500,000 lbs. of sludge will be produced.

The 100,000 lbs. of sludge already collected is enough iron oxide to provide supplies to one potter for 200,000 years. The same amount of sludge can only provide a few days of supplies to companies in the cement industry. Most potters are using iron oxide for glazes, and the amount of glaze used is minimal compared to the amount of pigment the cement industry uses. Potters use a specific color, particle size, and purity of pigment for glazing their ceramics. The cement industry uses a raw from iron oxide, requiring less labor and time. The pottery market can utilize the product the SWRC has available for sale, but selling all of the iron oxide on site would take years (Denholm, 2019).

Market Segment

When conducting market research, all possible markets were examined and two determinations were made: markets that may be plausible and markets that may be slightly out of reach. This led to the realization that there are few opportunities that are practical. After analyzing the markets, potentially viable companies were chosen to be contacted to see if they would be interested in using the iron oxides found in the passive treatment by-product. If the SRWC is interested, additional follow-ups should be made in order to keep a connection to their company and collect more information, if needed.

Several large-scale companies that were contacted include Hoover Coloring, Amerimulch, and Lokai. Others were smaller, locally owned businesses who may be interested in pursuing sustainable, raw material supply-chain initiatives. Though these companies were not all interested, it helped to expand knowledge on possibilities and opportunities for the project. Four markets/companies were chosen as the most plausible ones to enter. The first market that was evaluated was pottery, which has been attempted by Clean Creek Pottery, a local pottery company committed to using sustainable methods. Clean Creek uses iron and manganese oxides to color the clay used in their pottery. In the past, this was successful in finding a use for the iron oxides and producing revenues to help support AMD remediation. Although these revenues were small, they helped to shed light on a very important topic that is rarely sought out by the public. When looking at the pottery industry, multiple companies were found who could be interested in purchasing the sludge. Through the use of online pricing and information provided in-class speakers, a rough estimate was calculated for how much revenue could be expected from this industry. A final revenue stream of about $79,000 a year was calculated before any costs can be accounted for. Reference Table 4 below for calculations.

Table 4. Possible revenues from Pottery. (EPMA Marketing Team)

Pottery (Per Site)		
avg. price ($/lbs)	amnt. collected (lbs)	Revenue
$ 0.79	100,000	$ 79,000.00

Another plausible market was pure iron oxide sale. Iron oxide found in the sludge could be processed out and would gain further value from being dried. Finer iron oxide sells for upwards of $5 per pound, whereas the lesser processed iron oxide sells for about 30 cents per pound. Revenue could be produced if the iron found in the sludge were to be further processed. It was difficult to find companies interested in purchasing the pure iron oxide based strictly from online research. Table 5 below illustrates the calculations for potential revenue. This was completed using $5/pound as an average price, which was multiplied by the number of pounds potentially collected. This estimation was provided by Mr. Cliff Denholm during an in-class presentation. The final revenue was calculated to be $216,000, which is much higher than the potential revenue calculated for the pottery market. However, no potential buyers could be found, so it was determined to not be feasible.

Pure Iron Oxide Sale (Per Site)		
avg. price ($/lbs)	amnt. collected (lbs)	Revenue
$ 2.16	100,000	$ 216,000.00

Table 5. Potential revenue from Pure Iron Oxide Sale. (EPMA Marketing Team)

Paint pigmentation is one of the largest markets for iron oxides. Many paints and wood stains use iron oxides to produce strong vibrant colors, through sustainable production methods. Hoover Coloring is known to purchase iron oxides from environmental remediation projects in order to help better the world. Students called Hoover and spoke with an employee and discussed potential agreements between the school and company for future reference. Sadly, Hoover stated that they already are in a contract with another company. Fortunately, this demonstrates that this niche market is active and viable. The potential outcome for paint pigment was calculated to produce an annual revenue of $15,000. Table 6 below shows the calculations using 100,000 pounds of sludge. This market is small but entry is beneficial because it would allow for the removal of tons of the sludge from the sites in order to help clean them at a quicker rate.

Paint Pigment (Per Site)		
avg. price ($/lbs)	amnt. collected (lbs)	Revenue
$0.15	100,000	$ 15,000.00

Table 6. Potential revenue for Paint Pigment. (EPMA Marketing Team)

The Jewelry market was explored with a company named Lokai, which is a bracelet company that focuses their sales on helping different organizations who are giving back. For example, Lokai has helped organizations such as the World Wildlife Foundation and the Make a Wish foundation. Companies like Lokai have helped similar projects by donating $1 for every $18 that they collect. Lokai collected over $250,000 for an organization in just a month and a half. This was a larger and better known organization so it is expected that the revenues used are much smaller. Therefore, a potential revenue of $250,000 a year was used to be conservative. Below, Table 7 illustrates possible revenues below. This is a market that could potentially be entered considering Lokai would be absorbing all costs and donate money back to our cause. This would alleviate our costs and result in pure profitability to SRWC.

Lokai		
Cost(Monthly)	Revenue	Lokai Revenue
$ -	$ 250,000.00	$ 2,125,000.00

Table 7. Potential revenue from Lokai. (EPMA Marketing Team)

Competitors

The goal of the EPMA cluster course was to establish a steady cash revenue from the sale of iron oxide, however there are others competing in this market. One main competitor in the iron oxide industry is Robert Hedin. He has developed and created many passive treatment sites and has collected, dried, and processed large amounts of iron oxide. With this final product, Hedin had found a market in order to make a profit. This is shown from his own personal data in Figure 9 below.

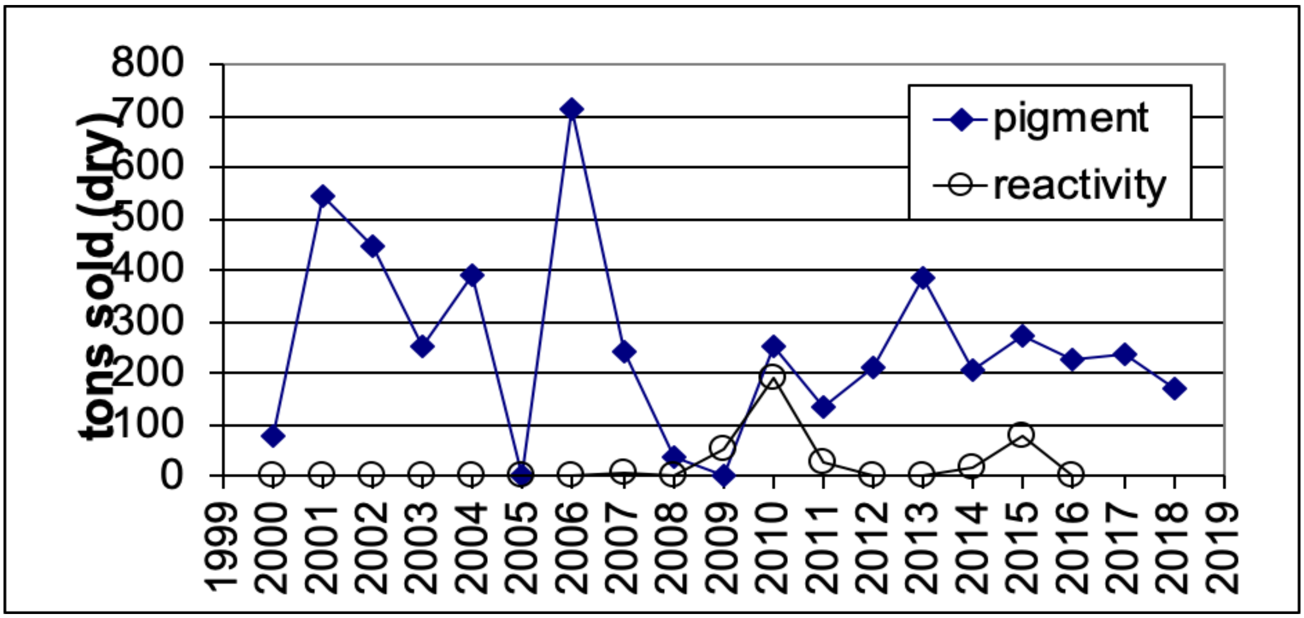

Figure 9. Total number of tons of dry sludge sold each year from 2000-2018.

Figure 9 shows the total number of tons sold in each year starting from 2000 through 2018. 93% of the sales is in the pigment industry with an average sale of 287 ton/yr. (Hedin, 2018). He has run into the problem in the past few years of selling the iron oxide because of the synthetic iron oxide becoming easier to produce and having been sold in larger quantities per year. Although Hedin is one of the bigger competitors in the iron oxide pigment industry, there were results from our research showing rare earth elements as well.

The rare earth market is dominated by China since the mid 1980's, with 85 to 95 percent of the world's REE's market as shown in Figure 10 below. Recently, a Chinese company has bought out the last REE producing mine in America known as The Mountain Pass Mine. Furthering the grip on the monopoly of REE, "This past June, an investor group with alleged ties to the Chinese government bought the mine for $20.5 million, beating out American bidders including entrepreneur Tom Clarke of ERP Strategic Minerals" (Roos, 2017). "China has lower labor cost and environmental standards making it economically unattractive for those producers to stay in the market or for new producers to enter" (Butler, 2014).

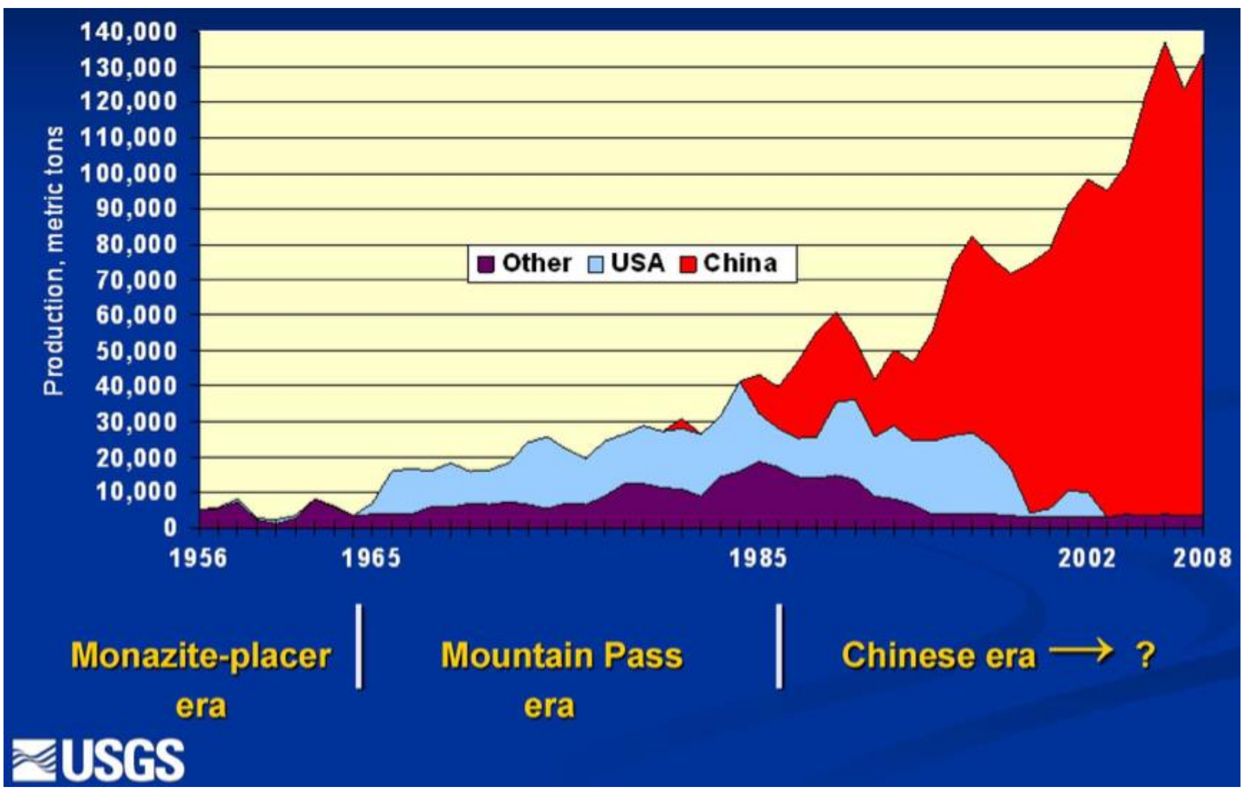

Figure 10. Production of rare earth elements in differing areas

While evidence exists pertaining to the size, scale, and profitability of the iron oxide market, it would require economies of scale with respect to raw material collection and processing in order to be financially feasible.

Cost Analysis

One of the most important aspects of the research has been determining all of the costs that are associated with the removal, transportation, and potential storage of the sludge byproduct from AMD. This cost analysis was used as a reference point that needs to be passed in order generate a positive value. In the past, the SRWC has procured various grants in order to cover their costs, and because of this, limited resources are a contributing factor to the overall feasibility. Cost projections for extraction, transportation, and storage were developed through independent research and information made available by the SRWC based on historically incurred costs.

Two possible methods of extraction of the sludge by-product were evaluated: manual hand labor and the use of an excavator. A few years ago, roughly 100,000 pounds of iron sludge from one of the larger sites within the Slippery Rock area was manually extracted by having a few interns shovel it out over about a 2-3 week period. With this information, a simple formula for extraction through manual labor was created. The team came to the conclusion that with 5 men shoveling, on a normal 40 hour work week, they could likely remove the sludge within 2-4 weeks. This range was determined by using SRWC's 2 week benchmark but with consideration for the possibility of outside forces such as weather. With 5 people working 40 hours a week for 2 weeks, a total of 400 hours of manual labor be would incurred. The labor hours are multiplied by a rate of $15/hour for a cost of $6,000. This method is somewhat expensive so the project members also looked at the possibility of using an excavator to remove this sludge. Table 8 below highlights these expected costs.

Table 8. Costs calculated for tractor trailer, (EPMA Marketing Team).

Category	Projected Cost			
Extraction w/ Excavator	**Subtotal**	**40 Hours**	**80 Hours**	**120 Hours**
Labor (Excavator) (Hourly)	$ 70.00	$ 2,800.00	$ 5,600.00	$ 8,400.00
Rentals (Excavator) (Monthly)	$ 975.00	$ 975.00	$ 1,950.00	$ 2,925.00
	Total:	**$ 3,775.00**	**$ 7,550.00**	**$ 11,325.00**
Manual Labor Extraction	**Ave. Hourly Rate**	**400 Hours**	**600 Hours**	**800 Hours**
Labor (Hand Labor) (Hourly)	$ 15.00	**$ 6,000.00**	**$ 9,000.00**	**$ 12,000.00**

Bob Hedin talked to the class about some of the costs associated with building and maintaining passive treatment systems along with the costs of extracting it. According to Hedin, it would cost roughly around $23,000 to extract the sludge from the systems per year (Hedin, 2018). This, of course, is site dependent and will vary from system to system based on a variety of external factors.

There are two costs associated with renting an excavator, renting the physical machinery and paying someone to operate it. If the SRWC already employs someone who is qualified to operate the machinery, they can cut a portion of this cost. The use of a mini-excavator is likely the best option being that they are less expensive and will be able to better maneuver on some of the smaller sites. The primary excavator looked at was an older model, John Deere mini-excavator, from a website called rent1usa.com. The average weekly rental cost for this model and other similar models was $975/week. Only 1-3 weeks was allocated as it was decided that using an excavator would likely be faster than hand labor. Pay rate for professional operators ranges between $50-85/hour. If all of the sludge was removed within one regular 40-hour work week, the cost of extraction would only be $3,775; however, if this method took a total of 3 weeks, then the total costs of extraction would jump up to $11,325. Even though extraction is certainly very important, there are still a few other things that must be considered when it comes to cost.

In order to sell the sludge it will have to be transported to the desired location. Many different aspects went into consideration to determine a cost projection for transportation such as how it could be transported and where it would be sent. A large box truck that is able to move 100,000 pounds of material at a time would be needed. Prices for truck rentals from Penske, a truck rental company, were acquired. However, it became apparent that this would not be large enough for the needs of SRWC. The largest box truck that Penske offers can only carry a load of 10,000 pounds, meaning either multiple trips would be needed or multiple trucks would have to be rented at a time. Both of these options would become very expensive and unpractical. Penske rents out tractor trailers with a pay system of paying for both the truck and the trailer based on miles traveled and days rented. These amounts were a total of 24 cents per mile and $230 per day. There is also a security deposit that costs $7,500.

To determine the miles traveled, four different locations that were being considered for the market analysis were evaluated; WVU, Lokai (based out of NYC), Steelite International (located out of New Castle, PA), and a pottery company based in Hiwassee, Virginia. To determine the total miles, the distance between slippery rock and the individual sites were multiplied by 2-for a round trip. Another cost to consider is gas. For this, the prices of Ohio's diesel gas were used since Ohio typically has cheaper prices than PA. Research showed that, on average, tractor trailers only get 8 miles to a gallon. The team found out that truck drivers needed to be contracted out. Through further research, an average price of $25/hour was determined for hiring a CDL driver. With all this information, the costs of transporting to the four locations was able to be determined. The costs can be shown in Table 9 below.

Table 9. Cost calculated for transportation, (EPMA Marketing Team)

Transportation	Subtotal	WVU (118 mi)	Lokai (366 mi)	Steelite (20 mi)	Hiwassee(383 mi)
Truck and Trailer (miles)	$ 0.24	$ 56.64	$ 175.68	$ 9.60	$ 183.84
Truck and Trailer (days)	$ 230.00	$ 230.00	$ 460.00	$ 230.00	$ 460.00
Security Deposit	$ 7,500.00	$ 7,500.00	$ 7,500.00	$ 7,500.00	$ 7,500.00
Labor (hourly)	$ 25.00	$ 100.00	$ 300.00	$ 50.00	$ 325.00
Diesel (Ohio per gallon)	$ 2.75	$ 686.55	$ 2,129.45	$ 116.36	$ 2,228.36
	Total:	$ 8,573.19	$ 10,565.13	$ 7,905.96	$ 10,697.20

The final variable examined regarding possible costs involved storage of the sludge. The SRWC as over 100,000 pounds of sludge sitting at one of their sites, so the team included the possibility of not paying for storage as well. Historically, SRWC has kept the sludge in large bags and placed them in a field near the passive treatment site. Research was conducted to determine if it was a financially viable option. Highly durable plastic barrels that are able to hold up to about 460 lbs of material within them were found. To hold all 100,000 pounds, the SRWC would need to purchase 218 barrels. The barrels cost $24.74. In the end, this is likely not a good idea for the SRWC to follow through with as they already have a free method of storing the sludge that also simultaneously dries the material out. The cost of the storage drums can be seen in Table 10.

Table 10. Costs calculated for storage drums (EPMA Marketing Team)

Storage	Subtotal	100T / 331lbs	Total (Drum)
Storage Drums (8 count)	$ 29.74	302	$ 8,984.89

In the end, the costs were much higher than initially anticipated, meaning that markets that can offer higher potential revenue will need to be found. The possibility of purchasing storage drums and renting a unit can be eliminated to lower the total cost, but no matter what, the sludge will need to be extracted and transported. There is no doubt that the cost for extracting, transporting, and storing the iron sludge are high; however, many markets and companies have been explored that offer a potential revenue stream.

Feasibility Report

Research was conducted to ascertain projected prices for the labor, storage, and transportation costs; the project team ultimately found that the overall feasibility of the project, as is, is not plausible. The market research group contacted local businesses and searched for markets for the sale of the iron oxide that comes from the passive treatment systems in the SRWC. Unfortunately, many of the businesses who were contacted have not responded and/or were not willing to discuss current raw material prices and sources. Larger companies, such as Lokai, were also contacted. Lokai, a company that makes inspirational silicone bracelets was selected due to their involvement with non-profits and their ability to reach a large market. The research group found many markets that can possibly be used in the selling of iron oxide pigment. These niche markets will continue to grow with years to come.

Estimates were also collected for extraction labor, the storage of the material, and the transportation of the sludge. The costs for the excavator and the hiring of someone to operate it coupled with the price to rent the delivery truck would not be financially feasible if the SRWC was to sell the iron oxide as is.

The projected revenues coming from this project are from pottery, Lokai, selling pure iron oxide, and the paint pigment markets. It is extremely difficult to compete with synthetic competitors and sell in mass quantities when it takes around eight to ten years to get about one hundred tons of sludge out of a SRWC site.

PESTEL Analysis

Political:

The political factors playing into the extraction, transportation, processing, and marketing of the sludge by-product of abandoned mine drainage includes many acts and regulations; namely the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Superfund. Passed in 1980, CERCLA gives the U.S. Environmental Protection Agency (EPA) power to regulate hazardous substances at contaminated waste sites, including abandoned mines, nationwide. The act also established the Superfund program, a federal system showing contaminated sites listed by priority and level of waste contamination, also known as the National Priorities List. As of April 2016, there were 113 proposed and officially listed abandoned mines on the National Priorities List of Superfund sites. The abandoned mines of Pennsylvania have the potential to receive federal funding for site cleanup. Superfund has increased the size of the funding to 8.5 billion (EPA, 2018). Superfund uses the Hazardous Ranking System (HRS), which numerically examines the potential hazards of a site based on groundwater, surface water, soil, and air contamination while looking at the toxicity, quantity, and significance of exposure to the environment and human health. If a site is high in all these areas, a high number will be assigned and the site is more likely to receive funding.

With each presidential administration, a variety of environmental, economic, and legal changes occur that can affect acid mine drainage. In the Trump Administration's Maintenance and Budget Blueprint, total EPA funding has been cut by 31%" (Trump et al., 2018) and a proposed "25% cut in Superfund budget, also calling for a 36 percent cut to a separate program for cleaning up contaminated former industrial sites" (Atkin, 2017). The Blueprint also states that “The agency would prioritize the use of existing settlement funds to clean up hazardous waste sites and look for ways to remove some of the barriers that have delayed the program’s ability to return sites to the community,” meaning that clean-up of AMD and other hazardous sites would be the responsibility of city municipalities and non-profits such as SRWC. In current political discussions, talk of the Green New Deal (GND) has been popularized within the Green and Democratic Parties. The GND has potential to reclaim funding for hazardous sites on the National Priorities List. This is important because “Cleaning up and redeveloping these sites is not only important for human health and the environment, but it can increase local tax revenues, grow jobs, lift property values, and ease development pressure off undeveloped lands” (Mangan, 31).

Economical:

A potential influx on local economies can be deemed as a potential economic benefit on the Slippery Rock Watershed Coalition and surrounding areas. An entry into the iron oxide pigment industry could create local jobs in order to carry out the sludge removal process and transportation associated with this process. The revenue of synthetic dyes of iron oxide ranges from an estimated 200 million in 2014 to 300 million in 2024. For natural dyes, it ranges from 100 million in 2014 to 150 million in 2024. This shows an increase of revenue in the iron oxide pigment market (Iron Oxide, 2016).

Social:

The social impacts of AMD on communities includes many threats ranging from adverse health, recreational, and homeowner effects. Metal-heavy AMD infiltrates streams and rivers, diminishing wildlife and destroying the aesthetic effects for recreational enjoyment. Many citizens are affected by AMD destruction of streams that run through their property. Not only does AMD kill wildlife and plant life, it also increases erosion, creating potential property damage. Although the health effects of AMD are not fully known, safety precautions should be met. Of the 48,529 abandoned mine sites shown on the map below, 36,191 are categorized “Priority 1″ or “Priority 2”, meaning they pose a “threat to health, safety and general welfare of people (Manthos, 2015). Although this water is not drinking water, small children playing nearby, or animals such as household pets, are at risk for contamination and toxic exposure. The recovery of AMD contaminated areas has potential to increase community health, especially for those living along streams. The living streams within the SRWC can be seen in Figure 11 below.

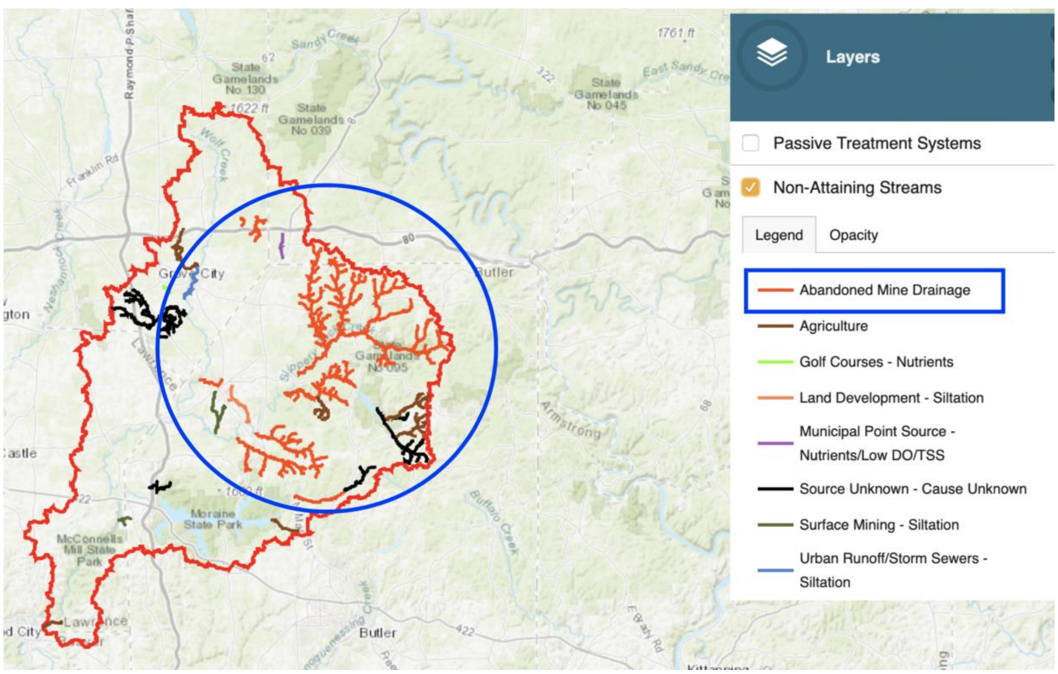

Figure 11. Outlined in red is the land area of the Slippery Rock Watershed. The streams colored in orange are affected by AMD.

Education and market opportunities for AMD sludge can create awareness for this issue. The Jennings Environmental Education Center has spread awareness through its passive treatment site tours and family-friendly lectures.

Technological:

An excavator, a shovel and a truck are the technology used to remove sludge from passive treatment sites. LaMotte field kits were used to conduct field tests. These tests were used to find the amount of iron, alkalinity and pH. ICP-OES was also used in the lab to further test iron, manganese, and rare earth metals. Multiple techniques are used to process the sludge such as drying and refining. SRWC does not have the capability to conduct these procedures, so assistance from experts would be needed to dry and refine the sludge. According to Dr. Hedin, following the implementation of passive treatment sites, a team will enter the site, drain a sludge-heavy pond and pump the remains into GeoTubes provided by GoWaterSolve, LLC (Hedin, 2016). GoWaterSolve describes the process as draining excess water through GeoTube containers, "through the small pores in the geotextiles resulting in effective dewatering and efficient volume reduction of the contained material. This volume reduction allows for the repeated filling of the GeoTube container" (WaterSolve). Biological treatment has also emerged as a cost-effective and eco-friendly result of the passive treatment of AMD according to Dr. William Sharpe of Pennsylvania State University. This includes the use of microbes, bioreactors and wetlands designed with microbial attachments that aid in abatement of AMD by facilitating reduction of metals, sulfates and generating alkalinity (Sharpe, 2019). Another simple technique utilizes ultra-filtration, reverse osmosis, evaporators and crystallizers to refine AMD sludge, which uses less chemical and energy consumption.

Environmental:

Acid mine drainage has proven to be an extreme detriment to the environment. The acidic nature of the water that is affected by AMD is polluted with an excess of hydronium ions. This excess causes a gradual drop in the available sodium ions to the living aquatic organisms which results in decreasing levels of oxygen being delivered to vital tissues. Eventually, the aquatic environment would be uninhabitable by all aquatic life. These affected water systems also have an adverse impact on the surrounding environment. The average pH of a healthy stream should be approximately 7; however, AMD affected waterways are typically at a pH of approximately 3.5. Water is the basis of all life and, therefore, this extreme shift in pH will affect all of the organisms that are within the environment, including local populations of people. AMD runoff pollutes waterways with heavy metals, which accumulate in living tissue when consumed, and can lead to a variety of extreme health issues. AMD also disrupts local plant life, both aquatic and land based, which promotes erosion. With all of these effects tallied, the environment suffers a massive loss in overall biodiversity and sustainability. There is a surplus of urgency in solving this environmental issue due to the extent of the harm it does to both the environment and human health. It has massively affected the local area with over 5,500 miles of streams being contaminated with AMD within Pennsylvania alone, yet the effects can be found in different segments of the world (Denholm, 2019).

Legal:

Due to the nature of the project, legal factors are a huge factor in the success or failure of the project as a whole. Advertising standards are continuously becoming more strict in terms of what they can and cannot include in their ingredient lists and to what degree of environmental responsibility they are produced at. Companies are offering consumers an ever-growing assortment of “green” options.[2] Whether the environmental claims are about the product or the packaging, one would need competent and reliable scientific evidence to support what is said. If it were the case that heavy equipment, such as an excavator, was needed to be used on private land, permission of the land owners would be needed and an operator with a CDL certified machine would be necessary. The ownership of the sludge as a resource is undecided as a whole. This is because the sludge is a product of the passive treatment site. The ownership of the resource could also fall to the company that worked the mine. However, both of these situations are rarely the case due to the liability associated with AMD recovery. The Slippery Rock Water Coalition is a non-profit organization that has partnered with BioMost Inc., who has developed advanced passive mine drainage treatment technology to support the specific needs of government and private organizations. If the project becomes profitable, for taxation and legal reasons, the idea would be turned over to BioMost Inc.[3]

RECOMMENDATION TO THE SRWC

It is recommended that the SRWC explore the development of strategic partnerships with local colleges, universities, and businesses such as Westminster College, Slippery Rock University, PPG Paints, and Steelite International, with a three-pronged goal in mind:

1. Work in conjunction with various educational departments towards the development of strategic STEM, marketing, and business internship opportunities.
2. Provide and extend service-learning engagements to students and instructors seeking grant-writing experiences.
3. Socially promote the environmental issues and business opportunities associated with AMD.

A marketing intern has previously been employed by the SRWC. Additionally, small, locally-based markets have been previously exploited via the use of AMD iron oxides by Clean Creek Pottery. Based on the research contained within this document, companies exist that are interested in producing sustainably-sourced raw materials. By partnering with local colleges and universities, marketing-based internships may be used in order to continue the exploration of potential markets and interested companies. These strategically developed relationships may ultimately save the SRWC expected expenditures by reducing the need to hire a full-time marketing professional. Additional STEM and business internships may be further explored in order to expand upon the work completed by the EPMA.

In addition to the development of internship opportunities, the SRWC may be able to achieve a synergistic relationship with these schools in the co-development and writing of grants specifically tailored towards the recovery of iron oxides from AMD. Students are often looking for engaging opportunities that are directly correlated to their marketability and employability after college. Successfully written and funded grants would assist students in ascertaining jobs after college while saving the SRWC the time and costs associated with either writing or externally funding the writing of these grants.

Aside from the many benefits associated with partnering with local colleges and universities, additional benefits may be realized through partnerships that could be developed with strategically selected business ventures. Businesses, like PPG Paints, that use sustainably sourced materials, may be interested in collaborating with the SRWC in co-promotional activities associated with bringing attention to AMD and the detrimental effects felt all across western Pennsylvania. Although cost-effective business opportunities are currently financially challenging, social awareness campaigns may shed light on unique business opportunities that have yet to be explored. Resulting business-related sponsorships may contribute towards the reduction of extraction costs, thus reducing overall barriers to entry into sustainably-sourced markets.

To aid in the extraction process of AMD sludge, it is recommended that the SRWC consider options in utilizing technology in developing or redesigning new or current passive treatment sites. Through the construction or updating of passive treatment sites, AMD sludge can be pinpointed and easily accessed by equipment to be extracted, dried, and in turn, loaded onto trucks for transportation to processing facilities. As a result, labor intensive costs can be decreased or mitigated entirely. Also, it is recommended that the SRWC explore replacing existing limestone beds with steel slag– a byproduct of steel production. Steel slag is a cheaper alternative than limestone as well as an effective alternative. Steel slag is successful in raising the alkalinity and pH of AMD and, in turn, treating it. The utilization of steel slag would also be a natural process of utilizing waste from another industry. Research on the use of steel slag for the treatment of AMD exists but will need to be carefully considered. Steel slag beds could ultimately turn to concrete, creating an additional and more problematic issue.

Successfully written grants for state and federal funding may be implemented towards reducing the costs associated with the construction and implementation of technology for passive treatment sites. Ultimately, the implementation of upgrades may reduce the barriers of entry for the SRWC to enter the market of processing and selling of iron oxide contained in AMD sludge.

To further aid in the profitability of AMD sludge, it is recommended that SRWC form a co-op with coalitions in the surrounding area. Due to the relatively small amount of sludge produced at the passive treatment sites, the feasibility to enter any market is limited since the cost to enter would be extremely high and the lifespan would not be long. Building relationships with other coalitions allows for more sludge to be collected in total. Therefore, larger markets become more feasible and economies of scale can be achieved. Establishing a successful co-op will also alleviate the financial strain from the SRWC since the costs of extracting the sludge would be shared.

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APPENDIX A -- FIELD TEST RESULTS

Introduction

During the early months of the semester, between late February and early March, students visited numerous passive treatment sites within the Slippery Rock Watershed Coalition. The purpose of these trips was to collect samples for analysis, conduct field tests of the water, and observe the sludge by-product created by the passive treatment process. Each group collected water and sludge samples from their sites and compiled data regarding the field test analysis conducted at the site.

Methods

To become familiar with the different sites, research was done on each unique passive treatment site before the trip. Sample locations were determined during this time and based off of previous sampling locations recorded on www.datashed.org. Water samples were obtained from each location on the site (~250 mL) to analyze the presence of dissolved metals using ICP-OES. Sludge samples (~15 mL) were taken at locations where a significant amount of the product was visible.

A schematic of each site visited is shown in Figures A1-A4, in which circles represent the locations where samples were collected. LaMotte Field Test kits, and Combo by Hanna pH/ORP probes were used at the site for analysis. Furthermore, team member roles were decided as to who would be in charge of recording data and taking photos of the site.

BC16

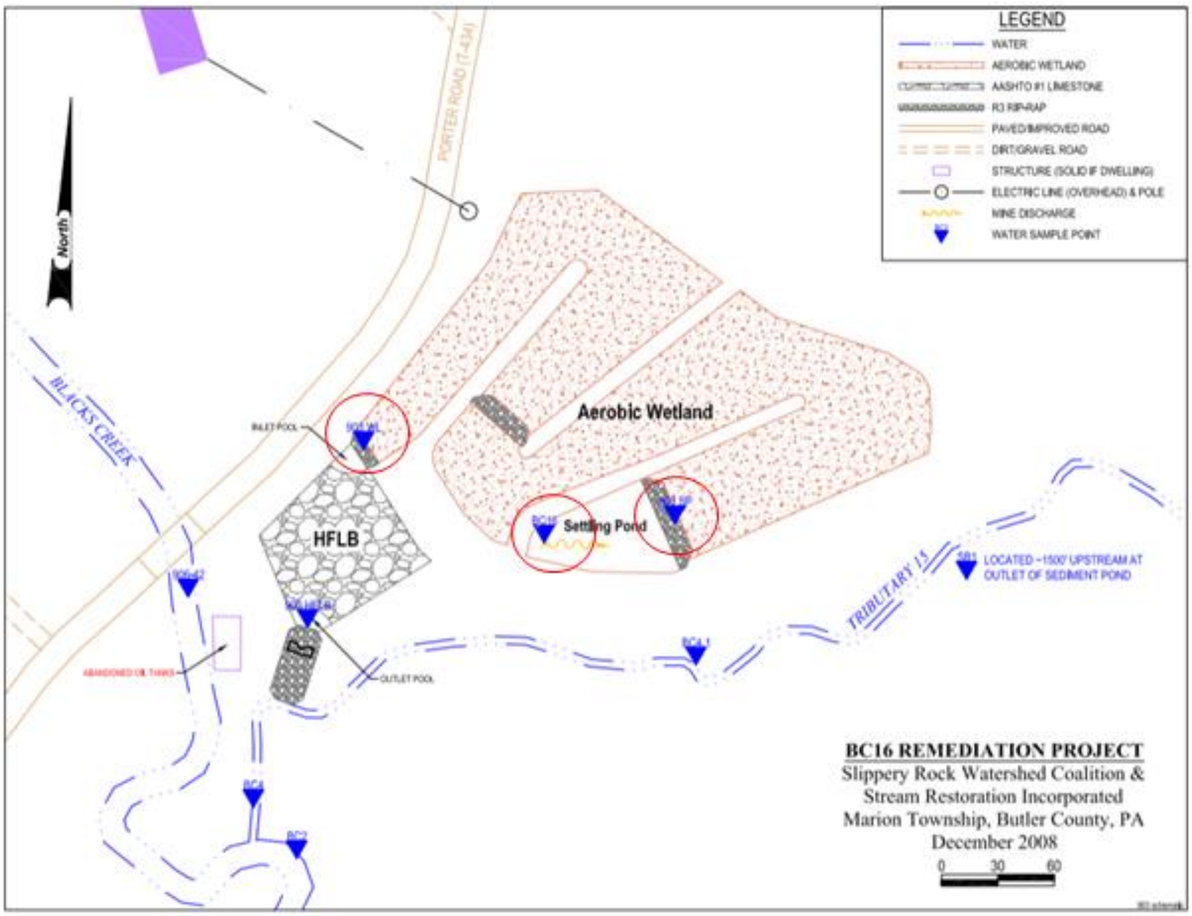

Figure A1. Schematic of BC16 Passive Treatment Site from Datashed.org. Sampling sites are circled in red.

Table A1. Field results of test kits from BC16 site.*

Sampling Site	Alkalinity (ppm)	pH	Iron (ppm)	ORP (mV)	Sludge Sample
SP	215	6.23	10.0	21.0	No
WL	87.5	6.84	7.75	51.5	Yes
HFLB	128	6.57	1.30	78.0	Yes

*Table figures are averages from 3 replicates of test field kits.

The first site of the passive treatment system was SP-BC16 (SP). As anticipated, the iron levels were highest at the SP sampling site. Also, the alkalinity and pH levels were surprisingly higher than expected. For site 903-Wetland (WL), which is directly after the aerobic wetland, there was an increase in pH and in ORP and a decline in alkalinity from the SP. The decrease in iron is evident of the alkalinity present throughout the aerobic wetland since alkalinity precipitates out iron. Test results from SP and HFLB indicated that the passive treatment system is functional. The results showed a decrease in iron concentration, an increase in ORP, and an average pH of 6.576, confirming the passive treatment system is successful at treating the AMD.

De Sale I

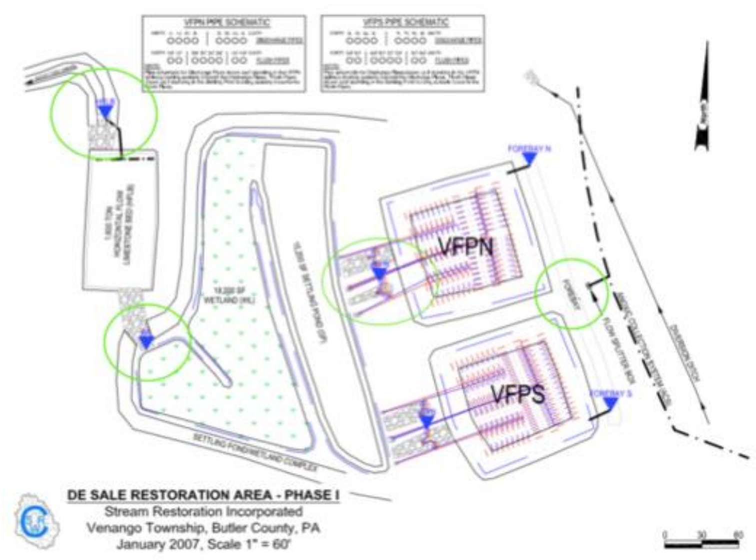

Figure A2. Schematic of De Sale I Passive Treatment Site from Datashed.org. Sampling sites are circled in green.

Table A2. Field results of test kits from De Sale I site.

	Alkalinity (ppm)	Average pH	ORP (mV)	Iron (ppm)	Sludge Sample
RAW	0	4.20	287	10	Yes, Fe
VFPN	50	5.75	69	10	No
WL	20	5.20	157	3.5	Yes, Fe/Mn
HFLB	30	5.87	122	2	Yes, Mn

After analyzing the results of the field tests, it was determined that the system was working properly since pH and alkalinity increase throughout the process. Furthermore, iron concentrations decrease to a minimal amount by the end of the treatment process. While specific values were not expected for each parameter, trends were observed in the data values. The pH was expected to rise as the passive treatment system progressed, and this is the observed trend in the data as well. The final pH of the water was about 5.9, and anything above 6.0 is considered to be a healthy stream. Additionally, the iron concentration decreased throughout treatment since as it precipitates out into a solid.

De Sale Phase II

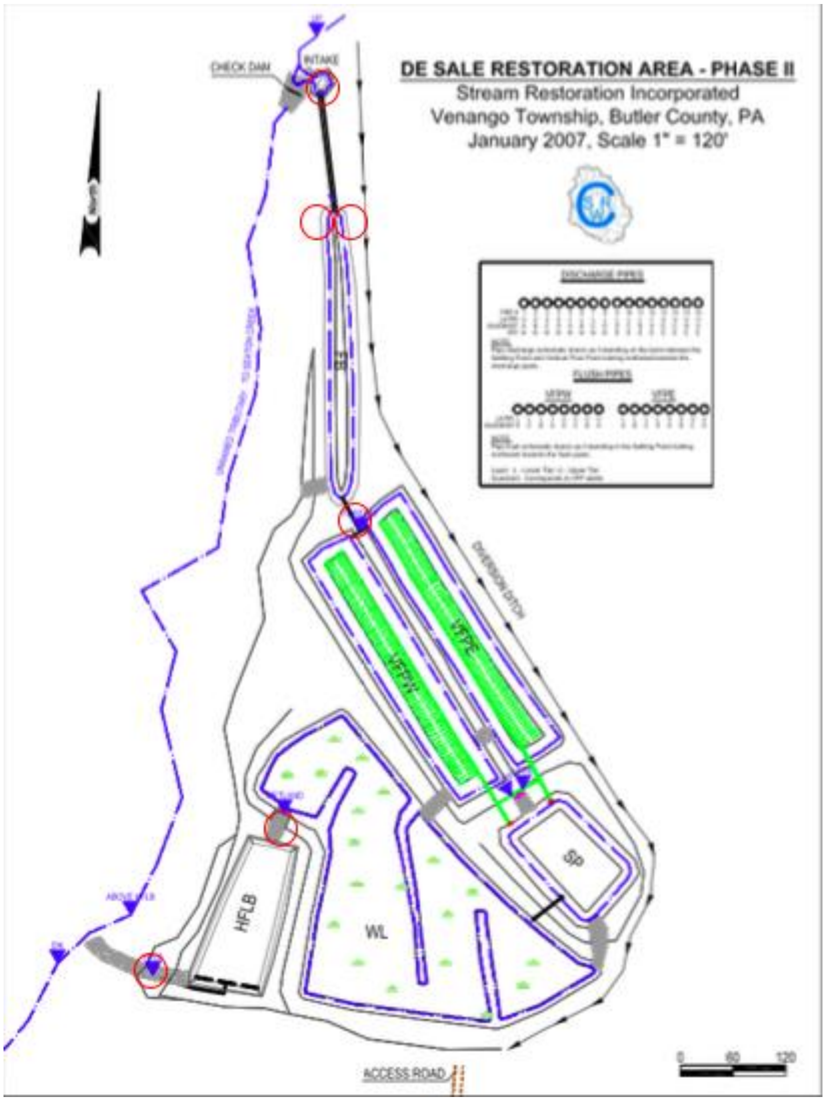

Figure A3. Schematic of De Sale II Passive Treatment Site from Datashed.org. Sampling sites are circled in red.

Table A3. Field results of test kits from De Sale II site.

Sampling Site	Iron (ppm)	ORP (mV)	pH	Alkalinity (ppm)
Intake	6.0	461	3.68	N/D
Forebay-West	6.0	463	3.59	N/D
Forebay-East	6.5-7.0	470	3.66	N/D
Vertical Flow Pond-EW	N/D	203	6.51	62
Wetland	4.5	320	5.28	2
HFLB-End	1.0	307	5.24	2

It was known that De Sale Phase II was at the end of its life, having too many metals precipitated onto the limestone and essentially not cleansing the water to the extent it should. This is the main reason that looking at Table A3 (from beginning of treatment to the end), the numbers are not ideal and fluctuate throughout. This is shown by looking at the results from the end of treatment such as the Wetland and HFBL-End, compared to the results from the Vertical Flow Pond, a component of the treatment center at the beginning. Iron is lower at the Vertical Flow Pond, along with a more stable pH and alkalinity while at the end of the system, a lower pH and iron are present. Overall, the relatively old treatment center is still raising the pH and lowering the iron concentration, creating a healthier flow of water than what enters the system.

De Sale Phase II was visited to further understand how passive treatment of AMD works as well as to collect water and sludge for further lab analysis. It was found after analyzing the samples that the system, while being old and nearing a day when it will need to be maintained, still successfully lowers the iron concentration and raises the pH to a more stable level. If the group were to go back, we would resample the six areas again to create replicate data from a month later to see if anything significant had changed, as well as to create a stronger database from the analysis.

McIntire

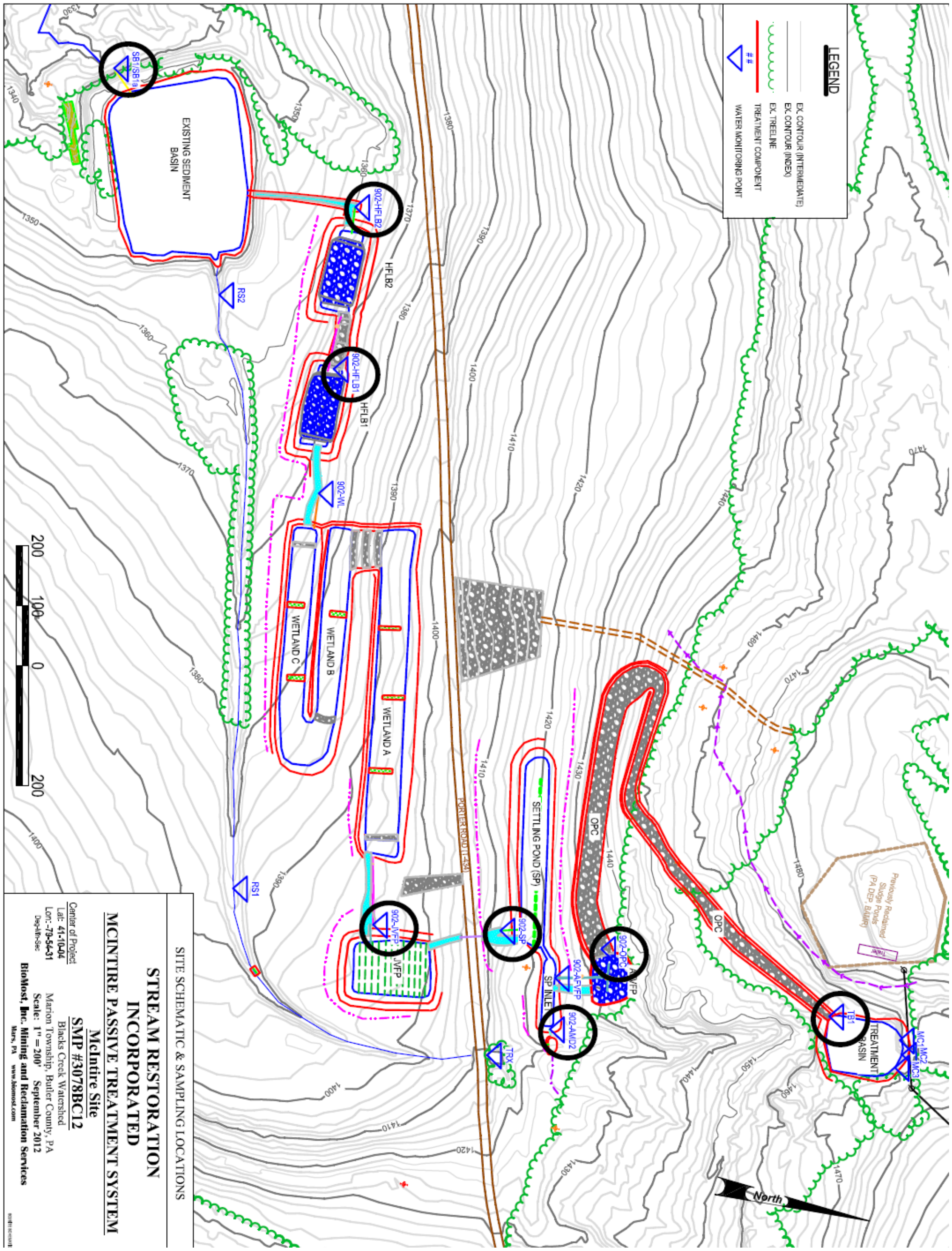

Figure A4. Schematic of McIntire Passive Treatment Site from Datashed.org. Sampling sites are circled in black.

Table A4. Field results of test kits from McIntire site.

Location/Site	pH Combo By Hanna	ORP (mV) Combo By Hanna	Alkalinity (ppm) LaMotte	Iron (ppm) LaMotte
RAW	3.15	402	ND	<10
902-OPC	3.03	478.5	ND	<10
902-AMD2	4.18	416	ND	0.75
902-SP1	3.29	470.5	ND	<10
902-JVFP	6.97	43	70	3.0
902-HFLB1	7.17	261	19	0.5
902-HFLB2	6.87	275	155	0.0
SB1/SB1A	7.15	247	131	0.5

For every sampling point at the top half of McIntire, no alkalinity could be detected. It is believed this occurred because there are multiple entry points of raw water. The iron samples were greater than 10 ppm because when the test was run, the iron levels were already above the highest possible measurement. No dilution was done, which would have given a more accurate measurement of the results.

About 250 mL of water and about 10 grams of wet sludge were collected for each sample taken from the bottom half of McIntire. Of the sampling points that were tested at the lower half, all had pH levels that fit the parameter of a healthy stream, which is 6.5-8.5. The ORP was close to optimal health in three of the components, but was much lower in the 902-JVFB point. While the low ORP at this portion of the system was consistent with information on *Datashed*, there was no prior data about the alkalinity of 902-HFLB1. The accepted values for a healthy stream for ORP are 300-500 mV. While all the sites were lower than the acceptable values, the 200 mV values were more consistent with *Datashed* than the JVFP point that had a value of 43 mV. The employees there informed the team that they have always had a problem with low alkalinity in the water. Contrary to that, the only two points that were below acceptable values were 902-HFLB1 and 902-JVFP. The iron content was low in all points except 902-JVFP. This can be seen by the high level of iron sludge coming from this specific component. Due to the cold weather and frozen state of the water system, it was difficult to find large amounts of sludge. Accordingly, the samples taken were collected on a rock, mixed with moss, or flowing into the settling basin.

Summary

Going to the site helped the team visualize how the passive treatment system works and flows. Observations and chemical analyses of pH, ORP, alkalinity, and iron content at the four specified sample sites were all tested. These results determined the health conditions of the water at the points based on healthy stream parameters. The specific sample sites were chosen due to their various locations throughout the beginning, middle, and end of the passive treatment system.

The samples that were collected from the top half of McIntire showed evidence of poor pH and alkalinity. The samples appear to be clear and free of minerals once collected, but since the acidity of the water was high, the minerals were dissolved. The sludge samples that were collected from each sampling point had an orange color to them. ICP-OES analysis was performed on the water and sludge samples to determine what metals are present.

If given the opportunity to return to McIntire, the group would like to test the alkalinity of 902-HFLB1 and the ORP of 902-JVFP to see if results were accurate or not. Inconsistencies in data could be a result of the cold weather endured on the trip, or any prior weather phenomena that occurred. Since that group gathered data on from the top half of McIntire, it would be beneficial to look at each other's data and make sure the system is working properly as a whole.

APPENDIX B -- LABORATORY RESULTS

Introduction

The purpose of lab work through inductively coupled plasma - optical emission spectrometry (ICP-OES) analysis was to determine the concentrations of each metal in the collected sludge and water samples from BC16, De Sale Phase I, De Sale Phase II and McIntire passive treatment sites. Laser Induced Breakdown Spectroscopy (LIBS) was also used to determine any elements present in the sludge samples that weren't tested for by ICP-OES.

ICP-OES Analysis of Water Samples Methods

Preparation of Standards:

The formula M1V1=M2V2 was used to calculate the volume of the stock solution which contained 400 ppm iron, 200 ppm manganese, and 20 ppm rare earth elements (REEs). From the stock solution, serial dilutions were conducted to create 20 mL of the desired concentration in each standard. Standards were transferred to a conical vial, placed in an autosampler rack and standard details were recorded on an analysis data log sheet.

Digestion of Water Samples:

A volumetric pipet was used to transfer each water sample (50 mL) to an Erlenmeyer flask. Working within the hood, concentrated nitric acid (2.0 mL) was added to the sample using a micropipette. The samples were boiled lightly for about five minutes, and then each was quantitatively transferred to a 50.0 mL volumetric flask and diluted to volume with DI water. Each sample (10-15 mL) were transferred after inversion to a conical vial, placed in an autosampler rack and standard details were recorded on an analysis data log sheet.

ICP-OES Analysis of Sludge Samples Methods

Drying of Samples:

Sludge samples were placed into a labelled pyrex dish using a scoopula and placed in a drying oven to prepare for future analysis.

Preparation of Standards and Quality Controls:

Standards of the following elements were prepared: Fe at 0-100 ppm, Al at 0-100 ppm, Mn at 0-40 ppm, and REEs at 0-5 ppm. These multi-element standards were created for the whole class and done through serial dilutions. Quality controls were created at 5.0 ppm for each analyzed element.

Digestion of Sludge for ICP-OES Analysis:

Dried sludge samples were photographed. Sludge (~0.25 g) was weighed and placed into a small Erlenmeyer flask. Concentrated nitric acid (2.0 mL) was added to the sludge sample and boiled until all solids dissolved. Concentrated hydrochloric acid (2.0 mL) was added if the solids did not dissolve completely. Each were transferred to a 100.0 mL volumetric flask, and diluted to volume with DI water. Two additional dilutions of each sample were conducted: 1.0 mL prepared sludge sample diluted to 20.0 mL, and 0.1 mL prepared sludge sample diluted to 20.0 mL. These sludge samples were placed in an autosampler rack and details were recorded on an analysis data log sheet.

Analysis of Sludge Samples by LIBS Methods

LIBS (laser-induced breakdown spectroscopy) was used to determine the other elements found within the sludge. To prepare samples for LIBS, a sample of the dried sludge was compressed in weigh paper up to 10,000 pounds. The flattened sample needed to be compressed in the middle of the paper so that the instrument could properly analyze the sample. Each sludge sample was ablated by the laser in a 3x3 grid. As the laser comes in contact with the sample, the individual elements are excited and then characterized by their unique atomic emission spectra.

BC16

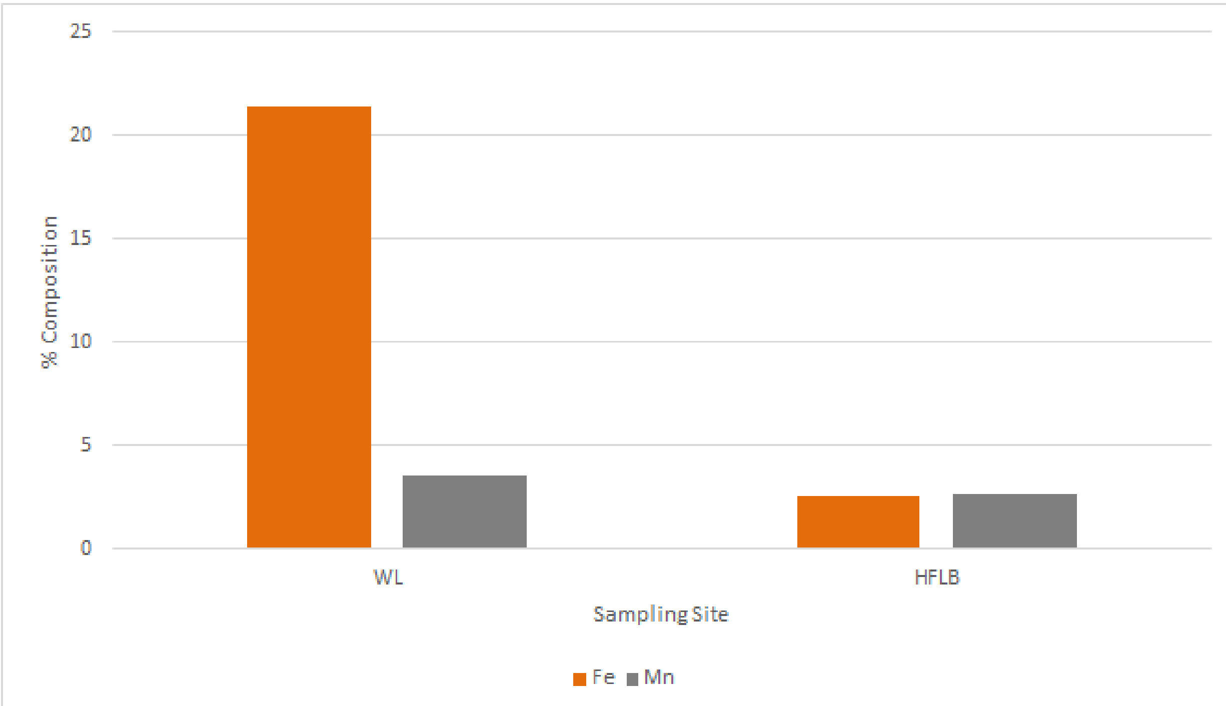

Figure B1. Metal concentration percentages in BC16 sludge samples.

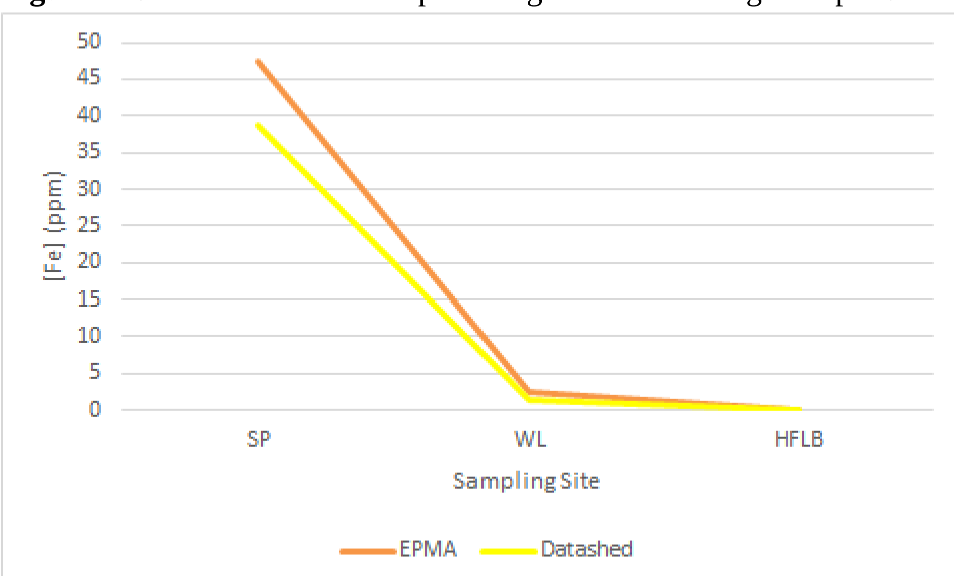

Figure B2. Comparison of the iron concentration in BC16 water samples. Datashed results were obtained from Datashed.org.

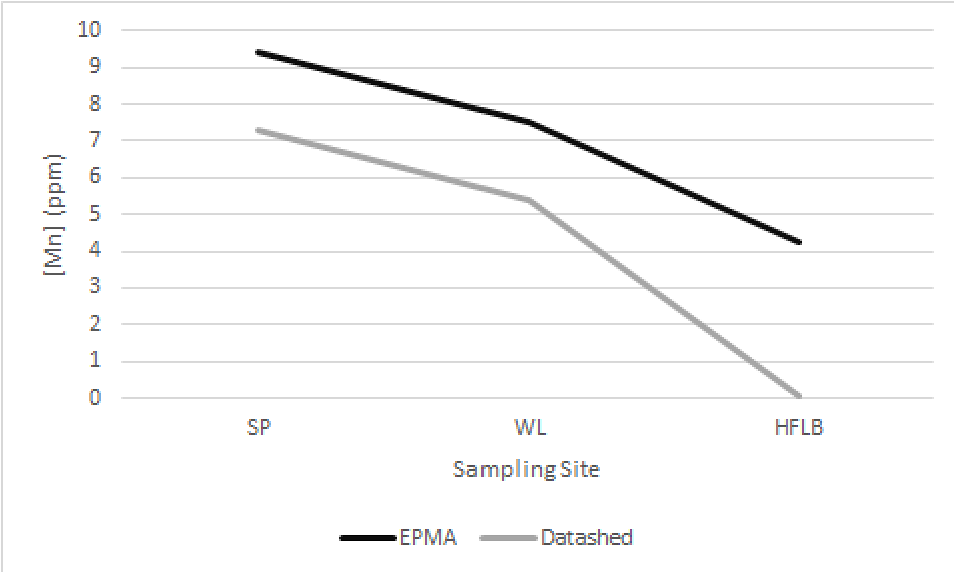

Figure B3. Comparison of the manganese concentration in BC16 water samples. Datashed results were obtained from Datashed.org.

Table B1. Metals present in the BC16 sludge samples from LIBS.

Sampling Site	Fe	Mn	Ca	Si
WL	**X**	**X**	**X**	**X**
HFLB	**X**	**X**	**X**	

Overall, the iron results correlated strongly with Datashed results. From the settling pond (SP) to the wetland (WL), we observe the largest amount of iron precipitation. This makes sense because the settling pond had a high concentration of alkalinity. By the time the water moves through the horizontal flow bed (HFLB), the iron concentration is miniscule meaning the passive treatment site is working effectively. The manganese results also correlated well with the Datashed results, but not as precisely. The trend is similar, but the EPMA concentrations were all higher on average than the Datashed results. From the WL to the HFLB, we observe the largest amount of manganese precipitation. A possible reason could stem from the iron precipitating primarily from the SP to the WL. However, the passive treatment site is still effective at precipitating a considerable amount of manganese.

De Sale Phase I

The results from the ICP-OES analysis provided the concentrations of dissolved metals in all the water and sludge samples. The results from the water analysis are depicted below in Figures B4 and B5. Average concentrations were obtained from previous data points obtained from Datashed at the locations where samples were taken. These averages were then compared to the calculated values from the ICP-OES analysis.

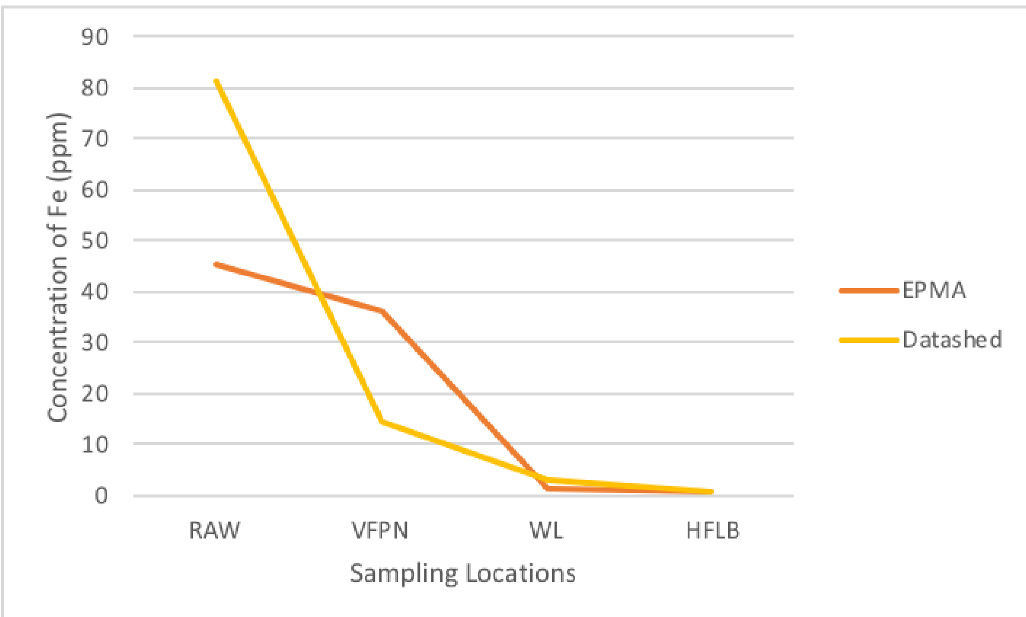

Figure B4. Comparison of iron concentrations in De Sale Phase I samples.

There is some disagreement within the first two iron sampling points. This could potentially be to the weather the day of the sampling trip, since rainwater, and snowmelt diluted the samples. Another possible explanation is that the samples were not properly mixed when being obtained, so at the specific point they were taken from there was a higher or lower concentration of iron present.

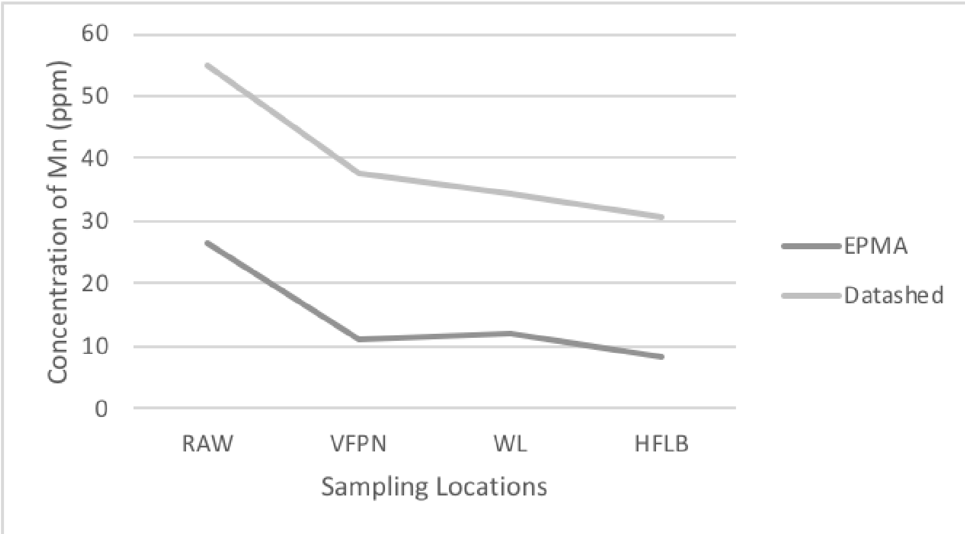

Figure B5. Comparison of manganese concentrations in De Sale Phase I samples.

The manganese concentrations have much better agreement compared to the iron. Rainwater dilution can be likely used to explain the lower concentrations of all of the EPMA samples compared to the Datashed values. Since the rain and snow melt introduces an increased amount of “clean” water to the passive treatment system, this causes the dilution in metal concentrations.

Figure B6 below shows the metal concentration percentages in the three sludge samples obtained from De Sale Phase I. Each sample has a distinct metal that is in the highest percentage. This is due to the fact that different metals prominently precipitate out at different points throughout the passive treatment process. For example, manganese precipitates out the most after the wetland, and iron primarily precipitates out before the vertical flow pond.

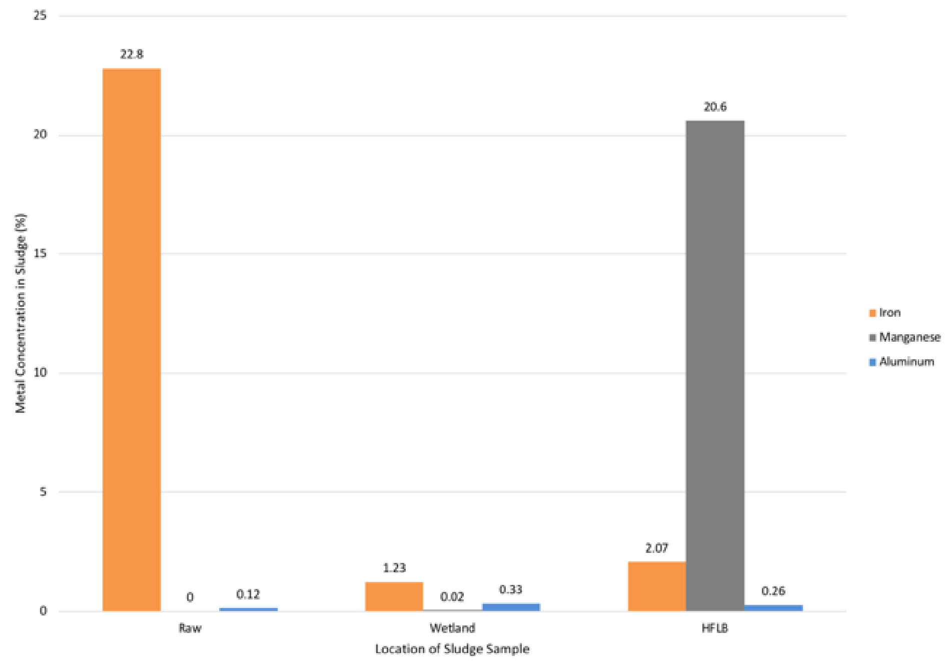

Figure B6. Metal percentages in De Sale Phase I sludge samples

To further investigate the components present in the sludge samples Laser Induced Breakdown Spectroscopy (LIBS). Table B2 details the main metals that each of the three sludge samples contained, with an X representing when specific elements were present.

Table B2. Metals present in De Sale Phase 1 sludge samples.

	Al	Ca	Fe	Mn	Si
Forebay Sludge	**X**	**X**	**X**	**X**	
Wetland Sludge		**X**	**X**	**X**	
HFLB Sludge	**X**	**X**	**X**	**X**	**X**

Overall, laboratory analysis of sludge and water samples obtained from De Sale Phase I passive treatment system provided further insight into the metal concentrations in the samples. Utilizing average data values from previous investigations allowed the current values to be analyzed for accuracy and to assess the function of the passive treatment system. This data can be used to determine whether or not the present metals can provide additional revenue for SRWC in their available concentrations.

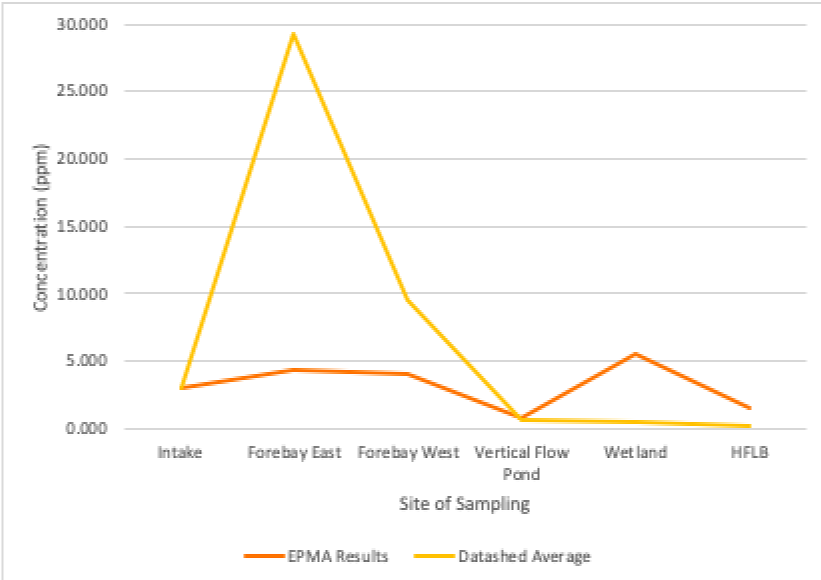

Figure B7. Experimentally found concentrations of iron compared to Datashed.

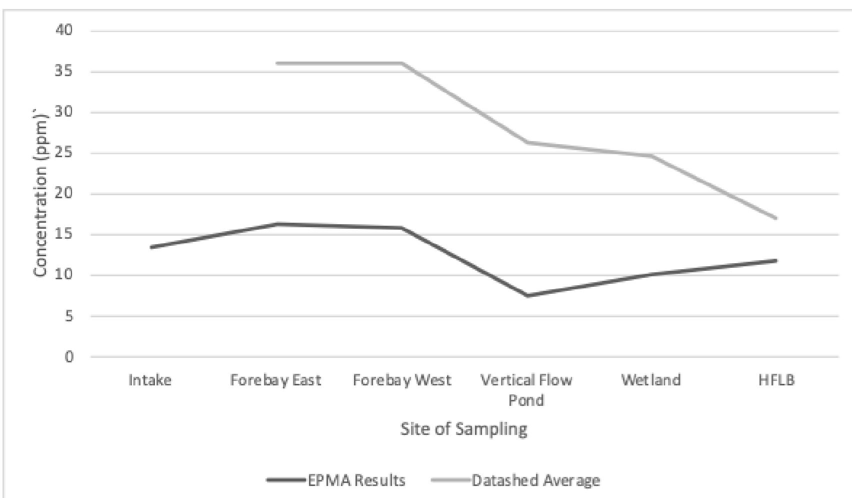

Figure B8. Experimentally found concentrations of manganese compared to Datashed.

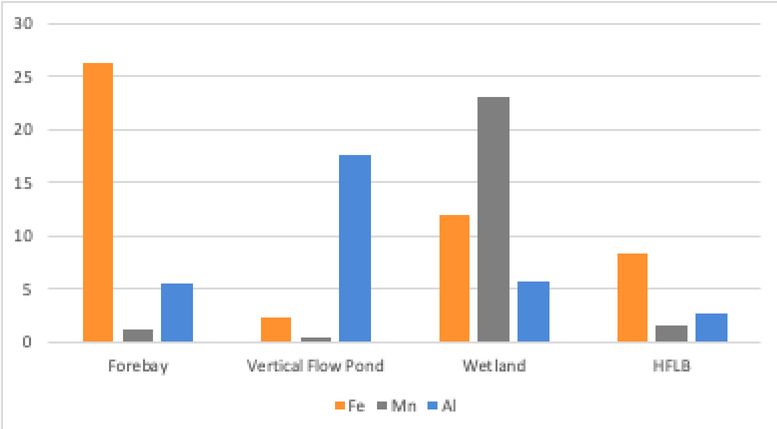

Figure B9. Percentage of elements in sludge samples by De Sale II sites.

Table B3. Concentrations of rare earth elements in sludge samples from De Sale II.

	Y (ppm)	**La (ppm)**	**Sm (ppm)**	**Ce (ppm)**	**Nd (ppm)**
Forebay	57.9	17.8	N/D	N/D	23.1
Vertical Flow Pond	378	48.7	40.5	130	135
Wetland	66.7	40	N/D	68.8	41.7
HFLB	9.9	24.6	N/D	N/D	N/D

Table B4. Elemental composition of each sludge sample from De Sale II by LIBS.

	DS2-Forebay	**DS2-VFP-EW**	**DS2-Wetland**	**DS2-HFBL**
Fe	X	X	X	X
Mn	X	X	X	X
Ca	X	X	X	X
Ni	X	X	X	X
Cr	X	X	X	X
Mg	X	X	X	X
Co		X	X	X

Experimentally found data was compares to an average of the data found in datashed. From Figure B7 and B8, it can be seen that the concentrations of metals experimentally found are not consistent with those found of datashed. This is most likely due to the lack of numerous replicates taken for experimentation and the lack of collection of samples to test over an extended period of time and weather conditions. Overall, it can be seen that there is a decrease of iron and manganese concentrations throughout the passive treatment system, showing that the system is still working.

Further analysis of the sludge showed that there were small, but detectable concentrations of rare earth elements in the sludge. Table B3 shows the concentrations of each rare earth element found in the sludge and where the highest concentrations are along the passive treatment system. This is an important finding since it opens another window for the marketability process due to the fact that REEs are in virtually every piece of technology. Through the analysis of the sludge samples by LIBS, an elemental composition spectrum was received. It is necessary to know that these elements may not be in high concentrations in the sample. Each peak that was observed from the analysis was recorded, no matter how small. From the LIBS test, a wider view of elements that could potentially be extracted can be seen.

McIntire (Top Half)

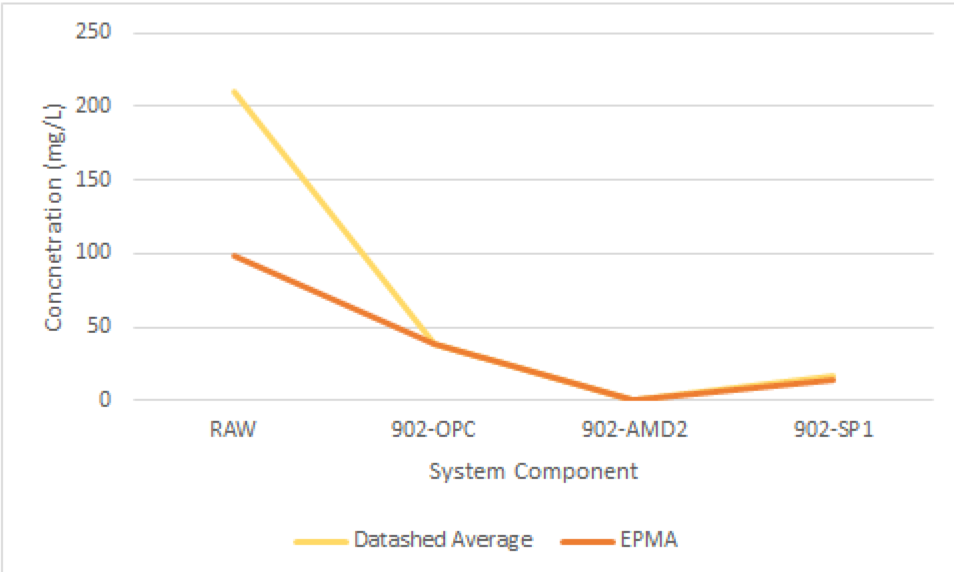

Figure B10. Displays the ICP-OES results of the iron content in the water at McIntire.

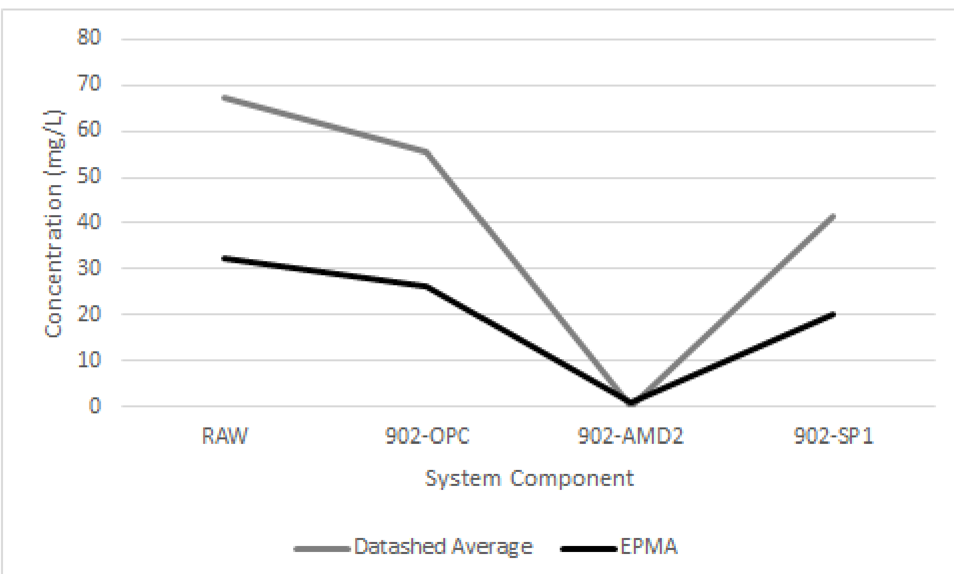

Figure B11. Displays the ICP-OES results of the manganese content in the water at McIntire.

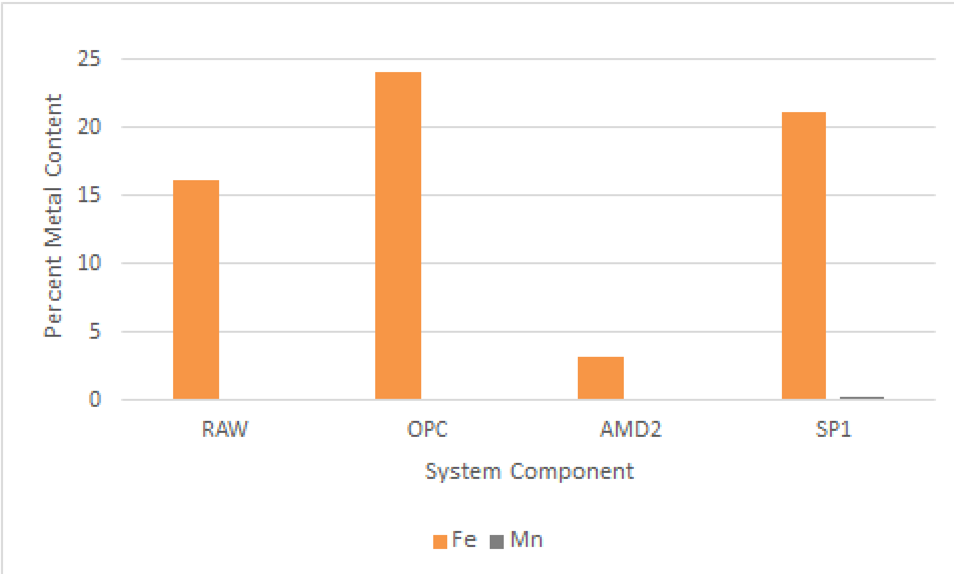

Figure B12. Percent metal content of iron and manganese for each system component.

Table B5. Metal content confirmation from LIBS analysis.

	Al	**Ca**	**Fe**	**Mg**	**Si**
RAW		X	X	X	
902-OPC		X	X	X	
902-AMD2	X	X	X	X	X
902-SP1		X	X	X	

When comparing the iron concentrations with datashed's water quality report, it was found that there was a lower concentration at RAW. The concentrations at 902-OPC, 902-AMD2, and 902-SP1 were all similar to datashed. When comparing the manganese concentrations with datashed's water quality report, we had much lower data points for all site components except 902-AMD2. The sludge samples did not contain a great enough concentration of REE's to consider further sample collection. However, some REE's (yttrium and lanthanum) were found at detectable levels in McIntire in sludge samples.

The water sample results found similar data to that on datashed. This can validate both the team findings and datashed's data. Iron and manganese were the two most prevalent elements in the sludge and water samples. The system components were compared to one another to determine the efficiency of the passive treatment site. While exploring the site, it was found that the data was fluctuating in ways that would mean that the site was not working efficiently. According to the schematic, there are three entry points of raw water entering the site (MC1, MC2, and MC3). These three entries were found throughout the site at varying points thus, causing the data to fluctuate. Towards the end of the site pH and alkalinity increased and the iron level decreased. The site also had a healthy ORP range (300-500mV).

McIntire (Bottom Half)

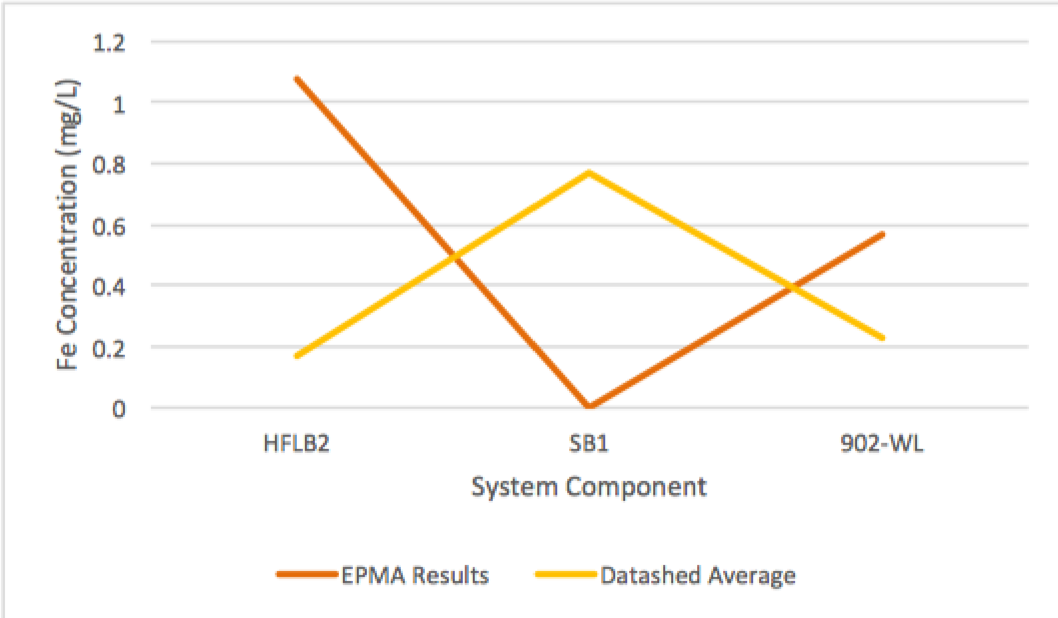

Figure B13. Displays the ICP-OES results of the iron content in the water at McIntire.

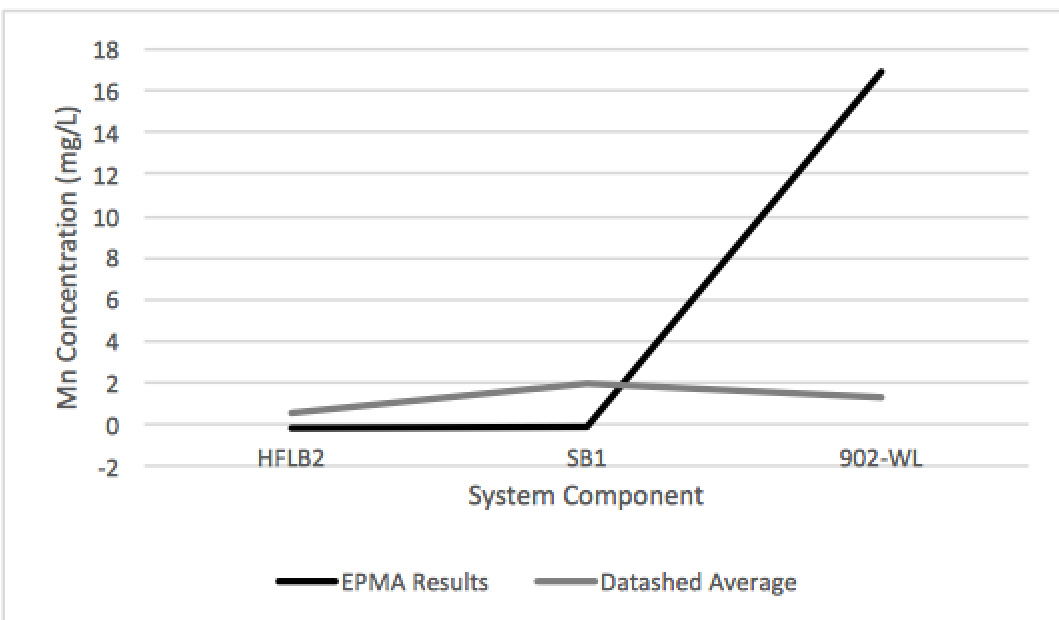

Figure B14. ICP-OES results of the manganese content in the water at McIntire.

Once the analysis performed by the teams was completed, it was then compared to the information on Datashed. Shown in the graphs above are the ICP-OES analysis results of the water content at the McIntire site. The data is comparing the group results to the information given on Datashed. The iron content graph, Figure B13 shown above, is not very consistent in results. The iron content analyzed by the group was found to be significantly higher in HFLB2 than on Datashed and significantly lower in SB1 than on Datashed. For the manganese results shown in Figure B14 above, the results are fairly consistent with each other, excluding the 902-WL area. The group's analysis produced a much higher manganese content than the information given on Datashed. The rare earth elements were not included due to their very low concentrations in the water.

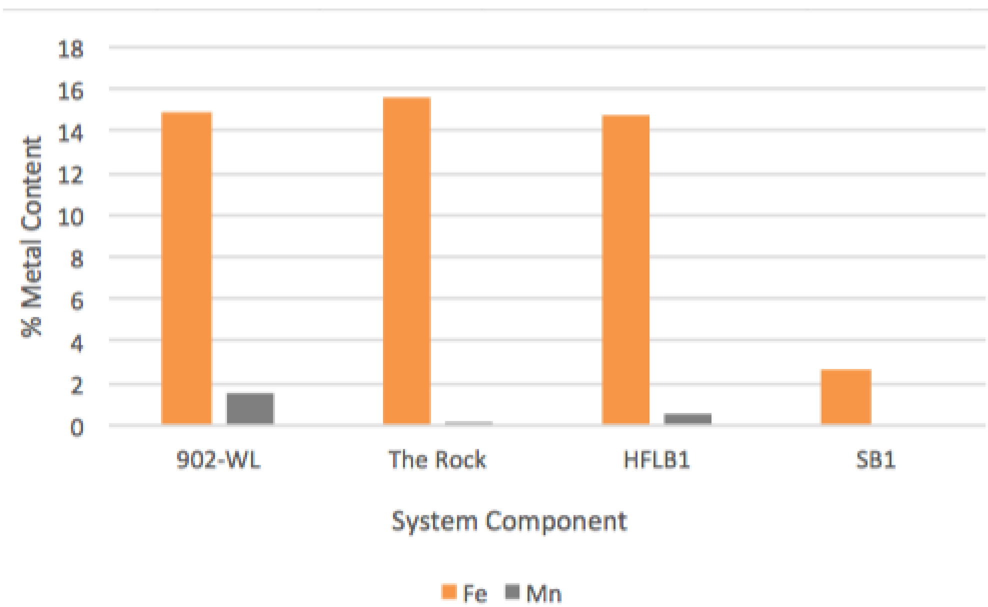

Figure B15. ICP-OES results of the metal content in sludge samples.

In Figure B15, the iron content of the sludge is high in 902-WL, The Rock, and HFLB1, and low at SB1. The manganese content of the sludge was low in all four of the components tested. Table B6 below confirms the findings of metal content in the sludge samples. While these results show there may have been more metals in the sludge than were tested, none of the results confirmed a high concentration of these other metals. The only peaks that were very high and very prominent for the LIBS analysis were from the iron and the manganese.

Table B6. Metal content confirmation from LIBS analysis.

	Al	**Ca**	**Co**	**Cr**	**Fe**	**Mg**	**Mn**	**Ni**	**Si**	**Zn**
902-WL		X	X		X	X	X	X	X	
Rock	X	X			X		X		X	
HFLB 2		X			X				X	
SB1	X	X	X	X	X	X	X		X	X

These results show that the system is working in reducing metal content in the water. Any data inconsistencies could be due to machine error, calibration standard error, or error in preparing the samples. There is also the phenomena of weather occuring that would affect the tested parameters of the system. If given the opportunity to go back, it would be in the best interest of the team to get more water samples to analyze. This would allow the group to confirm our findings compared to those Datashed, and if there was experimental or natural error.