EDNS151 Section 1

Group J3 - Professor PhD Aubrey Wigner - Fall 2022

Colorado School of Mines

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1.3 Introduction

1.3.1. Background

The team's task was to find a problem associated with waste and waste management. As a group, two main ideas were explored, the recycling of medical needles and the reduction of waste from mining. The group decided to focus on the hazardous waste of mining and its relation to water systems.

Abandoned mines are common throughout Colorado and although they were once necessary, they currently pose a potential health hazard. A study by the Colorado Geological Survey found that there are over 23,000 abandoned mines in Colorado alone. These mines contribute to sedimentation contamination, water pollution, air pollution, and various physical hazards. Furthermore, the Colorado Department of Health estimates that 1,800 miles of streams are impacted due to pollution from abandoned mines [1]. Although mining was necessary in order to gain many useful and precious metals, there should be a solution to alleviate some of this water pollution that it caused.

1.3.2. Team Problem Definition

After some research and brainstorming, the team defined the problem as follows: "How might we help to reduce hazardous waste in water systems caused by abandoned mines?"

1.3.3. Context

The ambitious goal of helping reduce the amount of hazardous waste in the Colorado water systems would be no easy feat. Acid Mine Drainage (AMD) is the #1 water contamination resulting in the loss of almost 27 billion gallons of clean water each year [2]. A first step that was taken was outreach towards potential stakeholders to fully understand the problem.

A helpful resource was the Colorado Geological Survey who provided data of the largest AMD contributing mines. An even larger stakeholder group involves those impacted by the acid runoff; these include ranch owners, neighboring town residents, real estate investors, and landowners that lost property value. By using geological maps that display acid runoff, gathering data provided by the government agencies, and by interacting with those directly impacted, the team gathered enough data and information to start providing solutions that approach the issues plaguing a large number of mines and people.

1.3.4. Existing Solutions

The dangers of mines and the waste that is produced are not looked over. While there aren't a large variety of solutions to minimize damages already caused, there are common solutions used to prevent potential damages abandoned mines cause. One method is known as Mine Reclamation and the process starts by controlling erosion, stabilizing slopes, and repairing the effect mining had on wildlife by topping it with soil and plant life. However, while Mine Reclamation has been successful in many accounts, turning land heavily impacted by mining back to what it used to be is not a perfect solution. Sometimes in an attempt to fix the problem it only worsens leading to poor vegetation coverage, worse erosion, runoff, and a poor soil structure.

1.3.5. Ancillary Complications

There are many issues that arise when it comes to actually executing the task of cleaning up an abandoned mine. While the worst mines receive the most attention, there are still thousands of mines around the state of Colorado that contribute to environmental detriment due to the hazardous materials they secrete [3]. Bureaucratic red tape surrounds the issues, with bills such as the Clean Water Act which limits the amount of work that can be done by organizations and nonprofits.

The same bill also makes it for those who would want to execute these cleanups would have to take responsibility for an entire water system, which can lead to costs overrunning most groups. Specifically, there is a long-standing concept that any group wanting to act on abandoned mine pollution may be held liable for problems that are much larger in scope than that group's original vision [4]. This leads to a massive discouragement for these groups who seek to chip away at the problem. A simple reduction of pollution from a water point source could engage laws to make an organization responsible for the entire cleanup of a mine and surrounding systems - a task that can cost upwards of $100 million dollars.

1.4 Stakeholder Outreach/Problem Validation

David Villalobos	Marco Salgado	Andrew Nester	Dawson Mueller	Fergus Huggins
Douglas County Water - Treatment/ Testing Facility Interview (40-mi)(+5pts) On-site Participation (Microchip Company) (80-mi) (+5pts) Documentary minutes (>30 mins)(+2pts) **Total Points: +12**	Phone/Zoom Interview x3 (+6 pts) Scholarly/Authoritative Articles x3 (+3 pts) **Total Points: +9**	On campus SME videos x2 (+4 pts) Documentary Video (+2 pts) Scholarly article x2 (+2 pts) **Total Point: +8**	Scholarly Article x4 (+4pts) Documentary x2 (+4pts) **Total Points: +8**	On campus SME talks x2: (+4 pts) Scholarly article: (+1 pts) Videos x2: (+1 pts) Phone interview: (+2 pts) Direct participation (There for an accident): (+3 pts) **Total Points:+11**

1.5 Group References

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1.6.1 Individual Section

Author: David Villalobos

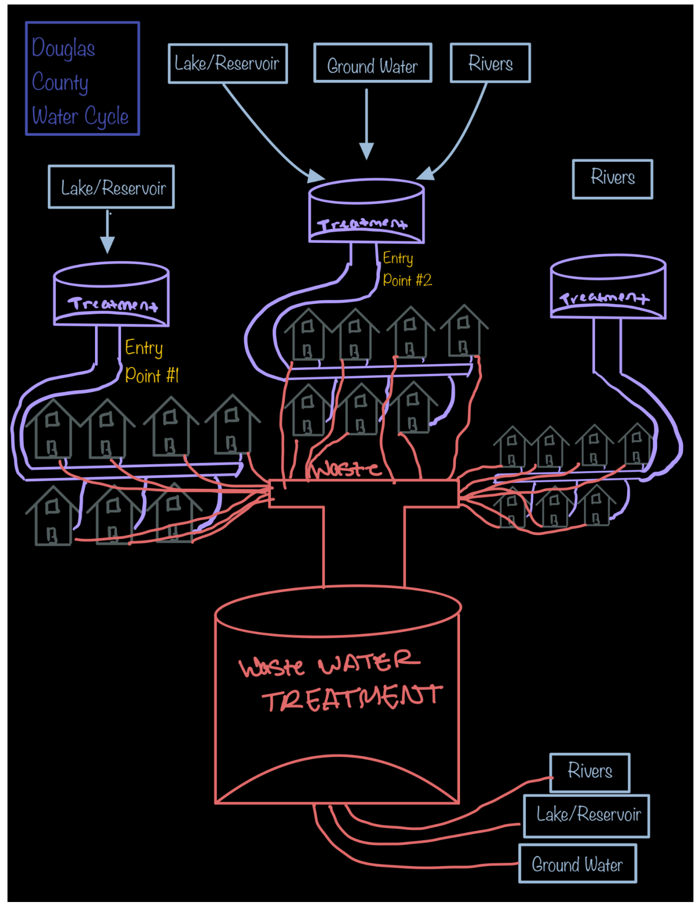
1.6.1.1. Summary of Prospective Gathering

For my first portion of stakeholder engagement, I needed to establish a good foundation on the process of mining to ensure I and all my teammates were well informed concerning the entire mining process. For a deeper understanding of the actual roots that cause the most mining contamination, I began by viewing a few long documentaries that describe the entire mining process from start to finish and simply taking notes. From there on I visited several government websites that provided information on the largest Colorado abandoned mines that contribute the most contamination. My objective was to learn and identify any major flaws with the efficiency of extracting rare earth metals from rocks in an attempt to think of possible solutions along the way. I realized that most of these mines are abandoned because of their toxicity and the danger to the public, unfortunately this results in a complicated process to reach those in charge of the mine simply to gather more data. I was able to locate an Independent mining consultant in Boulder Colorado named Dr. Ann Maest, who has a PhD in Geophysics from Princeton University. Dr. Maest provided so much insight into the #1 mining pollution: acid drainage. I learned that mining pollution takes several years/decades to show effects, which means that there's a big opportunity window to implement a solution. The problem however is once the mining drainage begins, it's extremely difficult to stop because it's known as an auto catalytic reaction which is an endless loop of sulfuric acid reacting with Thiobacillus Ferrooxidans and iron created from bacteria. A really impactful resultant is a change in water pH levels, turning the water really acidic and unfortunately exterminating all biotic wildlife. Other shocking statistics were introduced such as 90% of mining near healthy water actually exceeds the “safe” contamination levels and not a lot is legally done to enforce this. As we’re currently experiencing the effects of mines 4,000+ years ago, the team must acknowledge the potential threats to future humanity and make changes as soon as possible. **Please view the notes attached at the bottom of this section for Dr. Maest's in-depth notes explanation!**

For my second portion of stakeholder engagement I wanted to see if the impacts of acid mine drainage with neighboring cities was large enough to urge the development of a solution. I got an interview with the Douglas County Water Treatment/Testing facilities to view the process behind what is done to ensure a safe water supply for an entire county. What I learned is that this county water company complies with the EPA’s water regulations and has their own secondary water standards that ensure the odor, color and taste of the water is consistent. While this second level of testing isn’t required, it’s a measure of consistency. A growing issue however is lead contamination including the entire Denver Metro area and this has prompted the creation of a Lead Reduction Program. While this lead contamination can’t all be traced back to mining, most of these heavy metals in water are a direct resultant. This growing heavy metal contamination is creating an increasing urgency to develop a solution because once the acid mine drainage begins, it will be extremely hard to stop with the autocatalytic reaction. The last major contamination urgency includes PFC known as perfluorinated compounds. These are usually used in the production of goods, especially aluminum foil. A Mines study done in 2017 discovered that the removal/filtration of fluorinated chemicals from water is extremely difficult and the numbers are consistently growing [1]. Douglas County water provided this chart of water testing entry ports which test levels of PFA compounds in system entry water [2]. As it was noted the levels as of right now are low but more and more is being detected in the major water entry ways. Fortunately Mines has begun taking action and a team is working on a system that removes these chemicals from a Colorado stream[3]. The image to the right is a diagram which illustrates the Douglas County water system cycle and potential chemical entry points.

(All)

Water system name	Sample site	PFAS (ppt) PFOS	PFOA	PFNA	PFHxS	PFBS	MeFOSAA	EtFOSAA	ADONA	GenX	PFDA	PFDoA	PFHpA	PFHxA	PFTeA	PFTriA	PFUnA
	Entry point 2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Entry point 3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Entry point 4	6.2	7.1	ND	7.2	8.6	ND	ND	ND	ND	ND	ND	2.5	7.7	ND	ND	ND
	Entry point 5	4.6	4.6	ND	5.2	6.8	ND	ND	ND	ND	ND	ND	1.1	3.1	ND	ND	ND
	Entry point 6	6.2	6.0	ND	4.0	7.2	ND	ND	ND	ND	ND	ND	2.7	6.5	ND	ND	ND
	Entry point 7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND



For my third portion of stakeholder engagement I visited Microchip which is a company in Colorado Springs that produces computer chips. Clean water is one of the most important factors when creating computer chips because any impurity or metal in the water can ruin an entire set of chips which results in extremely expensive failures. The engineers walked the team through the entire process of the creation of a chip which requires extreme cleanliness of all materials including water. Large 500 gallon containers of extremely dangerous chemicals such as sulfuric acid, and muriatic acid are used for the creation of the chips and water treatment. Although no photographs were permitted, the best way I can explain it is as a massive white room full of 500 gallon containers of some of the most reactive chemicals. A few days prior to my visit there had been a large sulfuric acid spill and there was still acid eating away at the metal grates. The most important detail that I took away from this visit is that the water here in Colorado isn’t rated very clean for the development of microchips. The lack of clean water means that the development must be outsourced to another country with cleaner rated water to reduce the microchip failure percentage. The Colorado water system’s minor contamination is starting to become a large issue for development corporations that need pure elements for their development; this usually results in these companies outsourcing their developments to other countries with cleaner water. Microchip still produces small batches of chips in Colorado Springs but these are just the prototypes that will be sent to other countries for the mass production. There’s about a 15% chip development failure here in Colorado but when outsourced to other countries, the failure rate can drop down to about 5% saving millions of dollars.

1.6.1.2. Remaining Unknowns

Unfortunately with the limited data available to the public, it is difficult to distinguish between correlation and causation. The team cannot be assertive that the water contamination across Colorado is directly caused by mine drainage though it might be a large contribution factor. Seeing the increasing gravity of the issues however, the team can assume that most of this heavy metal water contamination is due to abandoned mines and their drainage while more data is released by the Colorado government.

Gold Mine Effects on Water

Dr. Ann Maest

- Independent consultant in Boulder Colorado
- PhD in geophysics from Princeton University
- 25+ years working as a geo-chemist and researcher
- Worked with state, federal agencies and environmental groups.
- Chief scientist for E-tech international which focuses on analyzing potential harm with mining in specific regions.
- Ann's role is to analyze the results of tests done on ores and the waste that comes from the ground to view contamination levels.

Acid Mine Drainage

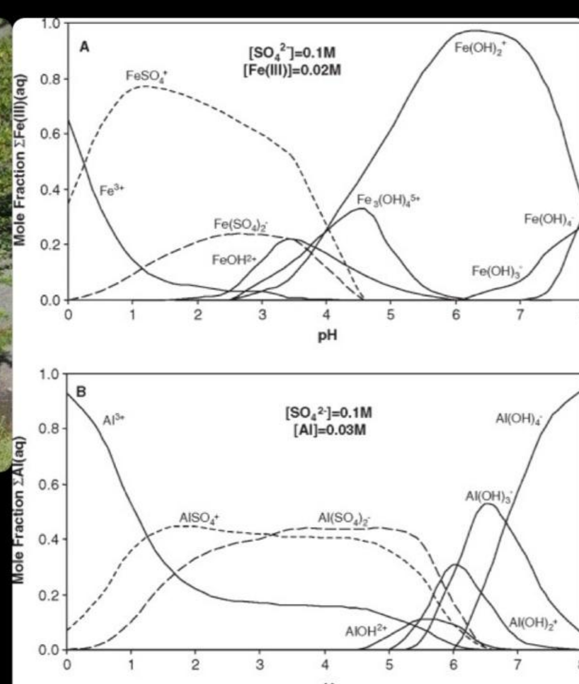
- #1 environmental water quality problem
- In mining there's very large levels of pyrite and when exposed to oxygen releases sulfuric acid.
- Other minerals such as arsenopyrite contains arsenic so when it weathers, these materials release it into the environment.
- Water streams appear red when iron gets into it then mixes with other clean streams causing a pH reaction.
- Once acid mine drainage begins, its really difficult to stop because it's known as an auto catalytic reaction. There's mines 4000+ years old still releasing dangerous chemicals into our streams.
- This is an endless loop in which bacteria called Thiobacillus ferrooxidents oxidize the iron which allow with the sulfuric acid to react once again to restart the reaction causing an endless loop.
- There's lots of abandoned mines in Colorado, yet there's no money set aside to clean them up.
- Short Process: Rock is mashed up, mixed with cyanide and mercery, the gold is extracted, and the rest is contaminated waste. Cyanide, mercery and arsenic caused all the damaged in waterways.
- Consider using calcite which functions as a base to neutralize the pH levels. There's natural occurring minerals that function as a base to neutralize acidity and these help slow acid drainage but there's usually more pyrite than base so we must find a solution. It can take years for the base to stop reacting and the pyrite auto catalytic reactions take over.

- To test acid drainage, companies will drill out rock, put it in plastic tubes, and repeatedly pour water to test the water sample results. It'll take years for the pH to drop but once it begins it takes off exponentially not giving time for intervention.
- Arsenic appears under any pH level so the auto catalyst reaction doesn't even need to take place for dangerous arsenic levels.

Water Threats

- Acid Mine Drainage
- Dangerous chemical release: Arsenic, Antimony, Mercury, Cyanide, Sulfuric Acid, ect...
- Blast mining releases nitrates and ammonia which increase nutrients to unhealthy levels
- Quality of water for drinking and wildlife.
- Extremely hard to stop the auto catalytic reaction so it's best stopped before the reaction begins.
- Studies show that 75% of environmental impact studies underestimate the impacts done to water quality(Kuipers and Maest, 2006)
- 90% of mining near healthy water actually exceeded the "safe" contamination levels.
- 64% of the Mines exceeded mitigation measures which are
- in place to ensure standards/regulations usually government standards.

Source: https://phys.org/news/2020-08-acid-drainage-treatment-valuable-critical.html



Source: https://www.sciencedirect.com/science/article/pii/B9780444527073500094

1.6.1.3. Research Summary

Through this research I have concluded that abandoned mine contamination and acid leakage is a very large issue here in Colorado resulting in companies having to move their businesses elsewhere as seen with Microchip in Colorado Springs. Local government and water providing agencies are also beginning to notice higher levels of heavy metals and acidity in water. Though a very good indication of mine spillage, the team can not completely be assertive that this is a cause without proper data backing it up. The lack of data linking mine spillage and water contamination in neighboring cities in the foothills is concerning but there’s very few factors that could lead to this type of contamination over time. Thus, given the information I have collected, it would be very beneficial and low opportunity cost to pursue the objective of designing a solution to assist with Colorado water contamination by designing a mine cleanup system. The current damage is quite minimal but once the auto-catalyst mine reaction begins taking place in nearby mines, water contamination levels will increase exponentially leading to lower water pH levels resulting in the death of Colorado wildlife. These increased contamination levels could also lead to human health concerns in the near future; right now is the perfect time to take action before the real issues begin to occur. It will be difficult to reach out to mine owners and take care of abandoned mines so the team must design a good system that the Colorado government is willing to adopt.

1.6.1.4. Individual Bibliography

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1.6.2 Individual Section

Author: Marco Salgado

1.6.2.1 Summary of Prospective Gathering

My first portion of stakeholder engagement was to connect with Mr. Jeff Graves, the director of the Office of Active and Inactive Mines for the State of Colorado [1]. As I only contacted Mr. Graves Monday (9/12), I have not had an interview with him, however, some questions that I would like to ask him would be regarding his time working during a 2017 study that observed water quality in and around abandoned mines in Colorado. Specifically, I would like to ask him how exactly water quality was measured, which of the mines that were visited specifically caught professional interest, and about any personal notes regarding concerns raised while conducting this research. I would also like to inquire about what minerals raise the most interest when discussing toxic mine drainage as well as what are major obstacles that stand in the way when trying to carry out clean up for these hazardous materials.

My second portion of stakeholder engagement involved contacting Mr. Andrew Ross, the Environmental Data Unit Manager of the same 2017 study that Mr. Graves participated in [2]. Similar to Mr. Graves, I contacted Mr. Ross on Monday (9/12) and have not yet conducted my interview. However, as Mr. Ross is an expert in water quality control, I would like to ask questions regarding safety levels of certain minerals in water, the environmental detriments that these materials may have on the ecosystem as well as human health, and how difficult it may be to clean up contaminated water systems. Mr. Ross works with the Colorado Department of Health and Environment, so I also hope to find insight into possible legal roadblocks that may result from attempts at carrying out any act when regarding abandoned mines, as they have no legal owner, may be on private property, and/or may be part of public lands.

My third portion of stakeholder engagement involves meeting with Lee Fronapfel, the manager of the Edgar Experimental Mine (EEM) [3]. For a little background, the EEM is a mine that is styled as an 1870s era mine and is used for education of current Mines students and as an experience for the public to learn more about the history of the “Rush to the Rockies” era. As the interview with Mr. Fronapfel has not been conducted, questions that I have are to learn about the EEM’s history and how this mine from the late 1800s has been retrofitted to meet modern-day standards when it comes to hazardous pollutants. The purpose of this is to learn how techniques and concepts either applied or created at the EEM could be used to reduce pollutants that are originating from any of the 23,000 abandoned mines that Colorado water systems may suffer from.

My fourth stakeholder engagement involved reading a report over the Gold King Mine and related Upper Animas Watershed and Upper Cement Creek [4]. Released by the Environmental Protection Agency, this report gave insight on how exactly heavy metals from mines can enter water systems. It gave a brief history into abandoned mines, prior incident releases, and a summary of the chemical reactions that cause hazardous mine drainage. The insight provided by this report clarified how the environment can be affected by drainage and how exactly these processes occur. This report established an essential foundation of knowledge that will help to guide more specialized problem definition and eventual solution crafting.

For my fifth stakeholder engagement, I read an article over the effort made to reduce water pollution caused by mines in Colorado [5]. The article showcased many techniques and attempts that those concerned with environmental health have exercised. It also described the scope of the problem within the public sector, listing many agencies and groups that have experience dealing with this problem. The article also showed that these public sector organizations offer many sources of information, from an inventory of abandoned mines containing detailed descriptions to studies done over the quality of water after efforts were made to reduce the amount of pollutants in water systems.

My sixth engagement came in the form of an article over the unusual prospect to use beavers to help mitigate the negative effects of abandoned mine releases [6]. The article expanded on the topic by suggesting how ponds created by beaver dams could help to slow the flow of discolored and mineral-laden waters. Of course, there would be downsides to this solution, however, the main purpose of this engagement was to think outside the box. As natural rivers would flow into beaver dams, the pond would act as a buffer that would slow down the flow of these hazardous materials allowing for emergency services to have more breathing room in conducting the cleanup of the spill.

1.6.2.2. Remaining Unknowns

There are plenty of remaining unknowns, specifically concerning the interviews as they have not been conducted. After reading the articles, some other unknowns that arise concern the technical specifics of each one. With the Gold King Mine report, it goes into detail about the history of mine spills similar to Gold King and talks about composition of hazardous materials, however fails to detail the efforts made to clean up. Likewise, the Reveal article fails to mention specific portions of legislation that limit cleanup efforts, opting to just list broad bills themselves. With the beaver article, it does not mention any environmental dangers that could occur when using animals to try to clean hazardous materials. These are some of many unknowns that are acknowledged while researching more into the broad topic of abandoned mine drainage.

1.6.2.3. Research Summary

Through the interviews, I plan to learn about the base of this problem. I intend on learning inside knowledge and gathering first-hand insight into issues that may arise when trying to clean water waste caused by mines. The people that are to be interviewed are either people who have specialized in mines or who have professionally contributed to solving problems that are associated with the team problem definition. Through the article I have read, I have created a foundation of knowledge to guide any potential solutions that the team as a group may come up with. The articles expanded thinking and informed the team on the scope of the issues that are at hand.

1.6.2.4. Individual Bibliography

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1.6.3 Individual Section

Author: Andrew Nester

1.6.3.1. Summary of Prospective Gathering

The first portion of stakeholder engagement began with a video by subject matter experts Dr. Lauren Poole and Dr. Tim Sweitzer [1]. From Dr. Poole the team learned that 75% of all waste can be recycled but only around 30% is actually recycled. The team also learned that there are 2 types of landfills, there are clay lined landfills and plastic lined landfills, these materials are used to prevent the seepage of waste into the underlying soil. Any type of recycling that becomes contaminated by food or trash is no longer recyclable and has to be taken to a landfill. There are 3 types of universal hazardous waste, dry cell batteries which are made out of lithium, wet cell batteries which are made out of lead and lightbulbs. The last thing that was learned from Dr. Poole is to reduce waste first, then start to take steps towards better recycling practices. Dr. Sweitzer specializes in pollution and hazardous waste. The main types of air pollution include lead, nitrogen dioxide, sulfur dioxide, and volatile organic compounds. These affect the ozone layer which in turn can irritate the lungs and can lead to shortness of breath. The EPA has classified Denver as over the EPA air pollution limits which can cause some of the aforementioned health impacts. The goal for Denver is to get below 25 tons of toxic emissions per year. There are 2 types of water pollution, point source which comes from pipes and nonpoint source which is stormwater. The Colorado School of Mines needs permits in order to operate their mine sites, construction sites, labs, and workshops. These permits require quarterly water samples in order to make sure that the school run sites are not dumping toxic waste into the water systems. Mines also need permits in order to store large amounts of diesel, gas, and oil. This is due to the large amounts being stored which is estimated to be about 37,000 gallons of all of these fuels combined. These permits must include a spill prevention plan. Lastly hazardous waste must be sealed and stored properly, and since Mines also stores chemicals and hazardous waste they pay around 125,000 a year in order to make sure the labs are up to date, to pay for chemicals and big spill prevention plans.

The second portion of stakeholder engagement is a subject matter expert video conducted by Jaime Styer and Sofia Schlezak[2]. Ms. Styer is doing a project in Columbia regarding the recycling of construction waste, specifically concrete. There are 4 steps in the process of recycling concrete: 1. Sort the concrete, 2. Crush the concrete, 3. Screen contaminating materials, 4. Separate aggregate by sizes. Since there have been little to no advances in construction waste in many countries this is a big issue, with waste piled up randomly. Lastly Ms. Styer went over the Waste Management Hierarchy. This includes preventing waste, reducing waste, reusing materials, recycling waste, recovering waste, and disposing waste with preventing being the most important and disposing waste being the least important. Ms. Schlezak is doing an electronic waste project in Argentina. There has been an increase in electronic waste in countries like Argentina, with many of the solutions being to burn the waste in the street. There are many informal electronic waste workers in Argentina who aren't recognized or get funding to clean up. When cleaning up all the different materials are sorted into different sections, this can be dangerous as it exposes the workers to potentially toxic materials. Ms. Schlezak also went over the Hierarchy of Controls which includes: 1. Elimination, 2. Substitution, 3. Engineering controls, 4. Administration controls, 5. Personal protective equipment, with elimination being the most effective and personal protective equipment being the least effective.

The third portion of stakeholder engagement involved watching a subject matter expert video from Dr. Ron Cohen who was a former professor at Colorado School of Mines[3]. The Gold King Spill spilled 3 million gallons of contaminated water into the Animus River. This amount of water is spilled into waterways all over Colorado every 2 days. These spills don't last long as the waste spreads out across the river, these spills will always happen. In order to cause acid mine drainage water, and oxidizer and a pyrite is needed, microbes are also involved as they enhance the speed of the reaction greatly. There are 2 ways to treat acid mine drainage, active treatment and passive treatment. Active treatment involves the mechanical addition of alkaline chemicals to raise the pH, this is proven to work and is well liked in the regulatory community, the only downsides are the high operation costs due to the chemicals and equipment, and how long the process takes. Passive treatment involves naturally occuring chemical processes and biological reactions in a controlled reactor. This process does not need much energy and has minimal costs but it isn't liked by the regulatory community and while it shows initial success, the process fails after 2 years or it doesn't lower the water acidity to the regulations. It is very difficult to prevent acid mine drainage as air and water always find a way in. Some solutions have come about but have not been very effective, plugs were placed in mines but the water backed up in the mines and found another way out, foam was used to line the walls but it was ineffective, manure was also lined on walls but it is only a temporary solution, another solution was to have a treatment plant outside the mine but that isn't feasible due to the location of many of these mines, and lastly there is the idea to treat the water before it gets into a main system. The biggest issue is for the treatment is money, the taxpayers are paying for the clean up and there is no one to be held liable for the thousands of old abandoned mines.

The fourth section of stakeholder engagement involved reading a scholarly article about the topic of heavy metal pollution from gold mines[4]. Tailings are a main source of pollution from gold mines and they are a mixture of finely ground rock and water that was used. Water infiltrates the mine and gets contaminated by tailings which then flows into streams and rivers contaminating the water. Water also can infiltrate the lower part of the mine and slowly seeps out of the rock into the water table, contaminating the underground aquifers. Chemicals used to process gold also cause much pollution with large amounts of mercury being discharged into tailings, air, soil, and water. Gold mining disrupts the heavy metal amounts in surrounding soil and leads to higher levels of heavy metals than the recommended amounts. These heavy metals severely affect the metabolism, growth, and morphology of the bacteria in soils. Some of the bacterias are unaffected but many showed signs of cell morphing, genetic determinants, biotransformation, biosorption, or bioaccumulation. Many of the bacteria were negatively affected due to the metals but some were unaffected and others grew somewhat stronger. Scientists are currently trying to research more into these stronger bacterias as potential solutions to solving some of the heavy metal pollution from gold mines.

The fifth section of stakeholder engagement is a scholarly article which involved a full study surrounding the environmental impact from tailings in South Africa[5]. Poor management of tailing dams lead to acid mine drainage. Inadequate vegetation and acid mine drainage lead to excessive erosion and major environmental issues. Acid mine drainage itself is a natural process but it is enhanced by mining and can produce large amounts of seepage. All mining sites used in the study had some level of acid mine drainage. Covers are needed around tailing sights in order to prevent wind and other erosion to stop seepage. There are 2 ways to treat contaminants, treatment technologies which remove the soil and process it, and on site management which is the isolation of the contaminants and reduction of bio-availability. The study concluded many things. Groundwater beneath, close to tailings on sites were contaminated, 3 sites were moderate-highly contaminated, 3 sites were highly contaminated, and 1 site was excessively contaminated. Soil conditions showed contamination in the groundwater and after leaching tests, reclaimed sites still showed the release of significant salt contents for more than 10 years. Lastly, clean up costs are expected to be high, with large amounts of fertilizer and lime needed, and even after clean up soil and groundwater could remain contaminated for an extended period of time.

1.6.3.2. Remaining Unknowns

There are countless remaining unknowns for this problem. More research needs to be done to see some of the chemical processes that are occurring with current solutions for acid mine drainage. More research needs to be done into existing solutions such as manure, foam, and mine plugs, we need to see exactly where these went wrong and why that happened. The team also needs to research where the best possible area in the acid mine drainage process is most likely the best to implement a solution. Another unknown is which type of gold mine the team should be focusing on, as all mines are different and provide a new set of problems and possible solutions.

1.6.3.3. Research Summary

Throughout the research the team has discovered how acid mine drainage is formed as well as some of the long term and short term effects that it could have on the environment. The group also learned about potential solutions that are somewhat working but aren't working effectively enough to hinder the problem to an acceptable level. The team can conclude that there are many factors in play and many solutions that are being implemented but all of these solutions present different problems. One of the biggest problems with current solutions is finding the funding to implement them effectively over thousands of gold mines. The final conclusion is that the team needs to find a cost efficient solution that is desperately needed in order to fight acid mine drainage in gold mines across Colorado.

1.6.3.4. Individual Bibliography

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1.6.4 Individual Section

Author: Dawson Mueller

1.6.4.1. Summary of Prospective Gathering

At first I was curious what kind of solutions already existed with the restoration of mining damages. Looking into it I found an article written by V. Sheoran , A.S. Sheoran, and P. Poonia, both V. Sheoran and P. Poonia works in the Department of Zoology at the Jai Narain Vyas University while A.S. Sheoran works in the Departments of Mining Engineering [1]. There article was about the restoration process known as Mine Restoration. The group went over this process in the Existing solutions but it's important to bring up how plants help in the waste cleanup of mines. The soil that is placed in or around these mines are most likely going to suck up the already established heavy metal water waste collecting in the mines. To combat this, metal tolerant plants are placed in the soil instead of any regular plant. This helps slightly in the waste clean up since these plants suck up the metal heavy water reducing the amount of waste at the end of the day. Of course mine reclamation is a tricky process and because of its slow process, knowing if it's done correctly or not won't become apparent until very late. So if the reclamation is done incorrectly it could mean botched vegetation job and ruin the environment more.

While doing my research on mine reclamation I was curious about the problems associated with the procedure. What I found was an official journal by the European Federation of Chemical Engineers[2] about Acid Mine Drainage. Acid Mine Drainage or (AMD) is a serious issue where water containing high amounts of metals is finding its way out of mines and into the ecosystem. The damages this drainage causes can come in many forms and are all very important when understanding the issue. These factors are Chemical, Physical, Biological, and Ecological. Chemical damages include increased acidity into the environment and increase in metal concentrate. Ecological damages are the eliminations of sensitive species, loss of food sources, and habitat modifications. Physical damages are increases in stream velocities and absorption of metals into soil. Finally biological damages include Respiratory damage, chronic toxicity, and Acid-base balance failure in organisms. All of these damages are linked to the high amounts of metals coming out of these mines. Another source I've found to back up the high levels of Acidity is a documentary produced by Point Park University called Downstream [3]. In the documentary the group meet Kathleen Lavelle who works for Trout Unlimited, a non-profit organization with the goal of conserving these freshwater rivers and lakes. She makes several statements in the documentary about how Pennsylvania abandoned coal mines are seeping waste, most likely AMD, into the water streams and disrupting the local trout who are very sensitive to environmental changes.

If the solution is to be sold to anyone who owns an abandoned mine or a company that is looking to clean up abandoned mines its a good idea to understand who owns these mines and is actively operating in them. In an Article on Abandoned Mine Land by the EPA[4] right at the bottom of the page it includes an Act known as the General Mining Law of 1872 Act. While most if not all abandoned mines are placed on federal land they are owned by the FLMA who can give these abandoned mines out to companies or even people who want to search for minerals. These people even get the benefit of keeping whatever they find in these mines. So one problem is that not all abandoned mines are open to being cleaned because they may be owned by someone who doesn't want others near.

Another part of my solution research brought ways AMD can be cleaned up and through the article Trace Elements Adsorption from Solutions and Acid Mine Drainage Using Agricultural By-products by Rogelio Carrillo-Gonzales[5] he describes a way of using manure to absorb trace elements of -As, -Cd, -Cu, and -Zn from the AMD using Cow, Rabbit, and Sheep manure.

In the last documentary I watched called Environmental Impacts of Mining[6], the first text seen says “Every year 39,543 pounds of new minerals must he provided for every person in the United States” so that makes me think what if there was a way to solve the problem of waste while also rejuvenating these mines so overall less damage is done to the environment. New mines won't have to be created if old ones can be revived. The documentary also mentions mine reclamation and once again it’s stated that even though the process is better than nothing it just isn’t much of a solution for older mines.

1.6.4.2. Remaining Unknowns

One of the biggest unknowns I haven’t found was how cleanup crews fix the AMD after it’s already released from the mines or even when it’s been releasing for years. How do you clean up an incredibly toxic river with so much water flowing inside, on top of, and around abandoned mines.

1.6.4.3. Research Summary

Acid Mine Drainage is the biggest issue surrounding all kinds of mine waste produced. No matter what even if it's gold mines, coal mines, iron mines, ect. Acid drainage is spewing out of these old mines into the freshwater source killing species and making people sick.

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1.6.5 Individual Section

Author: Fergus Huggins

1.6.5.1. Summary of Prospective Gathering

For my first portion of stakeholder engagement I watched the subject matter expert talk by Dr. Tim Sweitizer and Dr. Lauren Poole [1]. Watching this talk helped generate an understanding of the general difficulties of addressing waste problems locally and the issues that come with that problem solving. I think that a crucial part of the talk was seeing how someone who has already participated in these designs explained their process. I also saw their abilities to notice and take note of the problems instead of ignoring them. By seeing them focus on the practicality of the design, it helped the team understand that my focus should stay on the design itself and not external factors. The subject matter expert talk also showed the importance of communication and working with those affected by mine waste, placing more emphasis on those more affected. The talk opened up to the value of the engagement of those affected, because they understand the effects of a problem in a different perspective than any expert.

To follow up my first SME talk, I watched another talk on Humanitarian Engineering by Dr. Sofia Schlezak and Dr. Jaime Styer. [2]. This talk caused inspiration to view the business side of the design process, because ultimately a product can only succeed if it is supported by the market and the market's goals. By looking at the design process like this, it helped to narrow down the viable problems because ones that were not profitable are not going to be successful. I took away from that talk that a balance must be struck between business and creativity, and if that can be done successfully, then the project will succeed. By doing this I realized that the group could try and solve a problem that already exists, but is not a current waste problem like recycling.

The main portion of my time was spent reading an article by the Journal of Korean Medical Science on the health effects of abandoned mines [3]. The article was a great overview of all the consequences mine pollution has, and motivated the team to dig deeper into mining. The main direct health risk in relation to mines is the physical materials left at the site. Mines are often not near great infrastructure and old pieces of wood, metal, and even radioactive materials can be left exposed at the site of the mines for unsuspecting humans or animals to become injured from. This brought up one of my key questions. What are the parts of mines that remain the most dangerous? Is it the actual mine, or the threat of water contamination?

The article also talked about the dangerous long run effects of leaving waste like mining around. The main concerns are water and air pollution, with water pollution taking the crown as the most dangerous of all. Each abandoned mine holds thousands, if not millions of gallons of toxic, metal enriched water that is catastrophic if it is released into the local water supply. This narrowed down the true problem of waste in mining to its effect on the water supply, and that gave an idea.

Tracking down people who are affected most by abandoned mine waste is actually quite difficult, as there is no group of people who can be generalized as “victims”. This was my second key question. How can the group find people that have been directly affected by a waste disaster related to mining? I quickly realized that my family has been a part of the abandoned mine waste problem and that I myself was an affected stakeholder. I am from Durango, a small town in the Southwest region of Colorado. The town is not known for much, but in 2015 they were greatly affected when the river turned orange because of the Gold King Mine Spill.

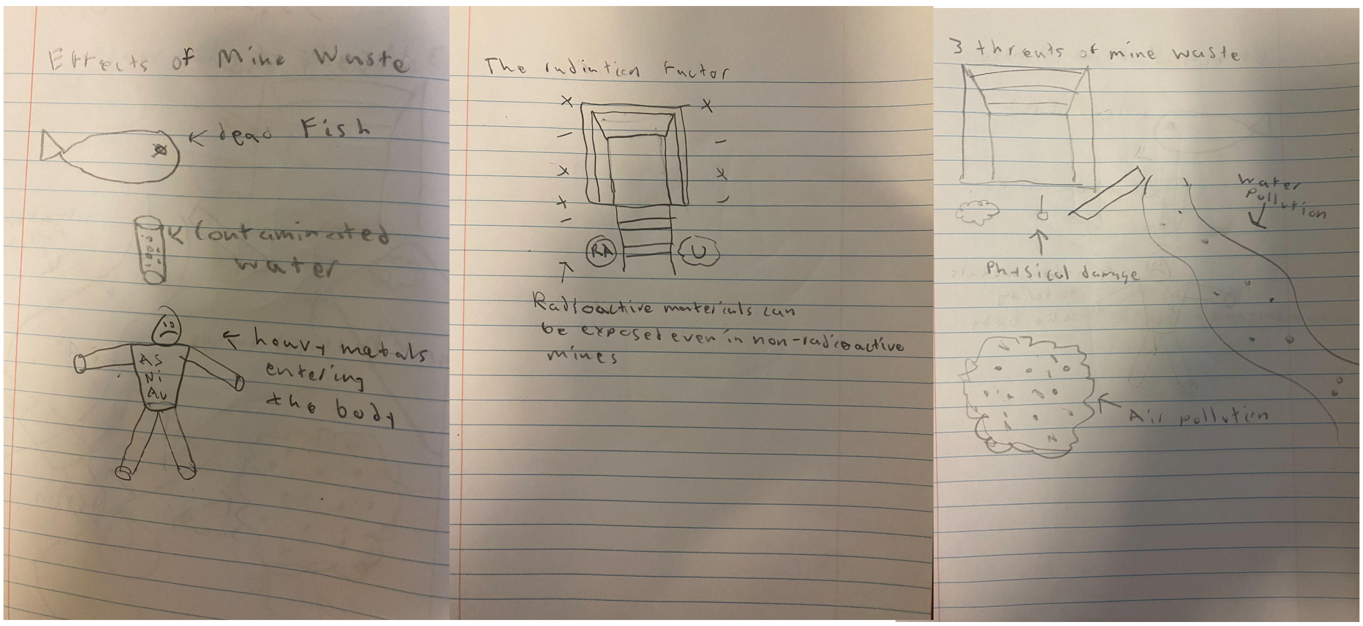
The Gold King Mine Spill occurred when the EPA accidentally unleashed 3.5 million gallons of toxic water into the Animas river while trying to open the Gold King mine. The direct result was the mutation of the beautiful river into an orange heap of death carrying heavy metals through town.

Animas River during Spill [4]

My best friend's dad on the river documenting effects of lead [5]

My life was disrupted majorly by the ensuing issues. We could not raft on the river, had to take extra precautions drinking water, and even noticed reduced fishing in the area. To confirm my story I called my dad and asked him if he remembered the event the same as me [6]. He confirmed, and even said it was only rivaled by the eruption of Mt. Saint Helens in terms of disasters he witnessed in his lifetime.

Pictures:



1.6.5.2. Remaining Unknowns

I have 3 remaining unknowns that I need to research more. The first is about the specific type of mines the group will be looking at. Should the group focus on one specific type of mine or a certain area of Colorado, beyond gold mines? Second, I am unsure what other stakeholders the team should interview. What group of people is likely to get the best information on mine related waste? Finally, I want to know about land ownership. What are the specific laws surrounding mine waste responsibility and how can those be used to sell a product?

1.6.5.3. Research Summary

Through my research, I was able to narrow down the topic from waste to the danger of abandoned gold mines. This process helped to find a great problem that I personally relate to and has local implications here in colorado. Listening to experts and talking to family gave a great perspective on the situation and helped the group generate the final problem statement.

1.6.5.4. Individual Bibliography

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2.1 Stakeholder Summary and Existing Solutions

The group initially struggled to identify stakeholders as many are not repeatedly affected by AMD, but found five key stakeholders that are believed to be crucial to design around. The first and most important stakeholder for the design is the government. The EPA is the number one buyer of mine cleanup solutions and is responsible for most mine cleanups, making them a top priority when considering the design. The next stakeholder considered was mine owners. Mine owners often are responsible for any disasters, so they would desire any cheap solution, a niche the solution would fill. Third, the group considered all those who own land near a mine would be more affected by AMD and would therefore need a solution to quickly stop damage. Fourth the group considered the outdoorsmen who would be exploring near mines. They would likely encounter mine disasters, and are therefore important to consider. The final stakeholder is the environment. While the environment is not a person, it is a legal entity and the team is considering it a stakeholder because AMD affects the environment most of all.

When it comes to existing solutions, there are currently 2 ways to treat acid mine drainage and there are 3 solutions in use. There is active treatment which involves the mechanical addition of alkaline chemicals to raise the pH and precipitate the metals, then lime is added to the water in order to neutralize the acidity. Some of the advantages of this solution are that the regulatory community likes the solution and it is proven to work. Some disadvantages include the high operation cost of this process, and the chemicals that are involved in the process are expensive. Passive treatment is a naturally occuring chemical and biological reaction that takes place in a controlled environment without powered mechanical assistance. Some advantages of passive treatment include the low need for energy and the process is not very expensive. Some disadvantages with passive treatment are that the regulatory community does not like it, and it often fails after 2 years of treatment. One of the solutions is to plug all the entrances and exits of a decommissioned mine. The goal of this solution is to prevent any material, liquid, air, or animal, from entering the or exiting the mine. This would eliminate any contaminants from leaving. One issue with this is that it is hard to plug a mine as there are usually unknown exit areas and if the plugging is done improperly it could be disastrous, a good example of a plugging going wrong would be the Gold King Spill where water built up behind a plug with enough pressure to blow the plug off and spill contaminants into nearby waterways.

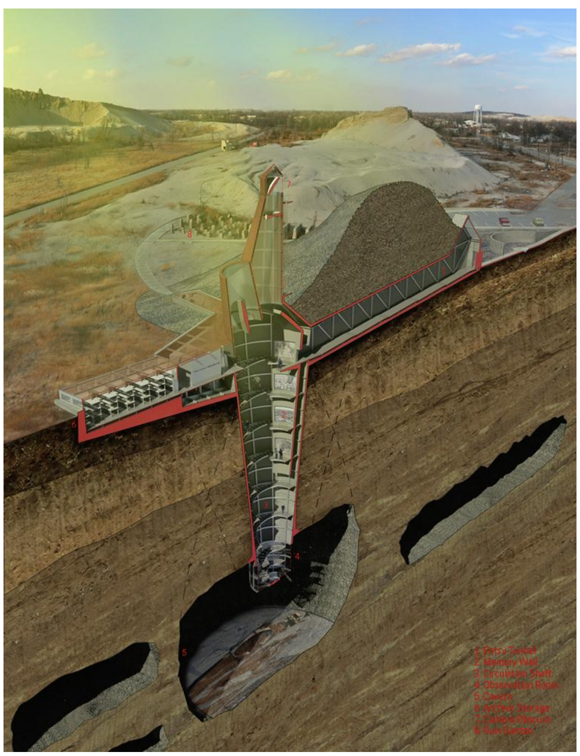


Figure 1: Mine plug [1]

Another solution is placing manure on the walls of decommissioned mines. This solution is effective for a short period of time until it decomposes and exposes the raw materials left to the elements of the world (not pictured). The last existing solution is lining the walls of decommissioned mines with foam. This solution was also deemed ineffective as leftover materials still found ways to become contaminated and exit the mine.

Figure 2: Mine Foam Packaging [2]

2.2 Customer Needs & Technical Specifications

Requirements	Customer Needs	Technical Specification
Safe to use	The device needs to stay on the plane at all times while in the air and the solution used needs to be non-toxic to the environment/people in contact with it.	The detachable aspect of the device can activate while the plane isn't on the ground and Intense government product testing to ensure EPA friendly/regulated.

Integration with Government mine cleanup programs	Government cleanup programs have to be interested in this product and see the positive effect it has on mine cleanup.	This device has to have features that make it more convenient to use than other solutions used by these mine cleanup programs.
Ease of use	It can't be confusing to use or too complex in a way that it becomes inconvenient. There needs to be little instruction for the operators and crew using the device.	The device has to be fully automated, require little to no maintenance, be integratable into today's cleanup operations, and compatible with planes used for emergencies like these.
Effective	When used, the device should clean bodies of water affected by AMD in a fast manner. The solution should also work well in cleaning this water.	It's low weight, aerodynamic, has high durability so as not to break while the device is being operated, and convenient to use.
Desirable	Government programs should be enticed into using this solution either by integrating it with other solutions or as a substitute to lesser solutions.	The device is effective in its job, it's affordable, easily implementable, safely used, and approved by EPA/government.

2.3 Individual Looks Like Prototype and Concepts

2.3.1. Individual Prototype: Coagulant Agent

One prototype idea that was generated was the idea and concept of a coagulant agent that would bind toxic heavy metals, such as zinc, cadmium, and copper. This agent would be used in the context of water treatment facilities and would be used as a general tool for clean up crews, from both the public and private sectors. Although the idea of this type of solution is not novel, some key aspects of this concept were the ability to be non-toxic both before bonding with pollutants and after going through a chemical reaction with pollutants to form a precipitate. The agent would also be identifiable in a multitude of ways both before and after bonding, for example via photospectrometry, TEM techniques, and even direct observation.

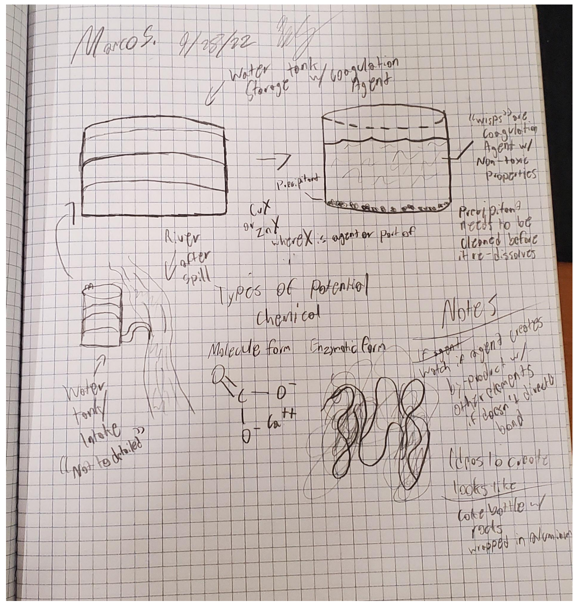


FIGURE 3. Technical sketch concepts of the Coagulant Agent

This solution would work in tandem with common water treatment techniques, such as filtration in municipality water systems, to aid groups in water clean up during mine spills. Seeing as many of the pollutants involve transition metals, such as copper and zinc, it would be relatively easy to develop a chemical agent that would react with these pollutants due to their inherent chemical properties. This solution was more to be an affordable option for stakeholders who would be actively engaged in combating the detriments of acid mine drainage.

2.3.2. Individual Prototype: Green Release

The Green Release device is full of a concentrated solution and will be attached on top of the “scooper" designed for the most common firefighting plane, the twin commander 500 & 600. The device will automatically engage with vacuum lines when the large tanks are filling up and drop an appropriate amount of solution directly into the tanks through a hose. This is adjustable from a knob to ensure the proper saturation. The tank will need to be filled very sparingly as it contains concentrate and treats hundreds of gallons of water with one full tank.

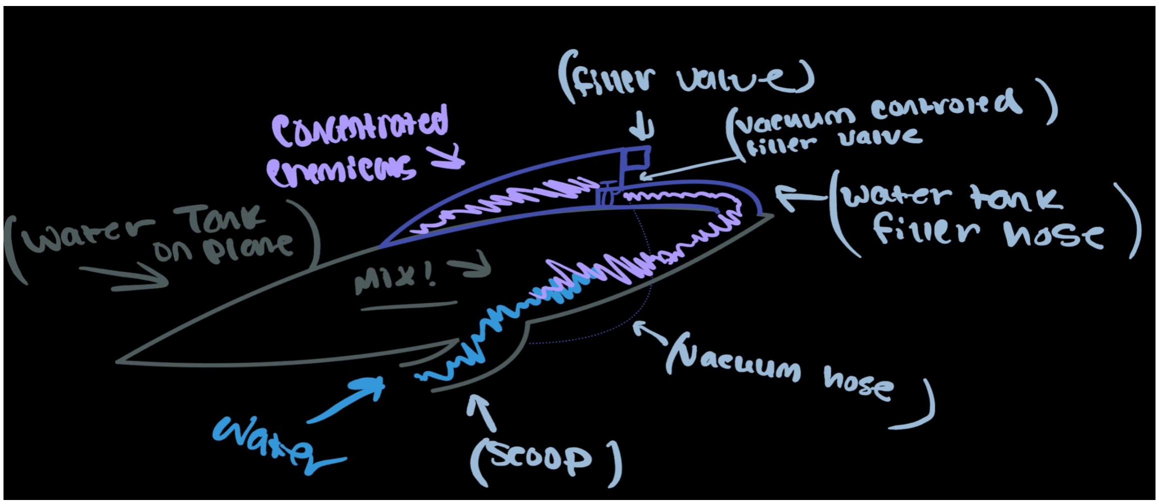


Figure 4: Technical Sketch

2.3.3. Individual Prototype: Heater

The thermoelectric heater is a passive device made to remove water from abandoned mines via evaporation. The device would be placed into a water-filled compartment of the mine by an automatic submersible drone that would maneuver the heater into a suitable position, then leaving the heater to passively evaporate water. The heater would be powered by solar panels placed outside of the mine and a long cable would connect the panels to the heater. The heater and panels would get deployed passively for multiple mines, and would be left to run until all the water was evaporated. The submersible would be used in multiple mines to continually move heaters around until each mine was no longer water filled. This would help reduce heavy metal and acid contamination as there would be no water to carry the contaminants into water systems inside the mine.

The goal of the prototype was to find a new way to address AMD that was preventative instead of reactive like all existing solutions. The solution would be easy to implement and was quite novel considering it is just a heater.

Figure 5: Heater submerged in water

Figure 6: Looks like prototype with Panel connected to heater

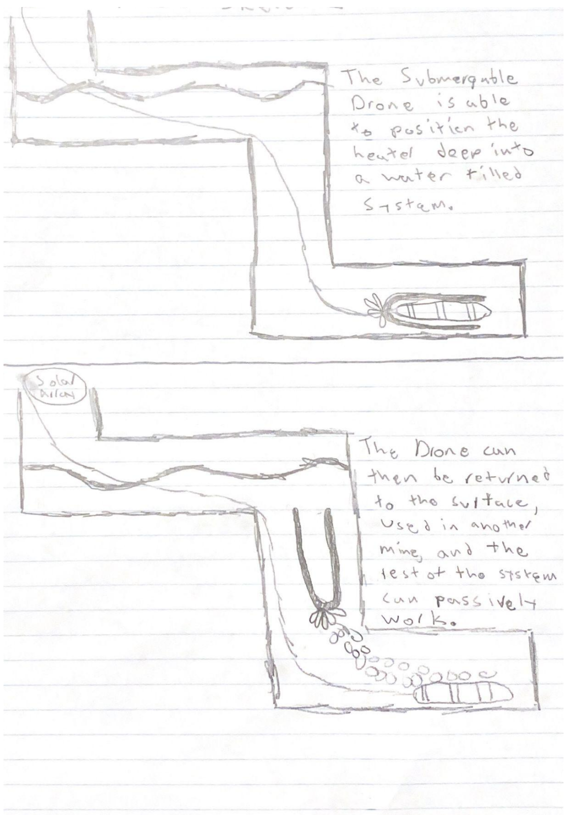


Figure 7: Field sketch of the drone positioning heater inside of a water filled mine shaft.

Solution Value Summary: The solution is a new way of thinking about acid mine drainage, from a preventative and not reactive standpoint. The premise of the solution is cheap and very viable and brings a lot of novelty to a century old problem that is acid mine drainage. The solution is great for the public and private owners alike, as it requires relatively low maintenance and generates jobs for workers to implement the technology and run the submersible drone. The solution is also government applicable as it is easy to see them using to solve other water related mine issues.

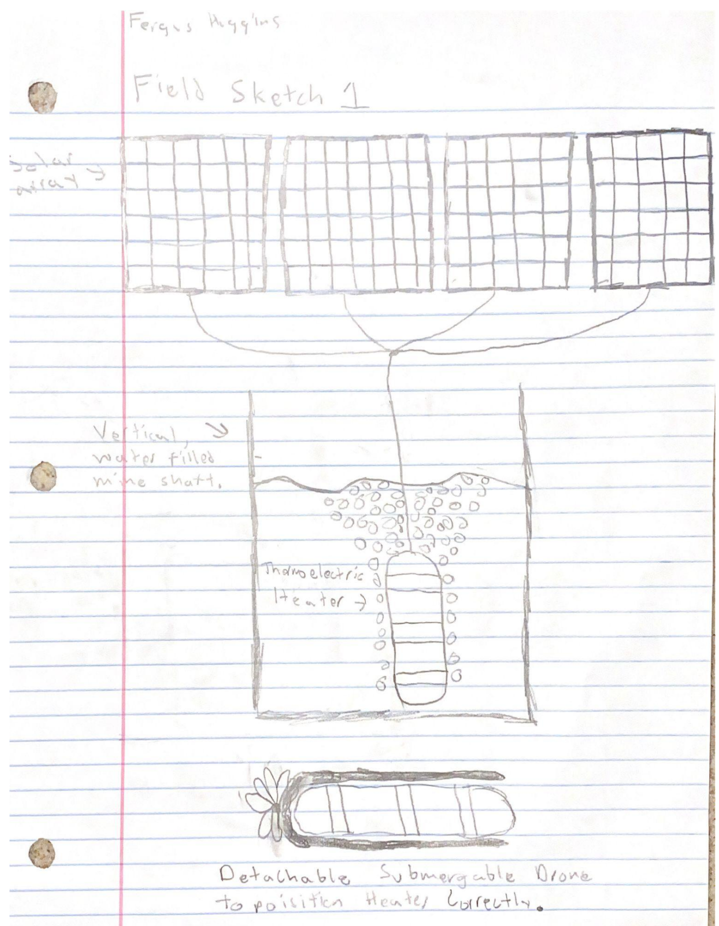


Figure 8: A sketch of the entire system and its setup.

2.3.4. Individual Prototype: Dam/Gate

Another prototype was a dam to stop the flow of contaminated water down a waterway. This would have involved a sensor further up a body of water reading the pH level of the water. If the pH reached a specific level then it would have caused a dam and side walls to lift out of the ground and stop the flow of water. Pipes would then remove the water into a large storage tank where it would be stored until the water could be cleaned. After the water has been cleaned there would be a release mechanism to send the water back into the waterway and lower the dam.

This prototype was meant to stop the flow of acid mine drainage into larger waterways where it would contaminate the water and cause environmental problems. If the water can be caught and stored early then acid mine drainage would effectively have been negated before reaching more heavily populated areas.

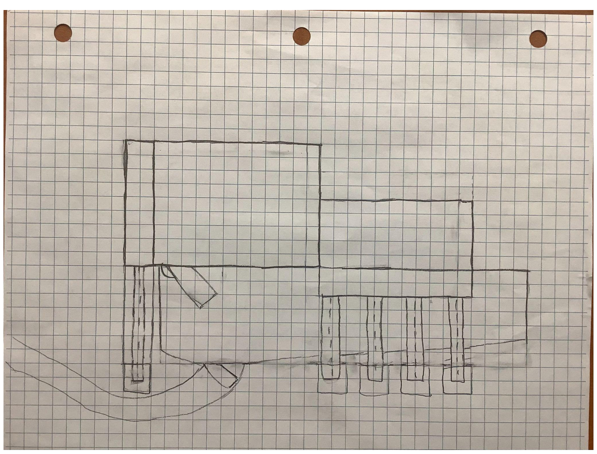


Figure 9: Technical Sketch

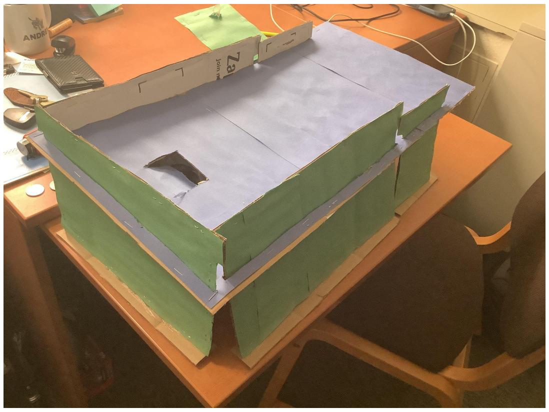


Figure 10: Prototype photo

Figure 11: Second Prototype Photo

Despite the interesting idea, the idea was not entirely practical. This technology would be hard to build around pre-existing waterways especially in difficult terrain like the Rocky Mountains. This is also not entirely a solution more than it is a deterrent for a solution to be used. This solution would also be extremely costly and would require regular maintenance and someone to go and clean the water that is stored in the system. Therefore the conclusion was made to go in a different direction than this prototype was suggesting.

2.3.5. Individual Prototype: Manure Device

The Manure Device is a handheld product resembling a gun that's main purpose is to make it easier for mine reclamation groups to place manure onto mines affected by acid mine drainage. The device has a tank in its handheld form that stores manure to be pumped through a hose into the nozzles. At the end of the device there are a bunch or small nozzles that can adjust to the mine walls rough exterior to get an even coating of manure. At the base of the nozzle a turning mechanism is placed on the inside to help the end turn back and forth from vertical to horizontal.

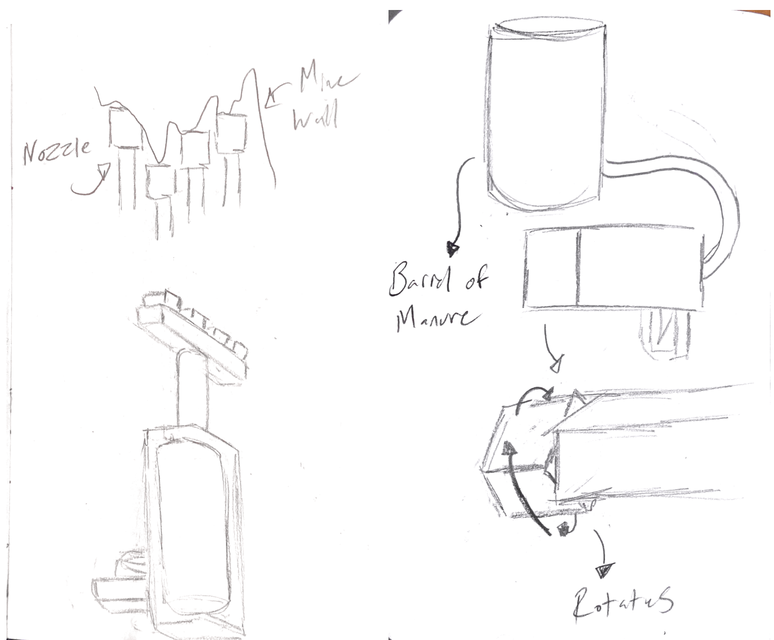


Figure 12: Technical Sketch

2.4 Decision Analysis Summary

To choose a final design to move forward with, the group used a holistic approach to evaluate and ultimately decide on the green release. As shown in Table 1, the team initially evaluated each prototype on viability, novelty, desirability, sustainability, and feasibility. Each of these objectives are paramount to the success of the final design, and in order to successfully choose the best prototype, the group ranked each in a decision matrix to quantitatively evaluate each choice and find its benefits and downfalls. The coagulant scored well in feasibility, but lacked sustainability and viability. The Gate scored poorly in all areas, so the team knew it would either need to be changed or be eliminated from contention. The manure was perfect for its novelty and desirability, thanks to its unique design, but lacked practical use as shown by the low sustainability, viability, and feasibility scores. The heater on the other hand, excelled in viability and feasibility thanks to its simple design, but inversely to the manure lacked novelty and desirability. The newly dubbed “green release” became the favorite for the final design thanks to the fact that it had the best average score and had relatively few issues. Despite the green release becoming the top choice, the team inferred from this that it was important to consider outside factors that were not just design objectives.

The group talked for around an hour about the upsides and downsides of each design, and decided to go forward with the green release as the final design. The team did migrate some of the ideas from the coagulant into the design, but in general stuck with the main design of the green release thanks to its ingenuity and durability.

	Design Objectives					
Design Alternatives	Viability	Novelty	Desirability	Sustainability	Feasibility	Overall Score
Coagulent	3	4	4	3	5	19
Gate	2	3	3	4	4	16
Manure	3	5	5	2	4	19
Green Release	3	5	4	3	5	**20**
Heater	5	3	2	4	5	19
Definition of Criteria:						
	Viability: The Price of developing and producing the product while mantaining quality.					
	Novelty: How similar the idea is to existing solutions; whether the idea is new or a new application of existing technology					
	Desirability: How much does the avarge stakeholder need the product; how often would the product be used.					
	Sustainibilty: A measure of how much the product effects the enviorment and ecosystems.					
	Feasibility: IS the product easy to make with existing parts and with existing support.					

Table 1: Prototype Decision Analysis Matrix

2.5 Proposed Final Design

2.5.1. Abstract Solution

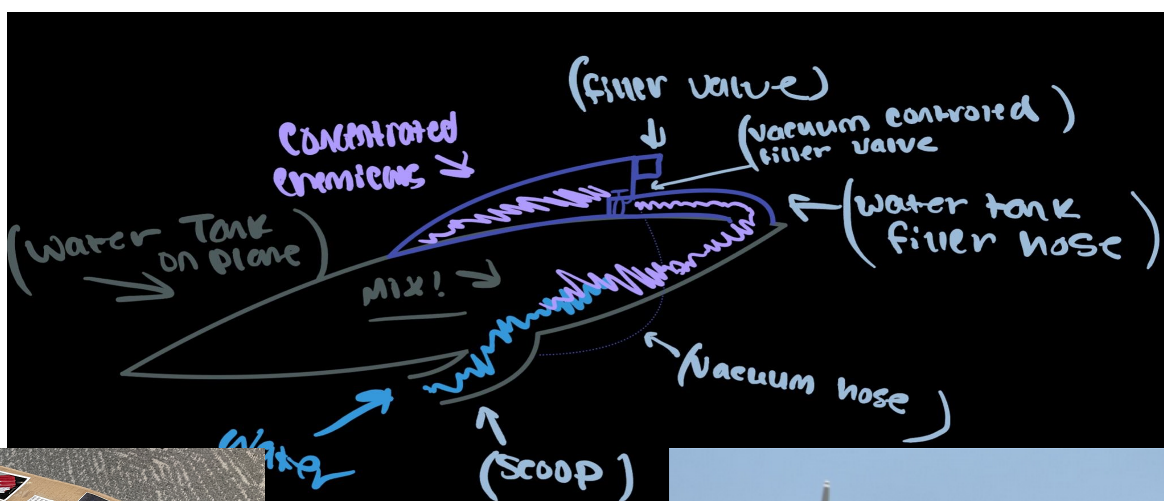
To balance natural pH levels, a base with a high pH level needs to be released all around an impacted area to balance an surrounding low deadly pH levels. This is done with the device named Green Release that attaches to an existing firefighting plane and conditions the water with the chemicals and any other custom additives the user may desire. Various versions of the very concentrated form of the base will be sold commercially and tailored to government agencies including mining companies for profitability. This product could be used as the only solution used for those 90% of mines that pollute nearby waterways. Since a very large number of mines pollute far above the government regulatory safe levels, the program will work closely with the government to ensure these regulatory standards are met with the product.

2.5.2. Thought Process

Firefighting planes are always on a rush to dump as much water as possible and be available for the next emergency. For convenience and a positive reaction from stakeholders, the team must ensure that the product doesn't interfere with their regular process. This will require a fully automated and a zero maintenance system that is integratable and comparable with almost all existent systems. A grand majority of firefighting planes simply use water without additives for the convenience and accelerated operations. Creating a product that is extremely easy to use will motivate users to use hassle free. With this system however the team must automate an emergency system that detects high levels of contamination release from a localized area and advanced algorithms will be in charge of pinpointing the contamination source to alert firefighters. The Green Release will be composed of several modules including a contamination detection system with sensors that communicate with an overall system. Other modules will be added to the Green Release to ensure the safety and effectiveness in the future as the team sees fit.

2.5.3. Actual Implementable Solution

The Green Release device is full of a mine treatment concentrated solution and will be attached on top of the “scooper" designed for the most common firefighting plane, the twin commander 500 & 600. The device will automatically engage with vacuum lines when the large tanks are filling up and drop an appropriate amount of solution directly into the tanks through a hose. This is adjustable from a knob to ensure the proper saturation. The tank will need to be filled very sparingly as it contains concentrate and treats hundreds of gallons of water with one full tank.



2.6 Module 2 Summary

In working on potential solutions for acid mine drainage and the negative consequences attributed, an important aspect was finding who the stakeholders were, from those affected to potential users of any solution produced. Upon completing a majority of stakeholder identification, the group looked towards solutions that have been explored, searching the entire scope of existing solutions to learn from the most efficient to the downright terrible. From this, each member of the group split up to research and create unique solutions along vastly different vectors of approach. The team explored options of stopping acid mine drainage at the source to physically constraining polluted water in waterways to minimize further contamination. In comparing and contrasting the multiple concepts that each member mapped out, the group decided upon the “Green Release.” Going further, the team plans to research more into both the mechanical aspects, chemical aspects, and social aspects of this solution to maximize efficiency, minimize expenses and upkeep, and end with a solution that addresses the problem in a way that is meaningful and useful to stakeholders.

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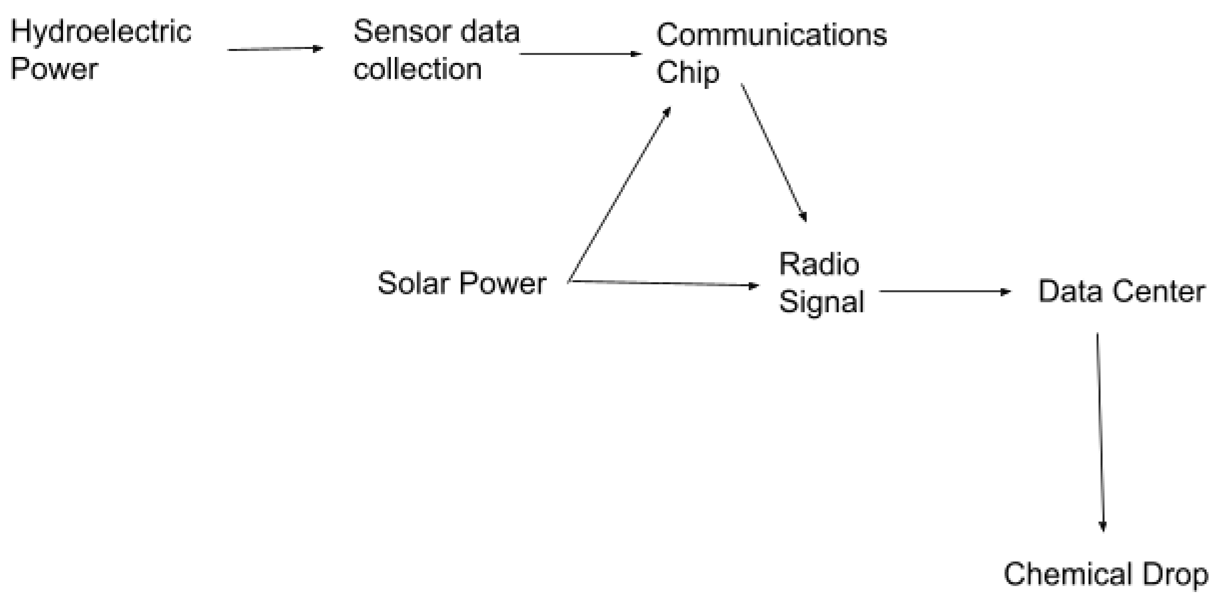
3.1 Subsystem Interfaces:

3.1.1. Design Diagram



3.1.2. Power Generation to Sensors/Comm Chip

Hydroelectric will be used to send constant power to the sensor so there is a continuous testing of the quality of the water, meaning any changes will be noticed immediately and can be relayed on. The turbine will generate 0.4881 Watts which will provide the sensor with sufficient power for 24 hours a day which is more than enough power for the subsystem. Any excess power will be used to charge a capacitor in combination with the solar panel.

The solar panel subsystem will be a back up to the hydroelectric power generation when it comes to powering the sensor. This extra energy will be stored in a capacitor along with the extra energy generated from the hydroelectric system. When it comes to sending the data through radio waves, the energy will be taken from the stored power in the capacitor which will power the computer chip and antenna system. When the power stored in the capacitor is used up, it is the solar panel's job to refill the energy that was lost.

3.1.3. Sensor/Comm Chip to Communications

The sensor will use a PH reader to gather the PH levels in the surrounding water. The PH levels are gathered continuously and all of the information collected will be sent to the communications chip where it can be stored until it is sent off.

The chip will receive the data from the pH sensor and store all of the information over a 24 hour period. After 24 hours the chip will send the information through wires to the radio antenna where the information will be sent. These radio waves will bounce off of towers until they reach the designated data center where the information will be received. This information will then be downloaded by the analysts at the data center who will then decide what to do with the information that they have received.

3.1.4. Communication to Ligand Dispersal

The radio receiver device will be stored in a large Google or AWS datacenter which is always monitoring sensor data. The system will read the recorded sensor data every 24 hours to analyze what steps should be taken next. The interface between the Ligand Dispersal and the communication system is the report that is generated every 24 hours. A report will analyze if the contamination levels have been rising at dangerous levels, it will then autonomously notify government entities to decide what steps are next with the location where the ligand should be dispersed.

After the correct bodies are contacted, the dispersal of the ligand would be relatively straightforward. These authoritative bodies would then use this ligand how they see fit, be it aerial dispersion via plane, helicopter, drone, etc. The communications aspect of the design would interface with the dispersal of the chemical in this way, allowing for correct usage and implementation of the chemical aspect of this design.

3.2 David Villalobos : Communication Subsystem

3.2.1. Communication System Introduction

The communication subsystem will receive all the data from sensors at nearby rivers that measure contamination levels. The data will be relayed through radio signals every 24 hours on a frequency that has been cleared and documented by the FCC to ensure compliance. A tower somewhere in the United States will receive that data; this is possible because the data will be relayed through the existing repeaters which means these radio signals can be transmitted across the US. The data will then be synthesized and a report will be automatically generated and shared which will allow the end user to view any action that needs to be taken. Since the signals are also broadcasted, different government agencies would have easy access to direct system data to monitor all contamination systems. If the levels are above a predetermined threshold, the report will include where, and when to drop chemicals to ensure optimal use. The actual sensors are a different subsection that will be handled by the sensor subsystem which is one of the interfaces that the system implementation must incorporate.

The communication subsystem is critical for the success of this acid mine cleanup program as it unifies all systems and formulates the decision making; in short, it's the brains of the entire operation. The communication infrastructure has been set up with existing radio systems which not only ensure reliability but have considered pricing in advance. This means that no new technology is created which simplifies the setup. All communication technologies are already existent, the software is the only aspect that is new. The development team has strategically chosen HAM radio frequencies because not only is the infrastructure already setup, but this communication form is a lot more reliable and cheaper than any newer technologies. Satellite communication would result in an excessive energy consumption to even generate such signals and using satellite resources would be very expensive and complex. Other potential options included cellular communication but, there usually are no cell towers near these abandoned mines and once again, the pricing for these communication systems would be far beyond a viable scope for cost. HAM radio frequencies are usually split into 2 frequency types, VHS and UHF which change many aspects [1]. The VHF frequencies have very crisp and clean communication with minimal static and data loss, however, these signals travel very short and dissipate quickly. UHF frequencies may have a lower resolution but have crazy travel distance and aren't easily interrupted. This is critical because most of the mines can be miles away from a radio repeater so it's important to have an extended communication range.

3.2.2. Subsystem Testing Protocol

Communication Protocol Introduction: The communication system doesn't contain many physical components that can be tested. The team concluded that the cheapest and most effective communication technique was to use the already existing HAM radio repeaters already established all across the United States. The only physical communication components include the antennas and on the small onboard computer in the sensor subsystems that are incharge of periodically reading input, and generating an output at a given time. The solar panel communication subsystem will be in charge of relaying the signal to the HAM radio repeaters which is where the team will take charge of developing the software to "listen" for that specific frequency, decode and forward the data where necessary.

Testing Protocol: To test the communication system, assume that the Solar Panel Communication Subsystem has already collected the data and has sent it to the repeater tower. From here, the computerized systems will have a “listener” which is a piece of code that is always waiting for something to occur, then takes action. In this case, the systems will be listening to the specific frequency that the sensors are sending their data to. From here the systems have now collected the data and it will now be parsed. This means that the team will breakdown/decode the actual message and an algorithm will run making the next decisions. If in the last few months, the acidic water reading has been rising steadily and reaches a threshold, then a message will be broadcasted to a frequency in which all firefighting departments with firefighting airplanes to take action and dump the acid mine drainage solution with the coordinate for best optimal use. The actual testing occurs between the team receiving an open air frequency signal, decoding input, and relaying that information forward depending on the algorithm’s decisions. The algorithm’s ability to make decisions is what must be critically tested because poor decision making could result in environmental damage.

3.2.3. Required Build Components

The only physical components to this subsystem include the listener/receiver that will always be monitoring the frequency the sensors are on to always capture the information released. A simple little radio scanner connected to a computer with existing software is enough to process the input. However! The team concluded that a simple scanner may not provide great functionality. With an actual radio that is able to transmit, the communication team would be able to communicate back to the water sensors. This could help in a case in which the sensors have glitched and a bug has resulted in them no longer working. For this, the radio home station could simply send out a signal and reset all sensors on that frequency. This is an inexpensive added bonus that could help the other subsection teams resolve major problems from their end. In short, all that the communication subsystem team requires is access to a computer, a small $100 radio, and the team will take charge of designing algorithms to input, process and output data in all directions necessary.

The team must note and be cautious with the frequencies and communication type as studies have shown that frequency amplification could result in skewed communications [3]. For example, small data communications like the ones intended for use between the sensors and the towers need to be amplified at the tower to be amplified. This however is an issue because there may be a slight altering of the data when this is done. This is an aspect that must be considered when testing, the team must verify that the amplification output is consistent with the input to remove the probability of the data being skewed.

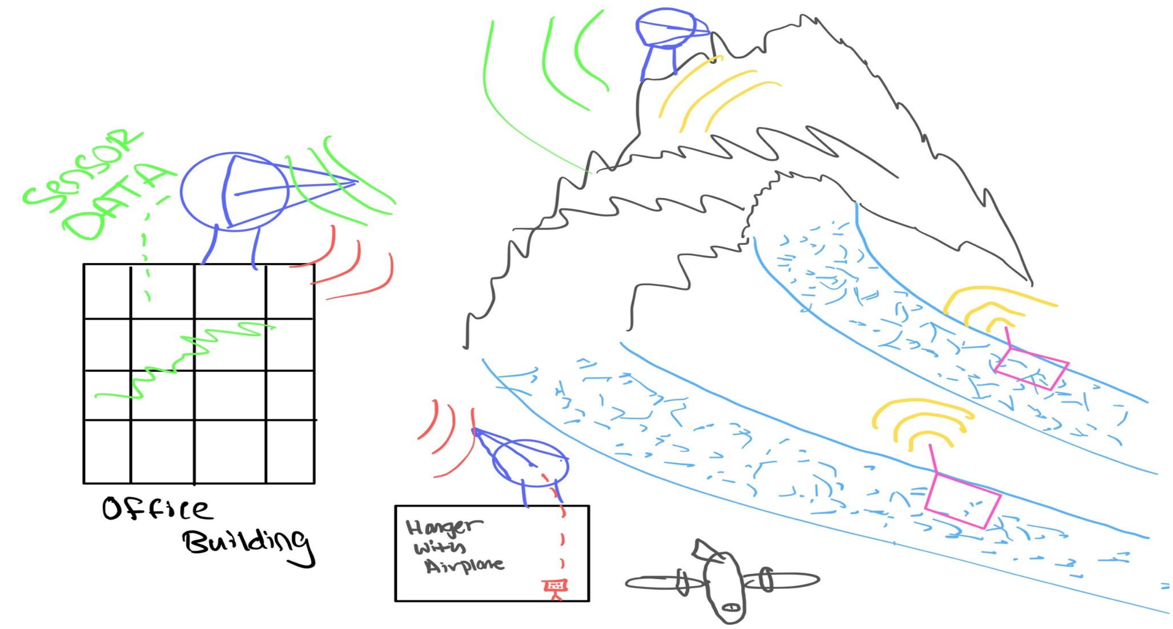
One final aspect that won't directly impact the system but is important are the FAA legal frequency regulations. For example, the systems must be fully FAA compliant which means that the solution must only transmit on a single channel and it must not interfere with any other frequency.

3.2.4. Subsystem Interfaces

The communication subsystem is critical because it combines all the different moving parts and makes the actual execution. This means that the communication subsystem will need to coordinate with the Solar/Sensor Chip communication subsystem to choose a valid frequency for which the data will be transmitted through. The teams must also work very closely with their software to know what data encryption will be used and the format the data will be sent in so it can be decoded properly. Other sensor functionality may be added such as metal concentrations measurement sensors, ect…

The communication subsystem team will have interfaces with local government agencies and firefighting airplane departments that are working with teams. Once the data has been received and parsed, it will then be sent to government agencies that want this data and to firefighting airplane departments with steps on how to proceed. The great part about this interface is that with one single step the program can flawlessly send data to any departments that could want this data. Currently, the system communications will be encrypted to prevent the sharing of sensitive data but the team could work alongside the government to release these numbers.

3.2.5. Graphical Representation



(This image shows the communication interfaces that will be made between sensors to end user.)

(This receiver is in charge of scanning and recording all sensor data from the repeater signals.)

Simulation with Theoretical Conditions & Calculations

Research has identified the 15-27 MHz frequency range to be most efficient for long distance communication with the least interference and cleanest communication. This is important because sensors will be placed in valleys quite far away from the repeater towers. ($\lambda = c / f$) is the formula for the wavelength of these HAM radio frequencies. To ensure the farthest reaching and most effective communication frequency, the group must find the largest wavelength frequency in the 15-27 MHz frequency which also ensures that the communication frequency complies with FCC regulation. While the 12 MHz difference may appear rather insignificant, the total distance that the signal travels increases by a few miles when working with the lower end of the spectrum. After plenty of research and calculating the frequency wavelength through differentials for optimization, the team has concluded that obtaining the smallest frequency in the 15-27 MHz range would significantly improve communication results.

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3.3 Fergus Huggins : Sensor Power Subsystem

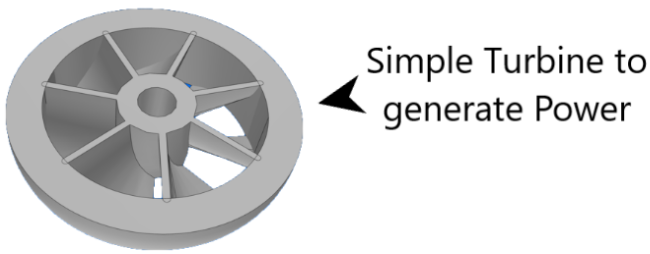
3.1 Summary:

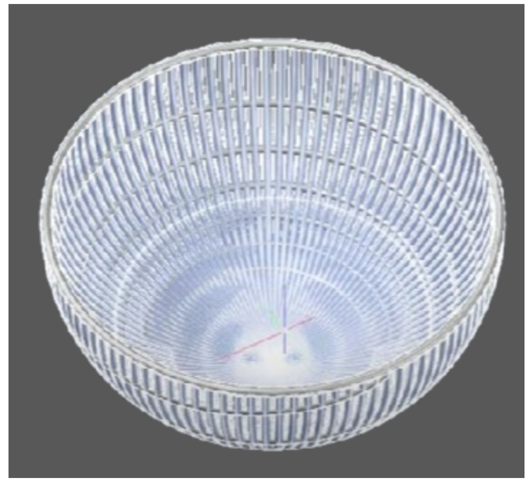
3.1.1:

The hydroelectric power generator subsystem's goal is to provide sufficient power for every other subsystem to function properly in the sensor, via the use of a submerged water turbine that uses the flow of the river to generate around half a watt of power. This subsystem will be responsible for 24 hour power generation without failure due to debris clogging the turbine. This turbine in the water will have a cable that connects it to the sensor, and inside the sensor the power will be distributed among its subsystems. The generator must be waterproof, self contained, include a turbine, drive, and generator, and have sufficient coverings to prevent sticks and other materials from becoming lodged in the turbine.

3.1.1.1:

At full size, the turbine will be a 2 inch diameter fan that is submerged 3 inches above the river floor, to ensure it continues to work even in low water scenarios. The front of the turbine will have a blimp shaped mesh in front to stop contaminants from slowing down the turbine, and the blimp like shape improves how well things will roll of the the mess and away from the turbine , and the interior will have a drive and generator attached to the axis of the turbine to generate power. This will be attached to a cord that connects back to the sensor itself, and carries electricity to the other subsystems. Below are the images of the turbine (left) and mesh net (right).





The physical turbine of the turbine part

Mesh net to catch any debris

3.1.1.2:

The subsystem works by using the flowing water to spin the turbine, generating rotational movement. This spins the drive chain which will spin the basic generator which induces current, which can be carried to the other subsystems. The system is effective because it is a tested reliable method of power generation, as hydroelectric power generates the most consistent power of any form of energy, and will be able to provide the necessary power for all other subsystems. An additional output of the system will be the fan speed. Because all produced power will be sent back to the sensor, if the level reduces then it is a sign that the subsystem is not working. It has self testing because it only outputs one thing, and any change in that thing will be an easy to spot occurrence.

3.1.1.3

Another reason the subsystem is simply effective is because it requires no inputs to run, it is a simple mechanism. Whenever water runs through the fan, it generates power. For installment this can be unplugged to avoid issues when installing, but once it is turned on, it needs no inputs to start a test or stop the power. The power will always be used by the sensor to collect data, and if excess is ever available, it will charge up capacitors for later use.

3.1.1.4

The four key components of the subsystem are: the turbine, the casing, the drive chain, and the generator. The turbine must be of high quality and water resistant because it will be submerged constantly and cannot accumulate particulates easily. The casing must be waterproof, non-toxic, and inexpensive because it will do the job of both covering up all electronics and make up 90% of the design materials by size. The drive chain must be short and extremely durable, as it will be running 24 hours a day and should be water resistant in case of leaks. Finally, the generator is standard and just needs to be compact enough to fit in the design. Heat is not any issue because it will be surrounded by running water and with water's extremely high specific heat.

3.1.1.5:

Product	Photo	Description	Cost
W&H 500 Series TK-100 L / TK-100 LM Complete Turbine		The W&H 500 Series is a small form complete turbine capable of reaching high levels of efficiency and is completely waterproof.	$129 for one but turbines are notoriously overpriced while not in bulk. Realistic cost is 10$

Topoox 6 Pack DC 3V 1730RPM Mini		The Topoox Mini is a compact generator capable of up to 3W and needs to e be waterproofed by the exterior	6/$8.99
18 AWG - 3 Conductor - 600V - Stranded Conductor - Unshielded - VNTC Tray Cable - Per Foot		The cable is built for water purposes and will connect the turbine to the other subsystems	0.70$ per foot

3.1.2:

Unfortunately, the design has completely changed since the preliminary design. This means that it is impossible to refer back meaningfully to the original table as it provides no value. However, there is the ability to talk about the different components and that is what will happen. Each component will be around 8 cubic inches in size varying slightly. The turbine will be two inches wide, two inches tall, and two inches in depth. The generator is 2 inches wide and tall, but only an inch wide, and finally the drive chain has a length of 6 inches and has a radius of .128 inches.

3.2:

Other alternatives that were approached included wind, solar, and battery powered sensors. The team did ultimately end up going with solar and hydroelectric power as the two sources of power because of the consistency of hydroelectric and the high output of solar. The choices made were ultimately due to the novelty and reliability. Things like wind and battery power were too unreliable, so the better option was to have a solid option like hydroelectric and a high output like solar.

3.3.1 Test Results:

To test the physical viability of the hydroelectric energy generator, a series of tests were completed in a sample body of water (Clear creek) to test the subsystem and its output. In testing, the results would be able to provide the group with valuable information on the expected power output of the main source of power for each sensor, as well as validate the idea that it was possible to use a small scale turbine to generate significant enough energy to be able to fill up a capacitor.

The protocols followed in testing were; the evaluation of the reliability of the hydroelectric subsystem, the recording of the counterbalance to be able to calculate power and energy outputs, the validation of a micro-turbine, and the solidification of possible parts to be used in manufacturing. Each of these protocols passed the standards, and improved the information and knowledge of the team. First, the design allowed for the turbine to be in the river where it would not float but also not sink, minimizing the amount of contaminants entering the turbine. This was due to the design of the support, allowing for a fixed turbine position that would not move due to river fluctuations.

Below is a CAD model of what the physical design was. The Turbine spun the large counterbalance on the other side, which had a tape measure wrapped around its circumference. By recording a video of the entire axle spinning, the velocity of the wheel could be found because time and distance were known.

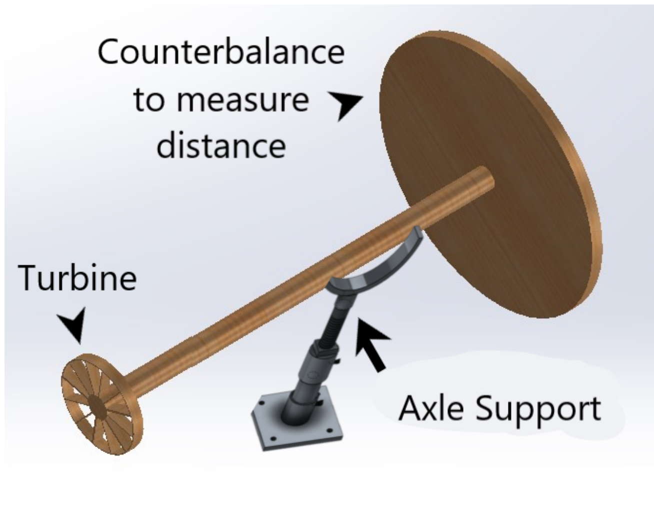


Figure 1: CAD model of the subsystem

Photo 1: Location of testing on Clear Creek

The large counterbalance was above the water and was able to spin, while the smaller turbine was submerged and used the current to spin the entire subsystem. In the final design, there would be no counter balance but instead the force of the turbine would generate and turn into electricity.

Five videos were recorded and each one was carefully analyzed to find the time and distance. The following are the results.

Table 1: Raw data collected via recording:

Raw Data:	Run 1	Run 2	Run 3	Run 4	Run 5
Distance (in):	97.5	95.5	86.3	94.5	98.9
Time (s):	4.13	4.04	4.2	4.46	4.34
Velocity (ft/s):	1.967312349	1.969884488	1.712301587	1.765695067	1.899001536

Average Angular Velocity: 1.862839006 m/s

3.3.2 Analysis:

The goal of the subsystem test was to verify if the hydroelectric turbine was able to produce sufficient power to run the sensor's systems and data collection, while also being enough to be stored up in a capacitor and be used in a burst to relay data back for data analysis regularly.

To calculate power output, start with the equation $P = \frac{W}{\Delta t}$ or the work divided by the change in time. Work can be simplified to $W = F\Delta d$, and plugging this back into power, then get that $P = W\frac{\Delta d}{\Delta t}$, but since velocity is just distance over time, power become $P = F\Delta V$. From here, use algebraic manipulation to solve for power output.

Initial Equations: $P = F\Delta V$ $\quad F = ma \quad a = \frac{V^2}{r}$

$F = \frac{mv^2}{r}$

$P\ =\ \frac{mv^2\Delta V}{r}$

Since the team only care about average power output, assume that the average power ΔV is equal to velocity v, therefore:

$P\ =\frac{mv^3}{r}$

The radius of the turbine used was 1 inch or 1/12 of a foot, and the cylinder of the turbine was made with cedar, which has a density of 23 $\frac{lb}{ft^3}$. The volume equation is $V\ =\ \pi r^2 h$ and with the radius of the cylindrical counterbalance being 4 inches and having a thickness of 1 inches, volume comes out to .3491 ft^3. Mass is volume times density, so the mass of the counterbalance is 8.02 lbs. Finally, in the tests the group found angular velocity, but to convert that to linear velocity (which is what is needed) $v\ =\ \omega r$ which means the true linear velocity is .15524 m/s. With these, the power output can be found.

m=8.02 lbs r=.0833 ft v=.15524 m/s

$$P\ =\frac{mv^3}{r}=\frac{8.02*0.15524^3}{.0833}=.3600\frac{lbft}{s}=.4881\frac{Nm}{s}=.4881\ W$$

.4881 W of power is about the value predicted. Considering the fact that the design had high friction and a large amount of torque, the amount of power seen is impressive. Any improvement from here to the final subsystem will get the output above .5 Watts, which will be enough to power the sensor. The two important things that the sensor will need power for are the sensor data collection and the sending of that information through radio to a receiver.

An example arduino water temperature receiver uses 3.3-5V at 1mA. Since Watts are Volts/Amps, the device only needs .0005 Watts at max to function, meaning the turbine will generate 100 times the power needed to operate the sensor continually. Sending a signal on the other hand, uses quite a bit of power. A low power FM radio uses between 1 and 100 Watts to send its signal. However, the radio does not need to transmit itself constantly, and instead only needs to send pulses of information everyday. This means that by using a capacitor, the team can create much more than a Watt of power for a short period of time by charging up the capacitor, then releasing it to send the signal at a high strength for a couple seconds until the capacitor discharges. This is where the true power of the turbine comes in. Because it constantly runs, it has no trouble building up a charge and then releasing it all at once, because the constant power consumption (the sensor) won;t even make a dent in the total power needed for the once daily radio transmissions.

3.3.3 Secondary research:

To confirm the validity of the physical subsystem, it is possible to calculate an estimated power output with the equation $P = mgH_{net}\eta$. M is the flow rate through the turbine, g is gravitational constant, H_{net} is the net head loss, and η is the product of all component efficiencies. The H_{net} is assumed to be a 10% loss, so it has a value of .9. The gravitational constant at Golden's altitude is 9.8013, so that is g. To find m, the flow rate through the turbine, all that is needed is the flow rate of the Clear Creek, the cross sectional area of the creek, and the area of the turbine. American Whitewater gave the CFS of the river at 62.9, and the USGS gives the cross sectional area of the river to be 184 sq ft. Dividing the CFS by the cross sectional area gets a value of .3418 CFS/SqFt. Now by multiplying this value by the area of the turbine πr^2, which is 0.02181 SqFt, there is 0.007457 CFS of water running through the turbine, which is m. Converting this to kg/s, m=0.2131 kg/s. η is the sum of all component efficiencies, and this is calculated by multiplying the percent efficiencies of the turbine, drive, and generator.

The small water turbine has a low efficiency rating of 50%, because of the high friction forces and ease of slowdown due to particulate buildup. The drive has a much higher efficiency, over 95% in large hydroelectric drives, but due to the compactness of the sensor design, a better estimate is 85%. Finally, the generators have been optimized at all sizes, and it is well known that almost every generator operates at 93%. Using this, $\eta = .5 * .85 * .93 = 0.3953$.
The calculated power becomes: $P = mgH_{net}\eta = 0.2131 * 9.8013 * .9 * .3953 = 0.7341$.
However, because the turbine had an angle with the water of 45 degrees, the final power number has to be multiplied by Cos(45) to find the power when the turbine will be parallel with the flow.
$P = 0.7341$*Cos(45)=0.5254 W.

This estimated value of 0.5254 Watts matches extremely well with the true power output of 0.4881 Watts. The decrease in actual effectiveness is likely due to a higher friction in the physical system and a general lack of ideal conditions that can be expected with early subsystem testing.

Using Secondary calculations, the math verifies that the physical power output was in fact accurate and validates the physical subsystem test of the hydroelectric power generator. Using efficiency numbers generated by respected papers, calculating a flow through value via the use of government data of Clear creek, and by considering the parameters of the situation (i.e. the angle it was tested at, water quality of clear creek), the math showed that the measured output was correct and followed its theoretical output.

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3.4 Marco Salgado : Chemical Ligand Subsystem

3.4.1. Chemical Ligand System Introduction

In researching potential ways to help reduce the amount of toxic materials, many avenues of approach were considered. First ideas went to grand concepts of taking water directly out of systems and treating it to be released. After consideration, this was scrapped due to large costs, potential disruption to the ecosystem, and the overall impossibility of the task. Next, the team focused on filtration, however, this also was soon dismissed as any practical application of filtration required concepts that were extremely similar with directly treating the water. Finally, the group stumbled across chemical ligands, molecules that bind with, and most importantly precipitate, metal atoms. Finding research articles over the idea of ligands to precipitate specific precious metals out of acidic solution led to further exploration into the science to see if any information was relevant to water treatment on par with the problem. Further inquiry led to a rabbithole of chemical ligand research concerning water treatment, with certain research proving that this would be the correct solution for certain circumstances, such as certain ligands being able to be excreted out without major side effects after consumption and certain ligands having magnetic properties for extraction in solutions.

To preface, it is important to understand common terms; the word “ligand” refers to a molecule that is able to form complexes with metal atoms. A “complex” refers to a molecule with a metal atom at its core. Ligands react and bond with free radical metal atoms to form these complexes, with properties that can be synthetically controlled. In the broader context of a scaled up solution, a chemical ligand would be synthesized – one that is non-toxic and relatively inert in most environments – and it would be released into areas with Acid Mine Drainage (AMD) to combine with free metallic atoms, ranging from Iron to Cadmium. The ligand would then be mixed with water in tanks that are attached to aerial vehicles (planes, helicopters, etc.) and be released above mines, mountains, and/or rivers to chemically bind with free metals passively. The resulting byproduct would be left in the environment or through other methods, as later validation will show the non-toxic and inertness of similar chemicals.

The goal of this subsystem is to be able to passively attack and reduce the effects of AMD. This simple goal would be achieved by using the same methods that AMD uses to get into water systems. In injecting this chemical via water into the environment where AMD is present, it would follow natural runoff systems to combine with AMD passively, essentially fighting fire with fire.

3.4.2. Subsystem Testing Protocol

Secondary research is the major contributor to the testing protocol of this subsystem, as actual creation and implementation would be out of the scope of Design 1 as well as the scope of the team's actual knowledge. Some articles that contribute to Test Results and Analysis are listed below.

A. Multidentate sulfur-containing ligands

This patent acted as a baseline for knowledge of ligand chemistry mentioned in this subsystem. Showing the versatility of ligands, specifically BDET, it gave a summary of this specific ligand and its ability to chelate with certain metals, and what properties the overall complex had. The patent showed much of the possibilities of chemical ligands. [1]

B. Chemical Precipitation of Heavy Metals from Acid Mine Drainage

This article elaborated on the chemical BDET, described in the paragraph above, and its efficiency rate in a scenario specific to the issue. By being introduced to water contaminated from AMD, the amount of certain toxic metals (in ppm) was measured, and showed that the concentration of iron in water systems can be reduced from 194 parts per million down to <0.009 parts per million in as little as twenty hours. The article also proved that this ligand worked on other elements, such as Cobalt and Lead, albeit at lower rates. [2]

C. Provocative chelation with DMSA and EDTA: Evidence for differential access to lead storage sites.

This article elaborated on the potential for non-toxicity of ligands before and after chelation with the heavy metal Lead. By giving this ligand in oral doses to South Korean lead workers, the measured lead excretion through urine showed that ligands DMSA and EDTA were able to be passed through a human body without much issues. Although the article was mostly to map lead storage sites in the human body, it gave proof that certain ligands can prove to be non-toxic, making them suitable for environmental use. [3]

D. Removal of Heavy Metals from Aqueous Systems with Thiol Functionalized Superparamagnetic Nanoparticles

This article showed how certain ligands can be tuned to have magnetic properties before and after being bonded with certain heavy metals. One key aspect of this article was that the ligand that it used was DMSA, which also helped to show that ligands can be very versatile as DMSA was also shown to be non-toxic in the previous reading. [4]

3.4.3. Required Build Components

Non-toxic properties would have to be the most important build component of this subsystem. Without context, the idea of putting a chemical directly into the environment, especially parts of the environment that both affect ecosystems and human life, conjure up negative connotations. Making sure that both excess ligand and chemical complexes created from metal binding with the ligand are non-toxic and inert are of utmost priority. After this key component has been reached, the chemical would have to be easily reproducible and commercially viable. As this subsystem would require kilograms on top of kilograms of chemical, making sure that the ligand does not include expensive components, such as precious metal base compounds, would need to be prioritized. Easily reproducible methods would also have to be used to make sure that synthesis does not need to require expensive tools or time-consuming procedures. One other key component of this subsystem would be the complete tunability of the molecule to fit many uses, such as allowing it to have magnetic properties when combined with specific metals, such as iron.

To elaborate on required inputs, most would have to be resources such as time, money, and manpower. Specifically, the largest part of this would be money. Securing a laboratory and research group to develop a reproducible chemical ligand that is non-toxic both before and after chelation. This money would need to also buy chemical components needed for mass synthesis of the ligand, such as chemical tools, base materials and compounds, and personnel required to work on synthesis.

3.4.5. Graphical Representation/Simulation

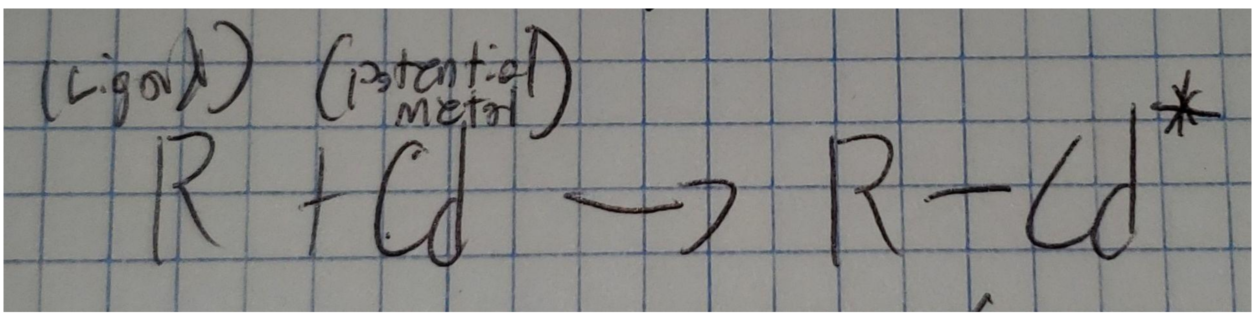

Fig. 1 - Potential Chemical Equation Symbolizing Ligand (R) Reacting with a Metal (Cd)

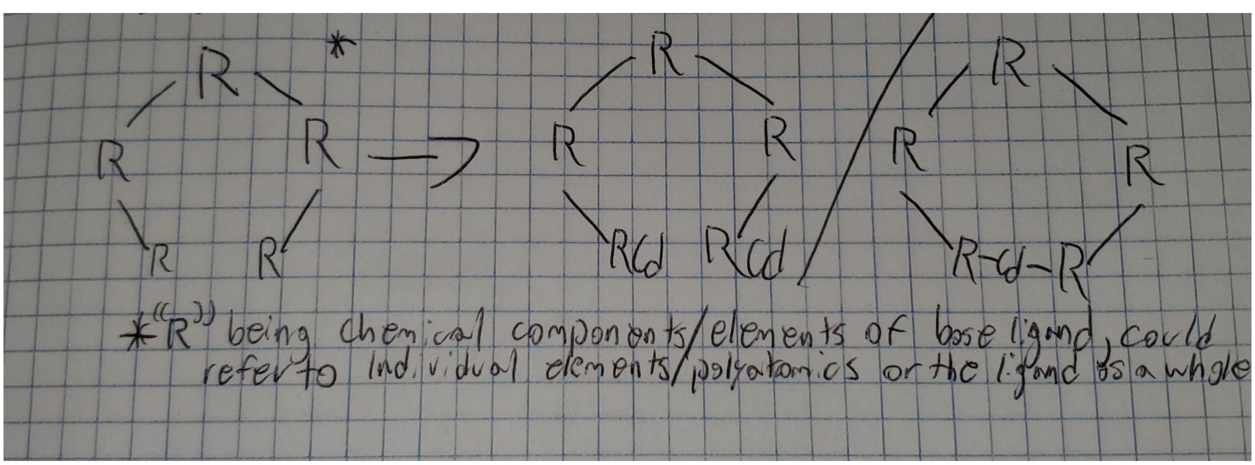

Fig. 2 - Line-Bond Structures Symbolizing a Molecular Geometry of a Potential Ligand

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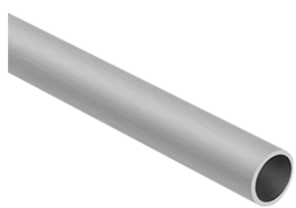
3.5 Andrew Nester : Solar Power Subsystem

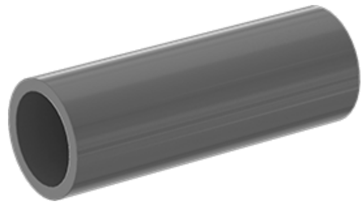
3.5.1. Solar Power Subsystem Description

This subsystem is an alternate power source to the hydroelectric power system. This subsystem will include a solar panel, and antenna for communications, the transportation and storage of energy in a capacitor based inside the sensor housing module, an arduino chip inside the sensor module which will analyze and send data out through the antenna using radio waves. The objective of this subsystem is to collect energy from the solar panel and store it as extra energy incase of a hydroelectric power generation failure and to send collected information regarding the current state of the water the sensor is in to data centers where information can be analyzed about potential acid mine drainage.

In order for this system to work properly there are a few things that need to occur. The solar panel must be fairly small, producing around 5 volts of energy and have an IP-68 rating which is the highest waterproof rating, and on top of those things the solar panel must also survive the harsh conditions whilst requiring little to no maintenance. The solar panel needs to be set to the correct angle which would be between 20 and 25 degrees from the ground up for a Rocky Mountain summer to ensure maximum energy production [1]. The angle for winter is not as important since snow is reflective which should make up for the difference in the angle displacement. The antenna for the communications must be able to send a 15-27 megahertz frequency 5 miles in order to reach towers which can further relay information. A metal pole around 8 feet tall with a one inch diameter will house the solar panel and antenna on top of it in order to keep the antenna and solar panel out of ground snow in the dead of winter and to keep them away from ground animals as best as possible. This pole will also need a concrete base in order to make sure that it will stay in the ground and will not be moving around during winter storm activities. The wiring to the and from the solar panel and antenna will travel through the main base pole into another piping system which will take it to the sensor housing module. Both of these pipes will need to be water resistant and animal proof in order to ensure the safety of the wires, an underground path could be utilized. The computer chip needs to be housed inside the sensor unit where it can be safely protected against all influences, the same can be said for the capacitor. These components cannot freeze or have any sort of interaction with water.

Some off-the-shelf components will include the computer chip, the pole used to elevate the solar panel and antenna, the materials used to house the wiring, the antenna, and the capacitor.

Product	Photo	Description
Telescoping Weld-Together Rails (round) 8 feet tall, 1 inch diameter	 Figure 1: Steel pipe [2]	This product is a steel pole which can be sealed into the ground with a concrete base, it will house the solar panel and antenna, as well as the wiring.
Arduino UNO Rev3 Microcontroller Board, ATmega328P	 Figure 2: Arduino Chip [3]	This product will house the data collected by the sensor and will send it to the antenna.

PVC Piping 1 inch diameter	 Figure 3: PVC Pipe [4]	PVC pipe will be used to transport the wiring from the antenna pole to the sensor housing safely, it is waterproof, and may be buried.
Maxwell Durablue 16V 500 Farad Supercapacitor Battery	 Figure 4: Capacitor [5]	This device will be used to store the extra energy produced by the solar panel and the hydroelectric systems.

Generally speaking, an 8 foot steel pole will be used to house the solar panel and the radio antenna. The antenna would be about 2-3 feet tall and attached to the top of the pole, it would need to be constructed with waterproof materials. The solar panel would also be attached to the top of the pole using some type of steel bracket, this solar panel would need to use waterproof materials and would only need to be about 1 foot wide and 2 feet long to produce more than enough energy. The capacitor would be about 9 by 5 by 8 inches which would be small enough to fit into suspected housing units for the sensor equipment. Lastly the amount of wiring would be subject to many differing factors that depend on location. Where the solar panel and antenna would be best suited for maximum sunlight, where the ground is stable enough to lay concrete, and possibly where it could blend in the best. The same goes for the PVC piping which will house these connection wires, it would depend on how far away the pole is from the sensor, whether the piping will be run underground, or what obstacles may be in the way.

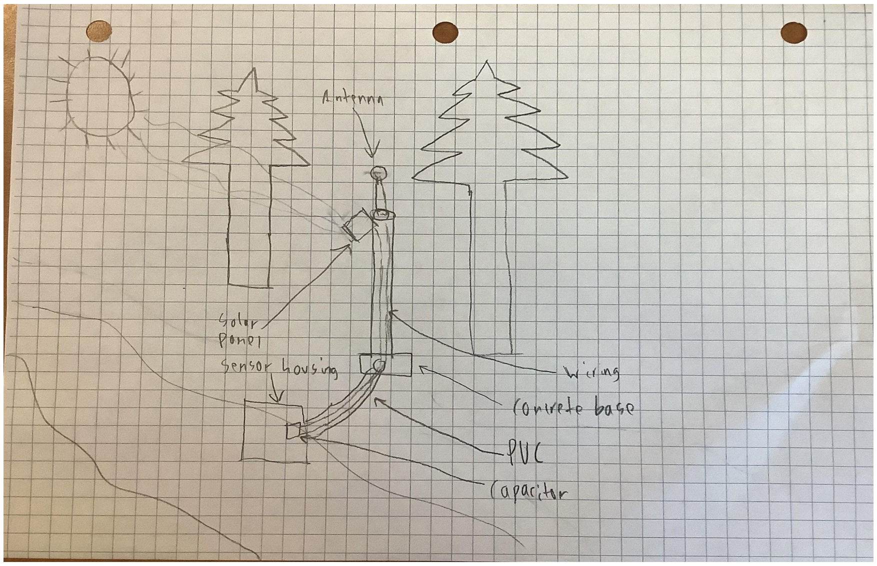


Figure 5: Solar panel subsystem in context

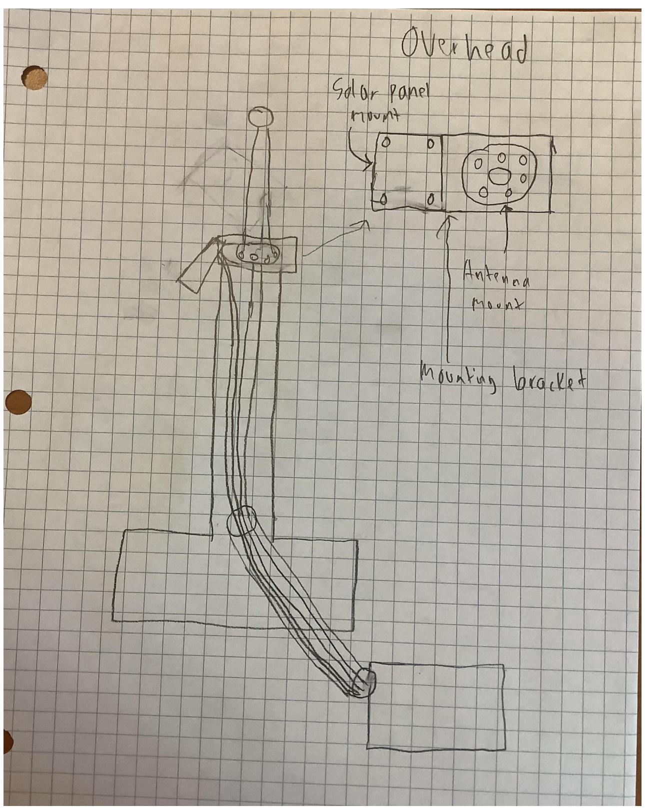


Figure 6: Solar panel subsystem close up and potential mounting bracket sketch

3.5.2. Idea Generation and Decision Making

There are many choices to choose from when it comes to a power source for the pH sensors. Some of these ideas include wind turbines to harness wind energy, batteries, nuclear, solar energy, and hydroelectric energy.

The idea for nuclear energy was simply not feasible. The power output needed would be far too great than the purposes that are needed to power a communication array and a pH sensor. It would also be unfeasible to try and build a nuclear reactor small enough to fit into the confines that are needed for the project. This doesn't even mention the potential environmental disaster that can occur from the use of nuclear fuels. Storage of spent fuels would also have to be specially procured and stored for a long period of time. The only upside would be the amount of energy that can be produced and how long the reactor could be sustainable for the sensors.

The idea for wind, while sustainable, is also not a good option. The rocky mountains do get high wind gusts at times but not consistent wind, it would also require a much higher elevation above the trees in order to maximize the energy output. Wind turbines would make it much harder to hide the sensors environmentally, they also pose a potential hazard to wildlife, need a large amount of open space to work, and they require a lot of maintenance as they contain many different moving parts which would be difficult in the remote parts of the Rocky Mountains. Lastly a wind turbine needs electricity in order to start moving which would be an issue seeing as how the wind turbine would be the sole power source that is generating energy.

The idea for batteries is definitely feasible for the use of the sensors. Batteries would last for a period of time while also providing enough power for all of the systems to work as designed. Batteries would also be fairly cheap, with the downside being the need for the batteries to be changed, and disposed of. With the idea of these sensors being potentially in areas where they could have little to no access, they need to have the ability to run for potentially a few years at a time. This would make the idea of batteries as a powersource inefficient.

Hydroelectric energy was chosen to be an energy source to power the sensors. Since the sensors would be placed in a moving body of water this would make sense, the sensor could cheaply generate power, and generate it sustainably. The water would drive the hydroelectric turbine which would produce energy to power the systems inside the sensor. The problem with this subsystem could be the result in the system breaking or being struck by an object moving down river, this is a reason why 2 different sources of power are being used.

Solar was decided as a secondary energy source for the pH sensor. This makes sense as the sun rises everyday in Colorado, giving it a chance to collect solar radiation from the sun and convert it into energy. The solar panel would not have to be very big to produce the small amounts of power needed. The only issues with the solar panel is that it needs to be placed in a position in order to obtain maximum exposure to the sun, and it could be susceptible to weather impacts or animals. With the right materials used, the solar panel will brave the harsh winter conditions and should be able to go for lengths of time without maintenance due to the durability of the panel.

3.5.3. Subsystem Validation

There are many different numbers and calculations that have to go into the process of making sure the subsystem will be functional. A typical solar cell will produce between .5 to 1 volt, the current plan is to have a 5 volt solar cell, which would be between 5 and 10 cells in the solar panel. A 1 by 2 foot solar panel should have more than enough cells to produce the output needed [6]. To send a radio signal, around a 7 volt burst will be required, and this energy will come from a capacitor which can store up to 16 volts of electricity, in case more than one burst needs to be sent [5].

Solar panels built with the right materials will be waterproof and anti-freeze [7][8]. The angle the solar panel is set matters because the sun is at different points in the sky depending on the location laterally throughout the world, for around the 49th parallel that angle is between 20 and 25 degrees off the ground [1]. Solar panels also can work underwater at depths of up to 50 feet as long as they have an IP-68 rating [9]. The adhesive attached to solar panel glass panes can have a great impact on whether or not the solar panel will be damaged in the event of a hailstorm. Depending on the material used as an adhesive, impacts to the glass pane will be spread throughout the solar panel so as to take stress off of the glass and thus makes the solar panel itself more durable to survive harsher conditions [10].

According to stakeholders and solar panel users, solar panels are a great investment and are a good way to cut costs on energy, which would apply to the power question. Over time the solar panels will pay for themselves compared to constantly subbing out batteries or doing maintenance on wind or other forms of energy [11]. High quality solar panels must be used in order to get the maximum potential out of them and to not have a solar panel end up in a landfill where it is spreading toxic waste [12]. For the purposes of this design high quality must be used in order to have the durability and life span desired although this will cause the overall price of the design to increase a significant amount.

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3.6 Dawson Mueller : Sensor Housing Subsystem

3.6.1. Sensor Housing System Introduction

The Sensor Housing Subsystem is the device used to track the PH levels of the rivers they are placed in. Along with a PH sensor they also broadcast through the communication system to a tower in the United States notifying a team about any irregular changes. These broadcasts will happen every 24 hours though most likely the sensor will write down the PH of the river consistently so as to not skip any crucial points when the water changes quickly. The sensor itself will not be very large since the data it's collecting doesn’t require it to be. Most if not all of the sensors will also be submerged in the water. Few parts like the antenna and power cables will not be underwater because they either won't work or would damage the subsystem if submerged.

A device like this is important to have for the solution because it gives responders the required information to deal with Acid Mine Drainage. PH is key to helping find when a river is being Affected by Acid Mine Drainage because of how low AMD can bring the PH of these rivers below safe levels. Humans aren't the only species affected either, animals and fish are hurt even more by AMD. These sensors can give the right information to the right people so they may neutralize the threat.

3.6.2. Subsystem Testing Protocol

There are tons of small things the team could test for this subsystem but the two main places to tackle are the material used for the shell of the sensor and how well the sensor can both function and communicate with the rest of the communication systems. The easier testing would be the material this sensor's shell needs to be. There needs to be a lot of sensors throughout tons of different rivers. That means the material needs to be cheap, durable in a variety of temperatures, water proof, Chemically resistant, and fairly resistant to erosion. The reason it needs to be this way is because not only will there be potentially hundreds of these sensors placed throughout the country but river currents can vary day to day. So it needs to be cheap because of the sheer abundance, it needs to durable because of the wide range on river temperatures, it needs to be waterproof for obvious reasons, chemically resistant as to not dissolve when the solution is put in the water, and finally resistant to erosion because the group don't want to keep replacing hundred of sensors due to the fact the shell can't deal with the rough flow of water. The best way to go about testing this would be to go to nearby rivers with researched materials but if that isn't possible just testing the waterproof or temperature resistant material might be in a tub filled with water or various temperatures and PH levels. Next the group needs to test the actual PH sensor along with the radio signal it uses to send the data.

The PH sensor needs to be accurate, so a controlled test where the team places the sensor in different cups of liquid with different PH levels, preferably water for more accurate results, testing if the PH sensor can detect the accurate PH of these liquids. While that test is self explanatory the radio test may be harder to do. We'd need to test if the sensor can send its data through radio broadcast from antenna to antenna. That would require the team to connect two antennas together to see if the receiving end gets the data from the PH sensor.

3.6.3. Required Build Components

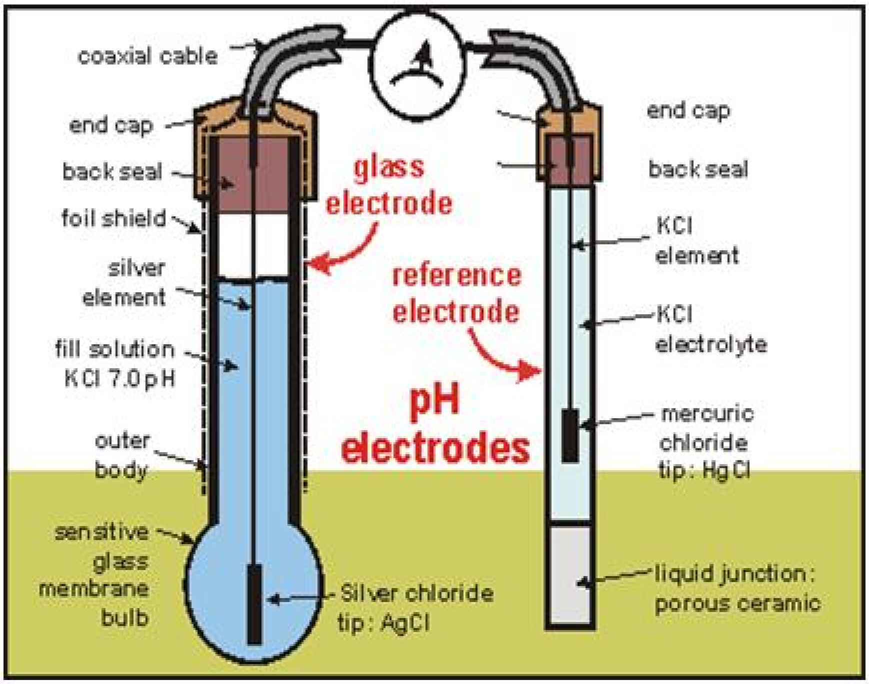
Most of this subsystem is physical so the required materials for building it are very easy to understand. After some research into different potential materials it was clear that there was one material that met the crucial needs for these sensor casings. PVC would be a good choice for the shell because it fits all of the criteria. It's definitely cheap being about $15 to $20 for 0.1'' thick walls and 8 ft in length, it's impact and chemically resistant so there's no worries in it ever breaking easily or being damaged by the chemical solution were using in the water, and PVC is known for its uses with water so it's bound to be waterproof if sealed of welded together well enough. There are even real world applications of PVC on the water since there are such things as PVC boats.

The PH sensor is the next component to the sensor and the smaller handheld PH sensors can cost anywhere from $30 to $40. These sensors do need an outlet to be plugged into and that requires a coding device known as an Arduino. These devices can help the PH sensor deliver its data into a readable form. Arduinos usually cost around $25 for the basic motherboard and will cost more if any additional components are needed. Lastly the data needs to be sent through a frequency so any antenna hooked up to the communication system would work fine in sending that signal.

3.6.4. Subsystem Interfaces

The sensor subsystem works primarily with the communication subsystem seeing where it sends all of its data. The frequency used for data transfer is decided by the communication system as a way to connect all other subsystems without complication. The data will need to be sent every 24 hours without any trouble. So working closely with to make sure the PH sensor is working and sending data to the communication system is necessary.

3.6.5. Graphical Representation/Simulation



(The PH sensor in use)

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4.1 Solution Design, VP, Risk & Mitigation

4.1.1. Value Proposition

When it comes to cleaning up of Acid Mine Drainage, existing solutions are resource intensive, time-consuming, and every action is plagued by red tape due to the unique nature of each mine. The design intends to exhibit value by not only giving novel and economical solutions of the aforementioned issues, but by also including other aspects that improve commercial appeal.

Major cleanup projects for mines usually require massive amounts of resources, such as concrete for plugging mines, and tens to hundreds of workers who have to dedicate their time [1]. One aspect of the design is a relatively hands-off cleanup system via low-cost, reproducible sensors that are self-sustaining and a non-toxic chemical ligand that utilizes passive movement to combat metallic substances. Because of this, it answers these two major issues that most cleanup projects encounter.

In cleanup pursuits, especially in Colorado, legalities comprise a large issue. One aspect of the design is that it is built to be a generic solution, a one-size-fits-all solution for mines. Due to this nature, the team estimates that issues with bylaws and regulations would be relatively minimal. Of course, some issues, such as property claims, are always going to be unique to certain situations. However, major issues with common laws, such as the Clean Water Act, would be easily solved between circumstances due to the generic nature of the design.

4.1.2. Cost Estimation: Works Like Prototype

Item : Description	Pricing (USD)
Turbine	$9.99
Motor	$5.00
Mesh	$2.99
LED’s	$0.99
Arduino Kit (includes wiring and led lights)	$20.00
Arduino Acidity Sensor	$15.00
Aluminum Foil : Simulate Radio Tower	$4.00
Salt	$2.00
Total	$59.97

Table 1: Works-like prototype materials and costs

4.1.3. Cost Estimation: Proposed Full Scale Solution

Item : Description	Pricing (USD)
Solar Panel	$57.37
Metal Pole	$27.83
Wiring	$29.49
Antenna	$15.99
Wiring piping	$30
Concrete Base	$9.16
Capacitor	$100
Computer Chip	$17.99
Turbine	$27.53
Additional Wiring	$4.20
Motor Casing	$8.25
FAA Communication Licenses	$600/yr
Base Station Sensor Data Receiver	$1,250
Sensor Analysis Algorithm Development/Maintenance	$2,500/yr
Sensor Housing Unit	$20
PH Sensor	$35
VHF Antennas	$60
Total:	$6042.81

Table 2: Full scale solution materials and costs

4.1.4. Risk Evaluation & Mitigation

The team's priority is to ensure the safety of all engineers working on the implementation of this system. There are minimal risks in the real world implementation, meaning that there are no life threatening risks; any problems will result in the system down but there is no scenario that could result in life loss due to poor handling. Communication frequency interference is one of the most dangerous threats to the system's functionality, this however is regulated by the FAA and is rarely an issue in real world. This issue is easily mitigated by change frequency; the reason it's of high magnitude however is because all subsystems are interconnected through the communication subsystem so it is a high risk for the operational side of this design.

Likelihood - What is the chance it will happen?	**Very Likely**	**Acceptable risk MEDIUM**	**Unacceptable risk HIGH**	**Unacceptable risk EXTREME**
	Likely	**Acceptable risk LOW**	**Acceptable risk MEDIUM**	**Unacceptable risk HIGH**
	Unlikely	**Acceptable risk LOW**	**Acceptable risk LOW**	**Acceptable risk MEDIUM**
		Minor	**Moderate**	**Major**
		Impact - how serious is the risk?		

Table 3: Risk analysis matrix scale

Risk Assessment and Mitigation Plan				
Risk	**Likelihood**	**Impact**	**Magnitude**	**Mitigation Plan (only for MEDIUM, HIGH, and EXTREME Risks)**
Redissolving of chemical	*Unlikely*	*Major*	*Medium*	*Mitigation include the incorporation of cleanup systems, such as magnetic properties of complex products, and creation of strong bonds bonds between reactants to prevent redissolving*
Negative reactions in the environment due to chemicals(Toxicity, etc.)	*Unlikely*	*Moderate*	*Low*	*N/A*

Reactivity of chemical (Flammability, etc)	*Unlikely*	*Major*	*Medium*	*Mitigation includes extensive safety testing and tuning of chemical properties to render reactant and product chemicals inert from outside forces (Heat from sun, flames from fires/cigarettes/etc.)*
Communication Frequency Interference	*Likely*	*Major*	*High Risk*	*The systems will immediately know when there's radio frequency interference as the input won't match what is expected. The mitigation simply involves changing the system's frequency. There's low risk however because the FFA regulates legal frequency use and ensures that frequencies aren't used by unauthorized ./individuals.*
Electrical Surge (Damage to Onboard Computing)	*Unlikely*	*Major*	*Medium*	*There's an extremely low risk that there's a flaw in the system and water gets into the main computers in the sensors. This will ultimately disable one of the sensors but all others will continue running which is enough to keep all systems operational. To mitigate this problem, it requires that the computer module housing is replaced but this issue is unlikely and can easily be prevented with a good housing design that's waterproof.*
Algorithm Logic Error : Unexpected Output	*Unlikely*	*Major*	*Medium*	*Algorithm logic error usually only occurs once during the development phase. Any logic error that is presented is mitigated through the reprogramming of the actual algorithms inside that determine which actions should be taken. Algorithm logic error is very difficult to occur because it's a one time deal. However if a problem arises with this algorithm, the entire system falls as this algorithm interwindes all the moving parts.*

Solar panel/antenna wires being severed/damaged	*Unlikely*	*Major*	*Medium*	*There is another power source, the hydroelectric turbine, but any damage to the solar panel wires might also damage the wires to the communication system which would make the sensor not able to send information which would be a major issue. Wires will be wrapped in waterproof material and enclosed inside piping to ensure their safety.*
Solar panel being covered (snow, ice)	*Likely*	*Minor*	*Low*	*N/A*
Sensor/ Turbine Freezes	*Likely*	*Moderate*	*Medium*	*There is always back up power (solar) so losing power will not be an issue. As for the sensor, each river will have multiple sensors so the freezing of one will not remove all data.*
Water Damage on Computer parts	*Unlikely*	*Major*	*Medium*	*This is an issue that would need repairing, but it is very unlikely and if it does occur, the sensor would just need to be replaced and evaluated, but thanks to the design the water should never enter the computer components.*
Power cord severed	*Unlikely*	*Major*	*Medium*	*This is such an uncommon occurrence it will likely never happen to any of the sensors. However, even if it does happen the cord will just need to be replaced.*
Turbine clogged (Partially)	*Very Likely*	*Minor*	*Medium*	*This is one of the most common risks in the entire system, but it will not stop the turbine and will just need to be serviced, and there is always the backup solar power.*
Turbine clogged (Fully)	*Likely*	*Moderate*	*Medium*	*This issue is less common than a partial clogging, but is a larger problem. There still would be backup solar power, but the sensor would need immediate service whereas a partial clog only needs eventual service.*
Breakage in the sensors shell	Likely	Moderate	*Medium*	*It's not a major problem if the shell of one sensor breaks because more sensors will be operational throughout the rivers. The risk would be the damage to the electronic parts inside the shell and the potential waste that would get*

				into the river. So the solution would be an immediate clean up team to the damaged sensor.
Damage to the internal electronics	Likely	Moderate	*Medium*	*Again it's not a huge issue if only one of the sensors has their internals damaged but the communication between systems becomes delayed. The solution is to send a repair team to replace the broken sensor for a new one.*

Table 4: Risk analysis matrix

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5.1 Proposed Full Scale Solution

5.1.1. Real World Implementation

The team's concept in a real-world environment would involve sensors like the one pictured below being placed in many different types of bodies of water throughout the United States. These sensors are be able to survive in any type of environment and provide the data needed with little maintenance over long periods of time.

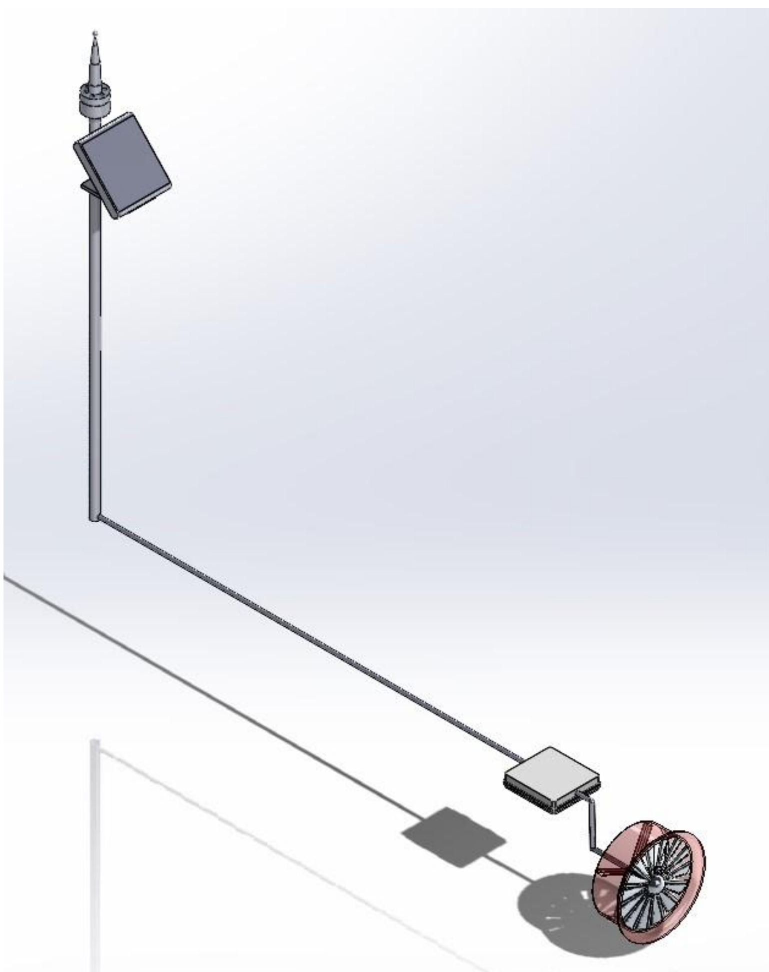
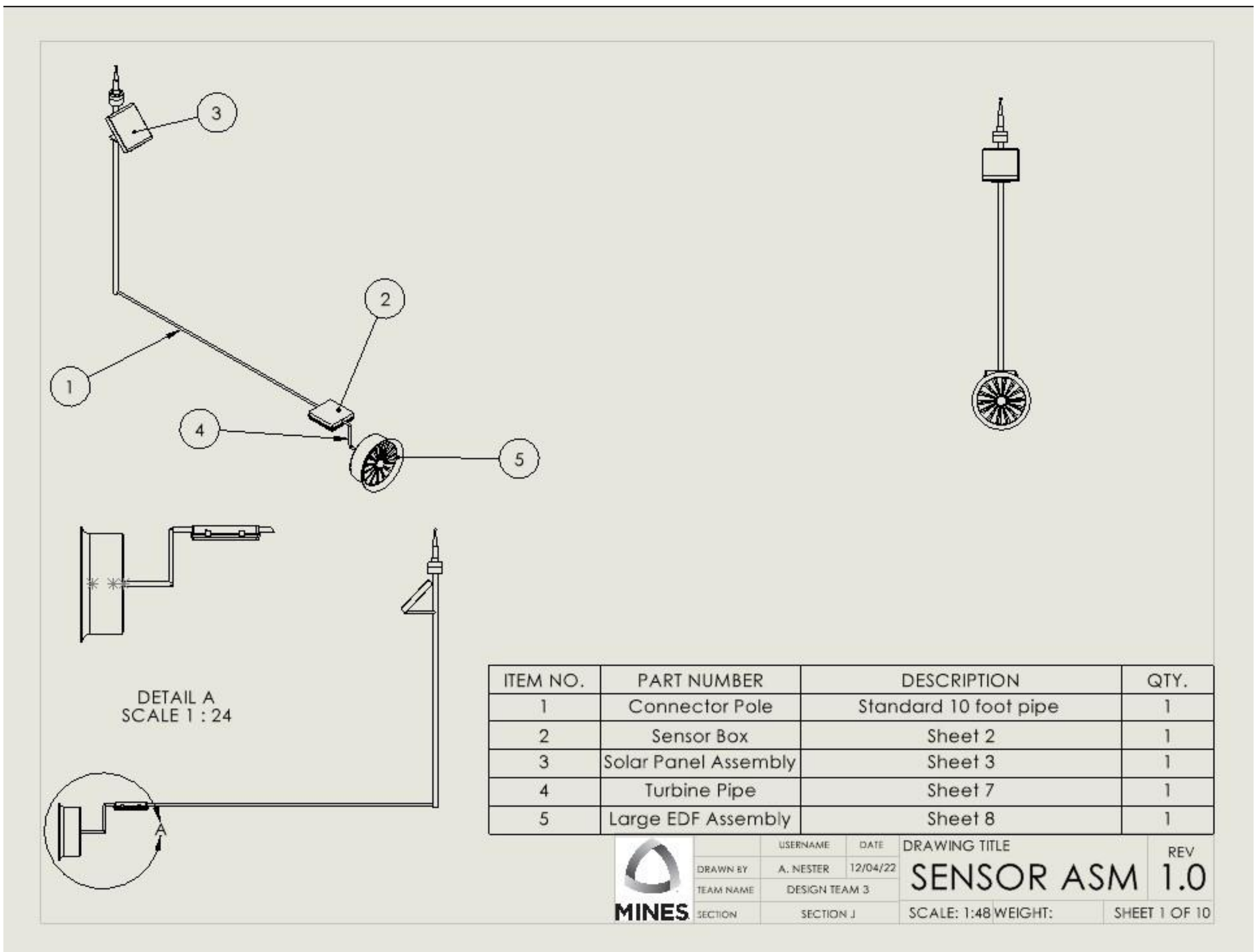


Figure 1: Full CAD Model

This figure depicts what a sensor might look like in a potential real world setting. The turbine would obviously face into the opposite direction of water flow in order for it to generate power. The box would generally be either completely submerged in the water or half in, half out in order to conduct measurements in the water. Lastly there would be a pipe connecting the box to the solar tower where information would be relayed out through the antenna, and secondary power would be generated by the solar panel.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Connector Pole	Standard 10 foot pipe	1
2	Sensor Box	Sheet 2	1
3	Solar Panel Assembly	Sheet 3	1
4	Turbine Pipe	Sheet 7	1
5	Large EDF Assembly	Sheet 8	1

Figure 2: Full Model Drawing

In this figure the team's sensor is modeled in a drawing which includes all of the parts and a full bill or materials. The drawings include the full assembly, and 2 sub-assemblies which would be the solar panel module and the water turbine module. There would also be 2 parts that would be bought straight from the manufacturer, the gearbox for the turbine, and the pipe connecting the solar module to the sensor box. The solar panel might also be bought from a manufacturer but it could also be developed by the team.

5.2 Concept & Specifications

This section will detail some of the aspects of the team's final deliverable. This section will also include user interfaces and functionality of each subsystem of the final solution. All of the numbers listed below are estimations into what the final deliverable might be like if it were to be implemented today. The design will most likely vary slightly depending on the environmental conditions of each place where the final solution is implemented.

5.2.1. Product Specifications

Description	Specification (Near Exact Estimate)
Deployment Space Required	Estimated 24 ft^2
Solar Panel	15 inches wide, 17.25 inches tall, 2.75 inches thick
Antenna Size	16 inches tall by 6 inches wide
Turbine Size	Diameter of 23.62 inches and width of about 9 inches
Sensor box	15.53 inches wide by 13 inches long by 3 inches tall

Sensor Communication Frequency	420-450 Mhz (FAA Cleared)
On-board Computing Wire Type	22 gauge wire for communication and wiring

Figure 2: Design Specification Table

5.2.2. User Interfaces

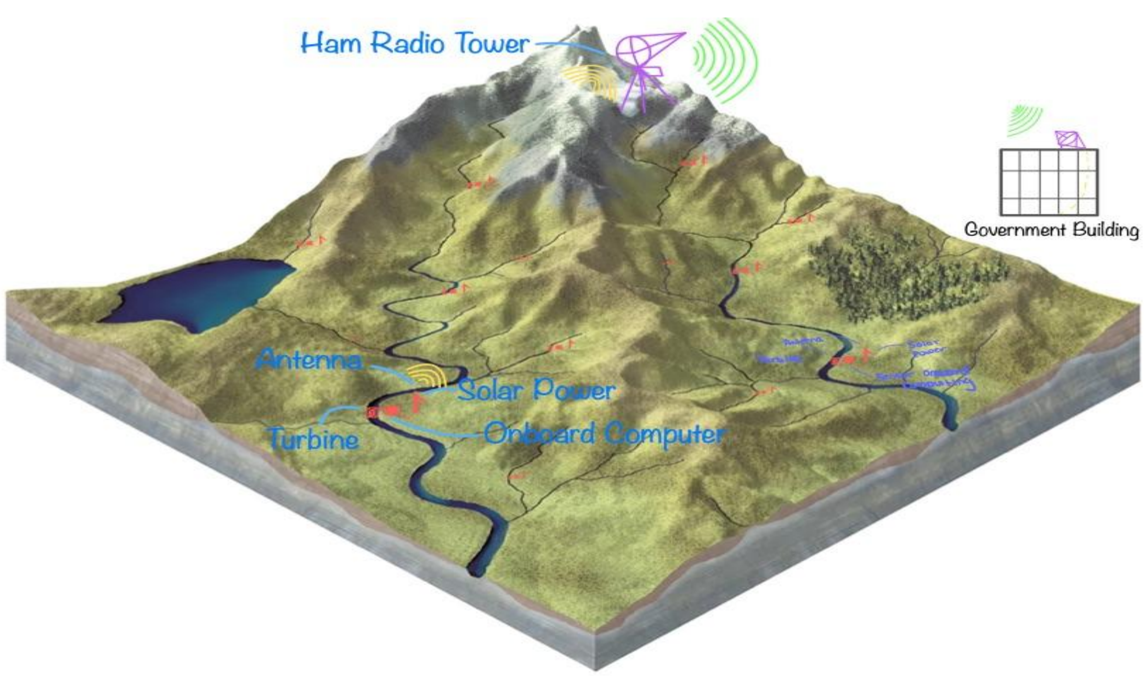
There are a couple of important user interfaces that are involved with the sensor. These can range anywhere from the installation, to the analysis of data, and maintenance. All of these different interfaces are important because they need to work, and be friendly for any type of user that will be involved in any part of the process involved with the sensor.

The first user interface will be with the people receiving the data received from the sensor. In theory each sensor will send its data at the same time everyday to the data center. This data will be organized by are and then more in depth as a sensor by sensor type of data organization. The data will include water temperature, any type of metal contents in the water, pH levels, and any other things that may be deemed necessary and included inside the sensor. This data will be organized so that it can easily be analyzed and a decision can be made using the information in the most efficient way possible in order to stop a potential problem before it can get any worse.

Another interface will be the maintenance of the equipment. The team has designed the solar subsystem and hydropower subsystem to be easy to work on, meaning that they will not be exceedingly extraordinary but relatively well known technology so as to make the maintenance easily doable. The sensor box can also be opened so that if anything inside the box needs to be accessed fairly easily, the sensor might be a whole other problem as the team intends to use many different types of sensors which might involve an innovative design that no one has seen before. The team plans to have the sensor to be little to no maintenance, but only time will tell.

Another user interface will involve nature goers or fishermen. The sensor as a whole will not be dangerous, there will be a mesh protecting the turbine from any non-water object from interfering with the turbine. The goal is also for this whole system to be fairly disguised or camouflage so as to kind of give more of a natural look, similar to some cell phone towers or power lines in much of the Rocky Mountains. The sensor should not inhibit any water activities, it will only take up a maximum area of around 20 square feet but only a small portion of that will be in the river. All wires will be covered inside pipes and the sensor box will not be able to be opened by just anyone, there will be failsafes involved.

The last interface is with the average mine or landowner. If a landowner or mine owner near a body of water wants a sensor installed, they can purchase one and in turn will have access to all of the data involved with the sensor. This should promote accountability in order to prevent any water pollution from mines or landowners. The goal is to limit any type of water pollution in bodies of water, with the main goal being focused on acid mine drainage and metal particulates.



5.3 Concept Validation

5.3.1 Decision Process

Design decisions were made primarily around the idea that solutions generated should address certain pitfalls of current systems in place for AMD recovery. Specifically, common solutions are time-exhaustive, require massive amounts of resources, and may only work for a short amount of time. As such, ideas constantly revolved around the central concept of easing many of these pains. The team wanted the design to be low-maintenance and not have to require a lot of relative input to output something on par with the modern AMD recovery methods. These ideas guided the team to find ways to make the design low-cost and highly reliable after designing an initial product with common material. By using inexpensive materials and by incorporating aspects for sustainability, such as the protective net for the hydroelectric turbine and doubling the RF transmitter as a second power source, the group overcame certain prevalent issues concerning the problem of AMD.

5.3.2 Scholarly & Authoritative Research

As alluded to previously, AMD is an issue that has and is being dealt with in a myriad of ways. Due to this, it was easy to find sources that detail what AMD is, common ways of dealing with AMD, and the extended detrimental effects of AMD. Scholarly research was found in published journals where articles would explore this issue scientifically and thoroughly, such as one concerning toxicity of water affected by AMD [1]. However, a large amount of information was found in authoritative research and documentation done by accredited organizations, subject-matter experts, and governmental agencies. Specifically, the EPA's "Abandoned Mine Site Characterization and Cleanup Handbook" proved to be a plethora of information that acted as a guide into the world of AMD activities and also as a foundation to compare ideas to real-world projects.

5.3.3. Testing

The hydroelectric power generation subsystem was tested in a local water source (Clear Creek) to validate the theory that it could produce sufficient power to power all other subsystems in the sensor. The testing consisted of five test runs, with each run documenting the time interval and the distance a heavy counterbalance wheel spun. With each run being recorded and turned into valuable data, the following table was generated:

Table 1: Raw data from Hydroelectric Power generation Subsystem testing

Raw Data:	Run 1	Run 2	Run 3	Run 4	Run 5
Distance (in):	97.5	95.5	86.3	94.5	98.9
Time (s):	4.13	4.04	4.2	4.46	4.34
Velocity (ft/s):	1.967312349	1.969884488	1.712301587	1.765695067	1.899001536

Average Angular Velocity: 1.862839006 m/s

From average angular velocity, using best estimates on wood density and power conversion, the turbine was given a calculated power output of 0.4881 Watts. This surpassed power requirements for the subsystem, solidifying the necessity of the subsystem. The high power generation by the subsystem led to revisions in the system design. The original expected power output of the turbine was much lower than the actual tested output, leading to the use of more power hungry components in other subsystems. The biggest revelation that came from the testing was the fact that it was no longer necessary to have a solar component for every sensor. The turbine could generate enough power for both constant sensing, but also build up power for data transmission, meaning that for areas where solar panels were cost or use ineffective, the turbine could generate all power necessary for the system. Examples of this include low solar output locations like Canyons or larger flowing bodies of water where the turbine would increase in efficiency.

5.3.4. Analysis & Calculations

The analysis and calculation mainly focused on the two power generation subsystems (solar and hydroelectric), comparing actual power generation to calculated generation for the turbine, and estimates of the power generated by the solar subsystem. The conclusion for the turbine was that it should have produced around 0.6 Watts of power, which matched closely with the 0.4881 Watts of actual power generated by the subsystem. Through simple solar calculation, the panels were given around 16 Volts of power generation, which combined with the turbine was well above adequate power levels necessary. These sets of calculations led to major design ramifications. The high energy output by both sources caused a remodeling of the energy system of the censoring, relaxing the strict energy requirements originally thought to be needed. The wiggle room created the opportunity to use a more accurate, but higher energy sensor, and other energy intensive parts.

5.3.5. Stakeholder Interviews/Feedback

One active stakeholder who was very helpful in guiding initial investigations was Jeff Graves, Director of the Inactive Mine Reclamation Program for Colorado's Department of Natural Resources. Very early on into the design process, the team interviewed Mr. Graves and asked about prevalent issues in all aspects of action concerning AMD, from initial data collection to active cleanup. Graves' input helped to show that an overlooked issue with AMD was data collection; researchers would have to go out and manually take samples, which when compared to the almost 23,000 abandoned mines that could potentially contribute to AMD, makes the task of checking each and every water system in Colorado alone daunting. After learning this, the team was conscious of applying aspects of what Mr. Graves discussed into parts of the final design.

5.4.1. Conclusion

Up to this point, science has failed to provide a way to assess and respond efficiently to mine disasters. Slow responses and expensive clean-ups have cost the government hundreds of millions in wasted dollars, as well as negative press and damaging lawsuits. A proper solution to this emergency would save money and reduce waste pollution in the environment. The project aimed to create a system to neutralize hazardous mine waste. The first iteration had a goal but no effective solution. A single mine disaster such as the Summitville mine can cost upwards of a quarter billion dollars [1]. The passive data collection system offers identification and remediation for a fraction of the cost of other solutions.

The system consists of a self sufficient sensor, able to identify changes in water quality and report back to a central server. A chemical ligand is readily accessible to be deployed when mine drainage areas are located, being dropped over the hot zone to reduce the effects of the waste on the environment. First testing indicated that a hydroelectric turbine could power the sensor's functions, and additional testing via the building of the works-like prototype confirmed the sensor system was viable and self-sustained. After testing the sensor based side of the project, further testing needs to be completed on the ligand and its deployment.

The goal of the project is to mitigate the effects and surprise of mine waste disasters, while decreasing the cost. The sensor is durable and self sustained. The ligand is inexpensive and solves a problem that has continued to be an issue for the past 100 years. An early detection and response to mine waste has the potential to save fish, plants, and infrastructure while reducing economic impacts on local governments and tribes. The environment is a priceless part of the earth that needs to be protected, certainly worth more than a network of sensors and a ligand.

5.5 References

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