THE UNIVERSITY OF BRITISH COLUMBIA, OKANAGAN CAMPUS
FACULTY OF APPLIED SCIENCE, SCHOOL OF ENGINEERING

APSC 169
Fundamentals of Sustainable Engineering Design
Project Report #4 - A2

Water and sediments contamination: Develop technologies for detecting and treating contaminants in water and sediments from mining areas to guarantee water quality and protect aquatic ecosystems and human health

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Chosen Solutions

Novel Solution #2 - Automatic Solution:

Novel solution 2 addresses the often exorbitant prices of environmental cleanup efforts, from the initial construction to the maintenance required for typical water treatment methods. A carousel system of filters reduces the number of costly trips required to these often remote mine locations. This solution takes advantage of natural water flow by having a ramp collection system that collects water from natural waterways for water intake. The water is diverted to an NF90 membrane that removes sulphate and metal contaminants. Each filter is part of a larger carousel-like wheel containing multiple filters and a water flow sensor. When the water flow sensor detects that the flow has dropped below a set threshold, it will cause the entire carousel to revolve, effectively replacing the clogged filter. This system increases the time that the system can go without manual maintenance by multiple times. As an added benefit, the structure that will direct water flow will be constructed with spots for replaceable limestone inserts. This will help with sulphate removal and make the solution both automatic and efficient

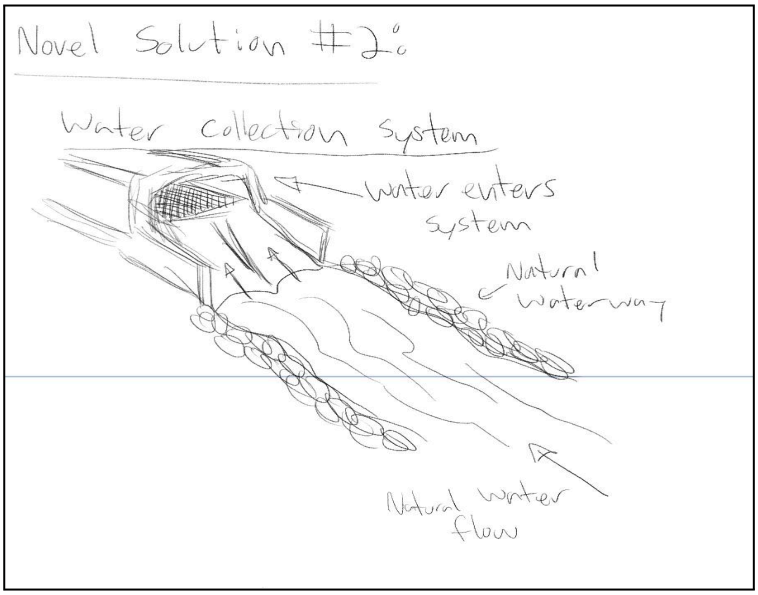

Figure 1: An external view of solution 2 showcasing how water will be collected and treated using a limestone lined pathway

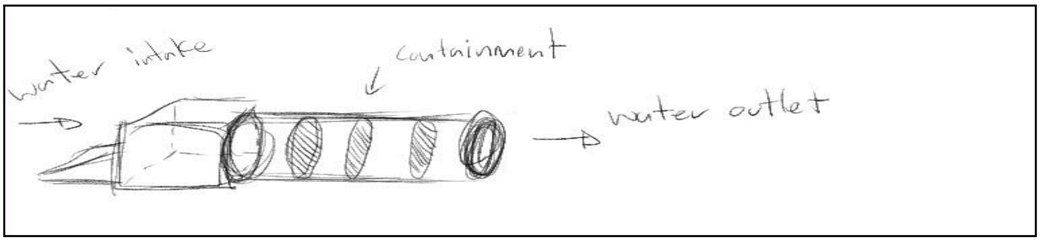

Figure 2: An internal view of solution 2 showcasing how the water will pas through a series of filters

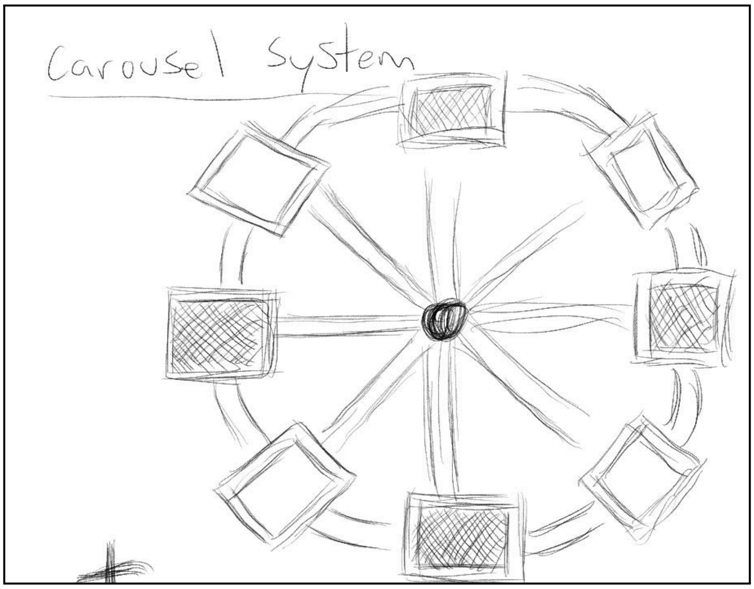

Figure 3: A close of of the carousel system in solution 2, showcasing how each arm will contain a filter

Novel Solution #5 - Natural Solution:

This solution places an emphasis on using the land and working closely with nature. Water intake is managed by digging channels to direct flow towards engineered wetlands. These channels are constructed with slots on the sides for limestone blocks, which can then be dropped into place and replaced once they erode. This erosion process releases limestone into the water, which helps precipitate and remove sulphates from the water. Then, rather than utilizing large water treatment plants to remove heavy metals, the solution utilizes a naturally engineered environment to achieve the same effects. Wetlands containing specifically selected plants, such as Typha orientalis and Cyperus glomeratus, known for their purification effects, will absorb and remove heavy metals and sulphate contaminants (Wu et al., p.1). A water wheel will be placed near the beginning areas of the wetlands to serve as a release timer for supplemental plant fertilizer as well as SRBs for additional purification. The rotation of the water wheel will be geared and attached to an analog timer, and once it rotates enough, the powder will be dispersed. This allows for resources to be saved as the amount of fertilizer and SRBs added to the water is proportional to the amount of intake water, while also not requiring electricity. Manual maintenance must be performed to ensure efficiency in the treatment process.

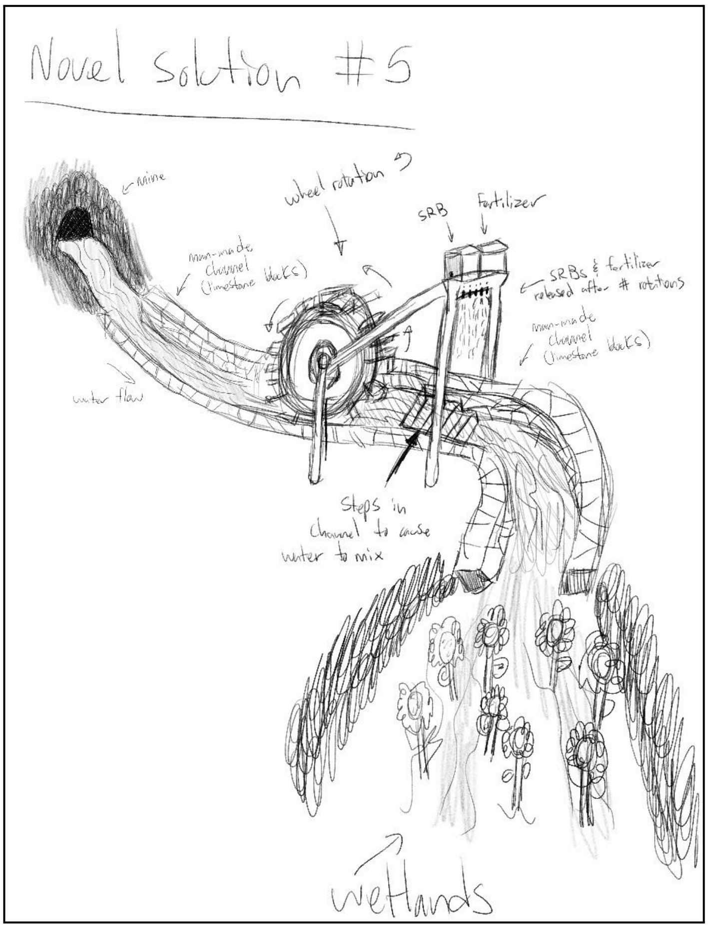

Figure 4: An overall look at solution 5, showcasing how the water flows from the mine adit through the waterwheel and into the wetlands

Novel Solution #6 - Small Scale Precipitation Solution:

The solution bases its water intake on water flow coming out of mine adit, which then accumulates into portable tanks situated outside the mines. Precipitation technologies can then be used to remove heavy metals within the AMD by adjusting the pH to meet the precipitation point of target metals—which can be determined by sensors which release valves allowing for the bubbling of calcium hydroxide to raise, and CO_2 to lower pH. The solution's sensors can then be powered using solar panels or some form of renewable energy, as the energy demands of this solution are miniscule. Waste is managed with the use of manual maintenance. However, it is important to note that rare earth elements can be collected from the sludge and sold off. Essentially, it operates in a similar fashion as the SAVMIN technology developed by Mintek. However, this solution proposes to downscale the operation from a massive operating plant that treats active mine effluent to a small-scale portable solution aimed at addressing individual abandoned mines.

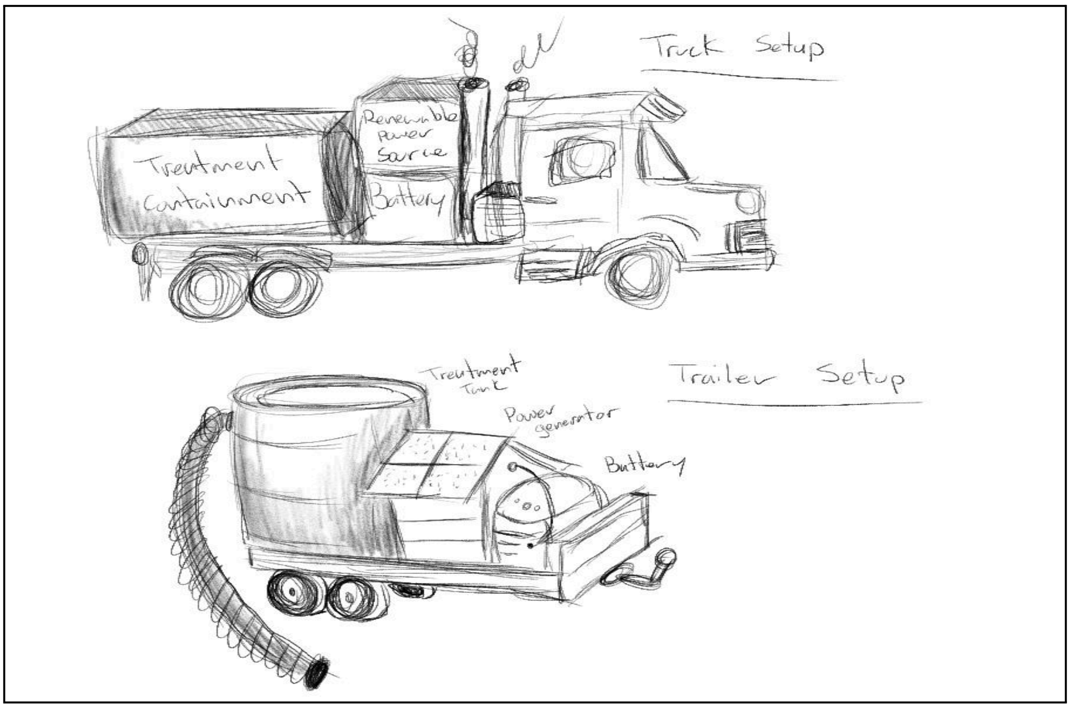

Figure 5: External view of proposed solution 6, which can be placed on a large truck bed and a trailer

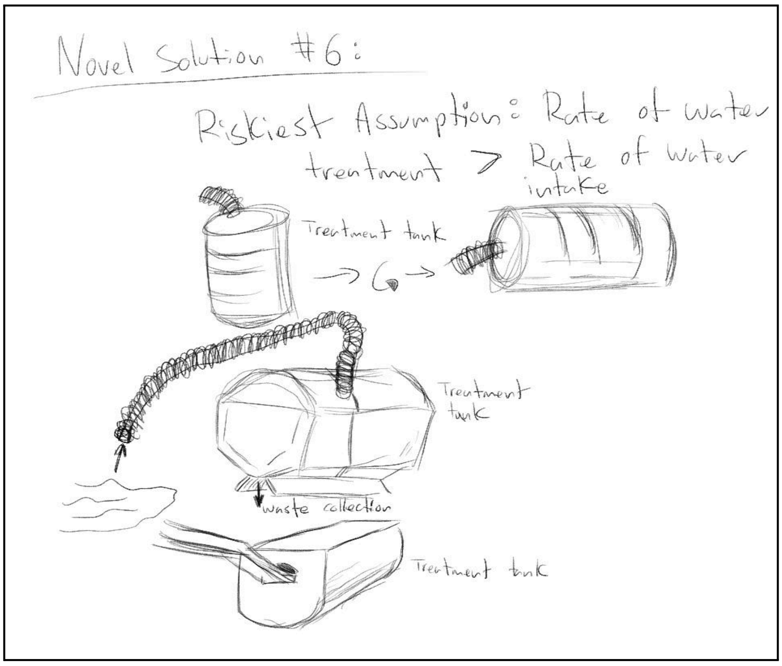

Figure 6: External view of pump that intakes water and

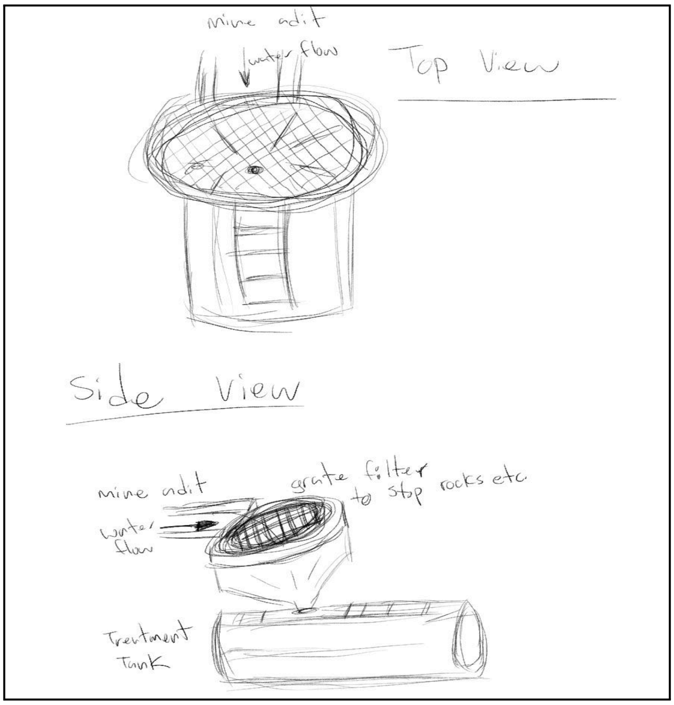

Figure 7: Top down view of solution 6, showcasing intake of mine adit.

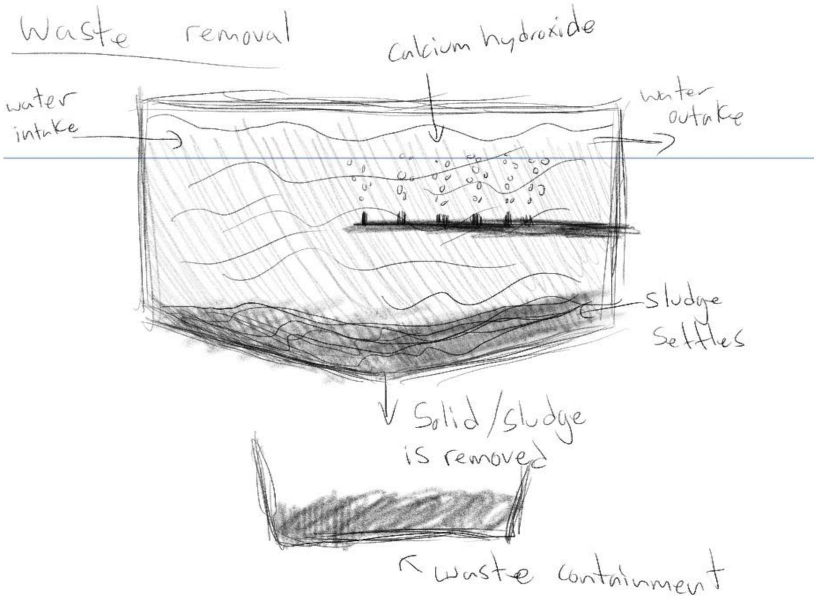

Figure 8: Internal view of solution 6, showcasing how the Calcium Hydroxide will be dispersed and how the sludge will be collected

Risky Assumptions and Low Fidelity Prototyping

Small Scale Precipitation Solution:

The small scale precipitation solution faces multiple risky assumptions that require testing prior to the continuation of the project. Testing prototypes is essential to building and finalizing a design that can carry out the functions intended while still adhering to constraints and objectives of the project. Assumptions made for this novel solution include maintaining a size and weight that can sustain being portable, waste removal and collection, rate of purification, and transporting the solution to the job site.

Maintaining a size and weight small enough to retain portability is an assumption that must be tested for this solution. The consequences of failing this test would result in this solution not being feasible for its intended use. First of all, testing of this assumption was performed by analyzing the literature. An existing solution for liquid transportation comes in the form of tanker trucks. While the proposed solution does not necessarily transfer water from different locations, a tanker truck provides a portable vehicle capable of water containment. An example of a tank on these types of trucks is the TC 407, which can hold up to 10,000 gallons or 38,000 litres of liquid (Odishaw, 2024). With modifications such as the addition of pH sensors, calcium hydroxide valves, a power source, pumps, and waste containment to these tanker trucks, one could carry out the functions of the project while being within the constraints and objectives.

The removal and containment of sludge waste posed another risky assumption that must be followed with tests. The proposed system has constant water intake and output, which works similarly to secondary water clarifiers found in the sewage treatment process. Secondary water clarifiers have water constantly flowing through the system where activated sludge waste settles to the bottom of the tank and into a separate waste collection while water on the upper level of the tank is pumped out as effluent (Pophali et al., 2009). The waste sludge is formed by precipitation of the heavy metals with the addition of calcium hydroxide (Quanyuan et al., 2009). Calcium hydroxide is added via valves that are synced to the pH levels of the water. The literature provided indicates that the assumption made is feasible.

The assumption that the treatment process will work fast enough is a key concern to the feasibility of this solution. If the rate of water flow out of the mine is faster than the rate of water treatment, then water will pool over or bypass the implemented solution without being treated. A 13-month study of adit discharge from abandoned mines focused on mines located in Avoca, South-East Ireland (Gray, 1998). The two adits they studied were the Deep adit and the Ballymurtagh adit (Gray, 1998). The rate of discharge varied depending on the season but it ranged from 6.3L/s to 37.3L/s with the average rates of the mines being 16.9L/s and 17.2L/s respectively (Gray, 1998). Assuming that these average rates are consistent for mines in the Pacific NorthWest, it translates to a discharge of ~270 gpm (gallons per minute). To match the average flow of the adit discharge the solution must pump a minimum of 270 gpm for water intake/output. Water will need a place to pool outside of the treatment operation to account for when the adit discharge is higher than its average rate. Similarly, when the adit discharge is below the average rate the operation will include the water that has accumulated in the pooling area. As long as adit discharge is monitored at the mine site where the solution is located, the rate of purification will be sustainable.

The assumption that the operation can be transported to the abandoned mine site is another assumption that needs further testing. If it is not feasible to transport it to the mine, then the solution will not be able to perform treatment to the water affected by AMD. Furthermore, roads to the abandoned mines may already be available or require some maintenance before they can be used such as pushing back vegetation and clearing debris from the road. Due to the majority of abandoned mines being located in remote locations, it wouldn't be uncommon for these roads to be completely overgrown with vegetation and deemed unusable. In this case, the use of a helicopter would be necessary to transport equipment and machinery to the mine site (Barazzuol & Stewart, 2003). Finally, there are different ways to transport materials or equipment to the job sites ranging from different costs but they all conform with the assumption.

Natural Solution:

A few assumptions were made with the natural solution. The riskiest is that the flow rate will be slow enough for the limestone and SRB to have an effect. As stated in previous reports, limestone and SRB work best with long durations of contact. Meaning the longer the contaminated water is in contact with these two neutralizers, the better quality the effluent water will be. In Taylor et al.'s 2005 research report, they claim that Limestone Treatments must flow at < 20 L/s for satisfactory results (pp. 16-18). However, the effectiveness is also related to the length of limestone used; Brahaita et al. (2017) showcased this effect, where the slowest flow rate, and the longest limestone length, produced the best quality effluent. In their laboratory experiment, they ran flow rates at 25mL/min and 50mL/min, which equates to 4.17×10^{-4} L/s and 8.33×10^{-4} L/s respectively. Although these numbers are not feasible for AMD treatment, their limestone lengths were only 1 or 2 meters long (Brahaita et al., 2017), which would not have provided adequate contact time had the flow rate not been significantly reduced. The proposed solution would have a much larger length of limestone, which would increase contact time without having to reduce the flow rate. Gray (1998) found that the flow rates of a particular mine adits fluctuated between 8.5 L/s and 37.3 L/s. While it seems that the flow rate would typically be kept under 20 L/s, it can sometimes reach double the rate. To control this flow, the waterwheel or branching streams may be used to reduce volume at one site. Longer lengths of limestone could also be utilized to allow longer contact time with the increased flow rate.

Another risky assumption in the design lies within the use of SRBs, as they are typically used in a closed environment and may not be effective outside of a bioreactor. This is because SRBs perform best in oxygen-deprived environments (Li et al., 2024), which a natural wetland is not. Despite this, a study showed that adding 500 mg/L of SRBs to AMD is still effective in treating SO_4^{2-} concentrations between 800 and 2,500 mg/L (An et al., 2023). However, sulphate concentrations can range from 500 - 21,000 mg/L in AMD (Ashane et al., 2018). To accommodate for this large fluctuation in concentration, more than more than 500mg/L of SRBs must be dispensed depending on the quality of the water. Perhaps the "odometer" type mechanism of the water wheel can be customized to dispense a specific amount of SRBs into the water. It should also be mentioned that limestone is also an effective sulphate treatment and thus would reduce the concentration in the water before SRBs are mixed in.

The third assumption made revolves around the efficiency of wetlands in heavy metal removal. This category defied expectations, as it turns out that wetlands are great at heavy metal removal and have many different processes of doing so. The first is catching dense heavy metal particles in their roots (Sheoran & Sheoran, 2006), which is great considering that the majority of the heavy metals will have already precipitated out of the solution thanks to the limestone. This also works for lighter molecules if flocculation occurs (Sheoran & Sheoran, 2006). Flocculation is the process where several particles join up to form "flocs" which become dense and precipitate out of solution (Mettler-Toledo, n.d.). Regardless of how sedimentation comes about, the particles are either caught by roots and leaves or by floating plants in the wetland (Sheoran & Sheoran, 2006). Sheoran & Sheoran (2006) also show that this is the most effective heavy metal removal process, as it removes "75–99.7% cadmium, 26% lead, 75.9% silver and 66.7% zinc". On top of this, there are several chemical processes that occur in wetlands that also treat heavy metals. For example, heavy metals are attracted to the soil or clay at the river bed by electrostatic attraction (Sheoran & Sheoran, 2006). Another example can be seen in a variety of roots which leak out oxygen, which causes iron and manganese to oxidize and fall out of solution (Sheoran & Sheoran, 2006). A final treatment example is found in certain plants like the Vallisneria Spiralis L., colloquially known as "Tape Grass" or "Eel Grass", which absorb heavy metals through cation exchange at their cell wall (Sheoran & Sheoran, 2006).

Despite the effectiveness of certain plants, their location of origin needs to be considered. It would not be wise to introduce an invasive species into an already fragile ecosystem. The assumption that suitable plants can be found is the fourth and final riskiest assumption for this solution. There are a variety of plants that are effective in heavy metal treatment, but not all are native. One such is the aforementioned Vallisneria Spiralis L., which is great for heavy metal removal, but not native to the PNW (Vallisneria spiralis L., n.d.). However, the plant Potamogeton Pectinatus L., or Sago Pondweed, is also a good heavy metal remover, especially for removing Lead (Sheoran & Sheoran, 2006), and is native to the Pacific Northwest (Government of Montana, n.d.). Other plants that help to absorb heavy metals are the Typha Latifolia, or Broadleaf Cattail, and the Scirpus Validus, or Softstem Bulrush (Karathanasis & Johnson, 2003). Both the Broadleaf Cattail (Turner, n.d.), and the Softstem Bulrush (Scirpus validus (tabernaemontani), n.d.) are native to the Pacific Northwest. Further research is required to determine what other potential plants could be used in an artificial wetland. It is important that only native plants are used so as to not disturb the surrounding ecosystem and spur on different problems in the future.

Automatic Solution:

There are many risky assumptions that must be investigated and addressed for the Automatic Solution. The riskiest is whether the rotation mechanism will work as intended with minimal leakage. Unfortunately, this is difficult to test without first conducting real-life tests. This is also the case with the assumption that there will be enough of a pressure buildup for the NF90 filter to properly function.

Other risky assumptions include whether the developed structure will be able to withstand the harsh environmental conditions of the Pacific Northwest. Because of the aquatic environment as well as the variable weather and temperature, any materials used must have a wide operating temperature and water resistance. Otherwise, the system may develop leaks and cause the water to flow out past the pipe or the electronics may fail and not engage the rotation mechanism. Stainless steel could be used for the pipe, as it is durable and has operating temperatures ranging from -200°C to 1400°C (MatWeb, 2024). However, because it will be in contact with water, its ferrous properties may cause it to rust, which is why it is not the ideal selection (MatWeb, 2024). Instead, HDPE can be used, as it has a wide operating temperature, ranging from -180°C to 137°C, and is non-ferrous, so it does not rust (MatWeb, 2024). For the motors, industrial motors can be found that are made to withstand harsh outdoor environments (DirectIndustry, 2024). For the assumption that the water will not need a pretreat, research indicates that that is largely the case with NF90 filters (Hilal et. al, 2005). If the water required a pretreat, the solution would need to be modified.

Performance Against Requirements

The automatic solution, utilizing limestone powder and a carousel-like filtration system, aims to address the functions, objectives and constraints set forth by the need statement made in Report 1, and further revised in Report 3. This solution will “purify contaminated water runoff originating from abandoned mining operations located in the Pacific Northwest”. The automatic solution (solution 2) was chosen due to how well it fulfills and accomplishes these various goals. Although it is not perfect, the mixture of affordability and effectiveness makes it the most optimal compared to other proposed and existing solutions.

To begin, it should be stated that all proposed solutions meet the constraints imposed on this project. These constraints are restated below:

- 100 CAD$ budget for the prototype
- Need proper permitting
- Working within the “Land Reclamation Budget”
- Monitoring the volume of effluent leaving a mine site
- Adhering to the Freshwater Guidelines set by the respective policymakers of the PNW

Additionally, the chosen functions are listed below:

- Must reduce the amount of sulphates in the water*—measured in g/L
- Must reduce amounts of heavy metal contamination in the water—measured in Δg/L
- Must decrease the acidity of water—measured in pH

*The original function was “Must reduce amounts of sulphide contacting water”

Each of the chosen solutions sought to accomplish these functions in their own unique ways. The small scale precipitation solution reduces the concentration of both sulphates and heavy metals alike through the method of precipitation. Precipitation uses Calcium Hydroxide to perform a single replacement reaction with the sulphates and heavy metals causing them to precipitate out. Calcium hydroxide also naturally increases the pH of water (Poorni et al., 2009). Meanwhile, the natural solution uses sulphate reducing bacteria to mitigate the sulphate levels in the water, and wetlands to reduce the concentrations of heavy metals. Limestone blocks supplement those two components in their tasks while also increasing the pH of the water. Finally, the automatic solution uses limestone powder and the rotating filtration system to purify the water. Membrane filters remove 95%-100% of all contaminants (Kapepula, et al., 2024) and the limestone powder neutralises the acidic water.

The previously chosen objectives were the deciding factor when it came to choosing a solution to move forward with. It was found that the automatic solution gave the optimal balance between each of our objectives. Below, the objectives for this project are restated:

- Maximise the variety of heavy metals that can be treated—measured by the number of different heavy metals removed
- Minimise contaminants in water—measured in g/L
- Maximise rate of purification—measured in L/s
- Minimise human control needed—measured in hours spent by workers at a mine site
- Maximise affordability (Cost in CAD$)

The automatic solution was chosen as it undeniably met the requirements laid out by these objectives the best. When it comes to maximising the variety of treatable heavy metals, filtration easily comes out on top. As stated earlier, filters can remove 95%-100% of contaminants (Kapepula, et al., 2024), which is hard to beat. The small-scale precipitation plant can treat water to drinkable standards (Matebese et al., 2024), however not all metals can be treated. For example, monovalent ions cannot be treated, and although these are uncommon among AMD, they are still present (Naidoo & Govender-Ragubeer, n.d.). Finally, the removal of heavy metals in the natural solution is reliant on the type of plants growing in the artificial wetlands. Unfortunately, as mentioned earlier in this report, some of the most effective plants are not native to the Pacific Northwest, and thus cannot be used.

As for sulphate removal, all three solutions fare well. The natural solution uses SRBs to reduce the concentration, however, this would require a lot of stock in order for there to be an effective amount of SRB to treat the incoming sulphates. The small-scale precipitation solution could theoretically reduce the amount of sulphates down to just ~69 mg/L (LORAX, 2003). However, the automatic solution was still chosen because, as mentioned earlier, membranes can reduce 95%-100% of contaminants (Kapepula, et al., 2024).

The weakest point of the automatic solution is the rate of purification. Though the rate can only be determined upon testing, it should be obvious that a given filter can only handle so much pressure before breaking. Unfortunately, there is no apparent statistic to calculate the maximum force a membrane can handle, so this value can only be determined through testing. Regardless of how much this unknown rate is, it seems improbable that it could beat the flow of the small-scale precipitation solution. A full size SAVMIN® plant can process roughly 231 litres of water per second (Mosai et al., 2024c), so even if the small-scale solution was ⅕ the size, that means it would still be able to process more than N.F. Gray's recorded mine adit flow rate of 37.3L/s (1998). As for the natural solution, it can have a more adaptive flow rate, being able to adjust the amount of SRB mixed with the water on demand. However, as previously mentioned, it can be resource intensive to ensure that the higher quantity of AMD is not met by lesser quality effluent. Despite its shortcomings in this area, the quality of the water was not worth the trade-off of a higher quantity of water, especially as the flow rate of water from a mine adit typically is not in the hundreds of litres per second (Gray, 1998).

With all that being said, where the automatic solution really shines is in maximising automaticity. Both the small-scale precipitation solution and natural solution would require a near constant restock of reagents, being calcium hydroxide and sulphate reducing bacteria respectively. While the proposed designs try to factor in these inherent flaws by creating storage space for these chemicals, they will eventually run out, especially as both use them as their primary treatment methods. This would mean that these resources would have to be shipped in, meaning more wages would have to be paid out, and more scope 3 carbon emissions would be produced. Granted, the water filters in the automatic solution would have to be replaced in a similar manner, but they wouldn't have to be replaced as 4 replacements would already be present to take the original's spot. These filters can also be cleaned and reused before truly needing to be replaced. The limestone supply would also need to be replenished occasionally, but with an adequately sized container, one tonne would only last for two to three months as is shown in Appendix C.

Finally, all these solutions are quite costly; especially compared to some of the current solutions on the market. When it comes to upfront costs, both the automatic solution and natural solution would have substantial construction costs. Land would have to be moved, structures, made of metal presumably, would have to be built, etc. Meanwhile the portable small-scale precipitation solution would be built off of a previously existing tanker truck, which would lower these upfront costs. With that said, getting it to the mine site would be expensive. Either old mining roads would have to be re-maintained, or it would have to be flown in via helicopter. On top of that, the tanker, and perhaps the helicopter, would need fuel, yet again increasing costs and likely making it the most expensive in terms of sheer upfront costs. Focusing on the natural solution, its main problem comes in the form of its operating costs. Although there is no exact cost statistic, most sources report SRBs and limestone as relatively inexpensive (Taylor et al., 2005). Despite this, because of the sheer quantity of SRB needed for operation, it will eventually stack up and no longer be a cheap solution. With that said, water filters are not cheap, costing around \$40USD/m^2 (Osipi et al., 2019). However, since filters can be cleaned and reused, there is a more long term benefit behind that purchase. There will be 5 filters in a carousel system, each with a diameter 4 feet (or 1.22m). This means each filter will have an approximate area of 1.17m^2. This means it would be just ~\$234USD for all five filters. Also, because the solution is fed by the pressure of the adit itself, it would have very low electrical costs, only needing electricity for the necessary sensors. A typical reverse osmosis plant, which has to create its own pressure, uses 8.03kWh/m^3 of treated water (León-Venegas et al., 2023), which means that our solution would likely use only a fraction of this amount, thus lowering the electrical costs. Although the natural solution likely would have the cheapest upfront costs, when accounting for the amount of required maintenance and restocking, the automatic solution would still provide the best quality water for the amount of money spent.

Prototyping and Explanation:

Although many risky assumptions were addressed through research, there are certain assumptions which require physical prototyping. To address these, physical prototypes were constructed.

Prototype 1

Type: Works-Like

Purpose: Explore whether a system can be developed that has rotating filters and prevents leakages

To address the riskiest assumption "Will it turn/move as we want it to without any leakage?", a works-like model was developed. If it is not able to turn/move as we want, the entire system will be useless, as the filter will quickly become clogged and cause the water to build up and flow around the pipe. A works-like model was chosen as it allowed for the testing of the filter replacement mechanism, which does not fall into the purview of the other prototype types. The prototype was based on the ideation completed in report 3—a solution that incorporated five holes into a larger disk—and a model was created at 1:36 the scale of the real solution. The overall diameter of the disk was 5 inches, and the outer diameter of each hole was 1.25 inches, which was chosen as it best accommodates the readily available PVC tubing diameter. To attach the filters, inserts with an outer diameter of 1.25 inches and an inner diameter of 1 inch were used. This model was 3D printed and is shown below:

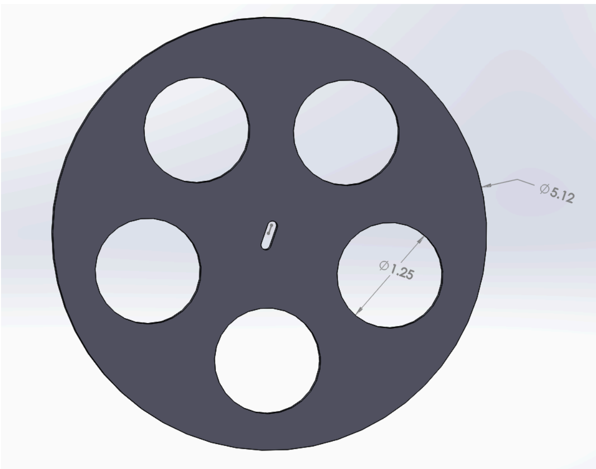

Figure 9: The solidworks model of the initial rotary design

Inserts with a hole side of 1 inch were printed and used to secure a sample filter into each hole as shown in figure 10:

Figure 10: A view of the mechanism holding the filter in place

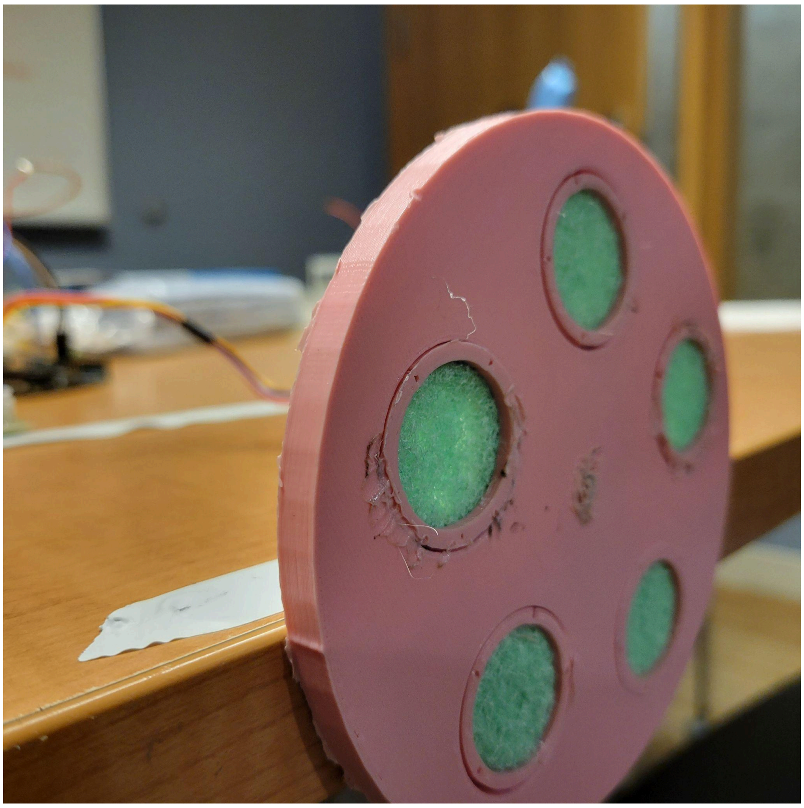

Figure 11: The rotary wheel hooked up to an arduino and a motor

When it was printed, the first thing that stood out was the size of the disk compared to the tubing. It was much larger, which did not seem feasible in a real world application. Thus, a secondary option was considered. Rather than use a single rotating mechanism, a linear option was considered. It had 4 linear slides all in line, each containing 2 holes. One hole was left empty and the other had a filter placed inside. When it came time to replace the filter, one linear piece was moved upward while all others were moved down, which placed only one filter in line. This was modelled in Fusion360 and 3D printed. This mechanism is shown in figure below.

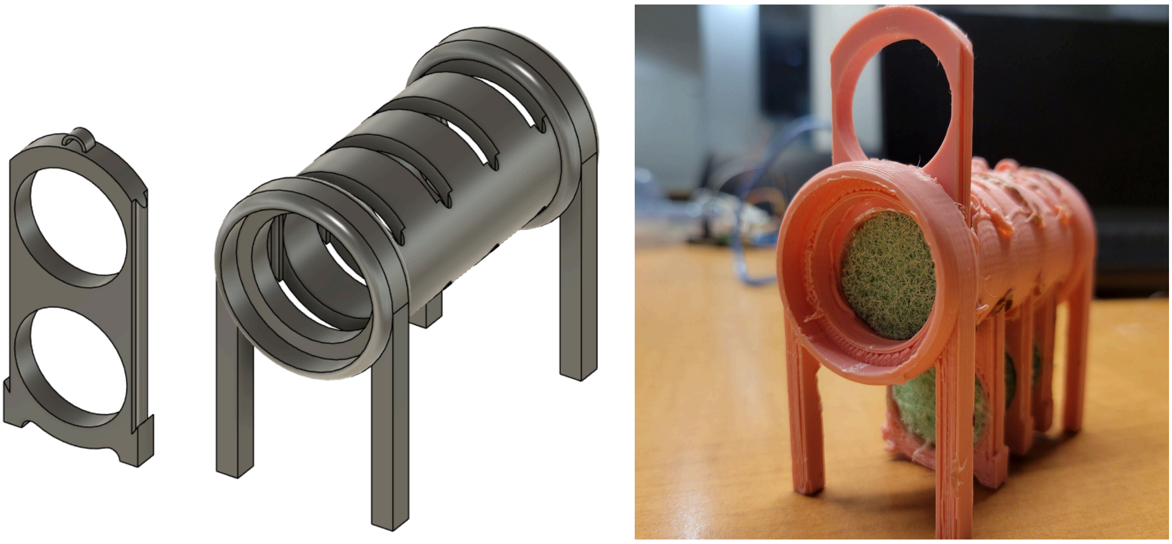

Figure 12: Linear system CAD design and 3D printed

Testing showed that both solutions were successfully able to replace the filter, the rotary system with a single stepper motor, and the linear system with 4 independent servo motors. Thus, an experiment was devised to test whether they allowed water to flow without leaking. A rubber PVC pipe was connected to each solution on one side. 50mL of water was sent down the pipe and the water emerging from the opposite side was captured in a large beaker and measured. The results are recorded below in table 1.

Table 1: Results showcasing the volume of water able to pass through the printed prototypes

Trial	Rotary Design (mL of Water)	Linear Design (mL of Water)
1	35.1	2.43
2	31.1	0.0
3	30.8	0.0
4	31.5	0.0
5	25.2	1.49
Average:	30.7	.8

As table 1 shows, on average, 30.7mL of water made it through the rotary solution. In contrast, just 0.8mL of water made it through the linear solution, showcasing that the rotary solution was vastly better. Some of the leakage may have been caused due to errors in build quality, but these affected both solutions and the difference was too large to ignore. This may be because the linear solution has more points of failure, as each slide must independently move and potentially leak. Each slide requires an individual motor to move, which also vastly increases the power intake as well as the initial costs. Due to these reasons, a decision was made to go with the rotary design with some modifications.

To address the initial concerns with the large size of the rotary solution, the design was modified in Solidworks to decrease the overall diameter of the disk to just 10 feet, rather than the 13.3 feet it would have been in the initial design. Additionally, a rubber gasket was added to the final design to create a better seal and prevent leakage.

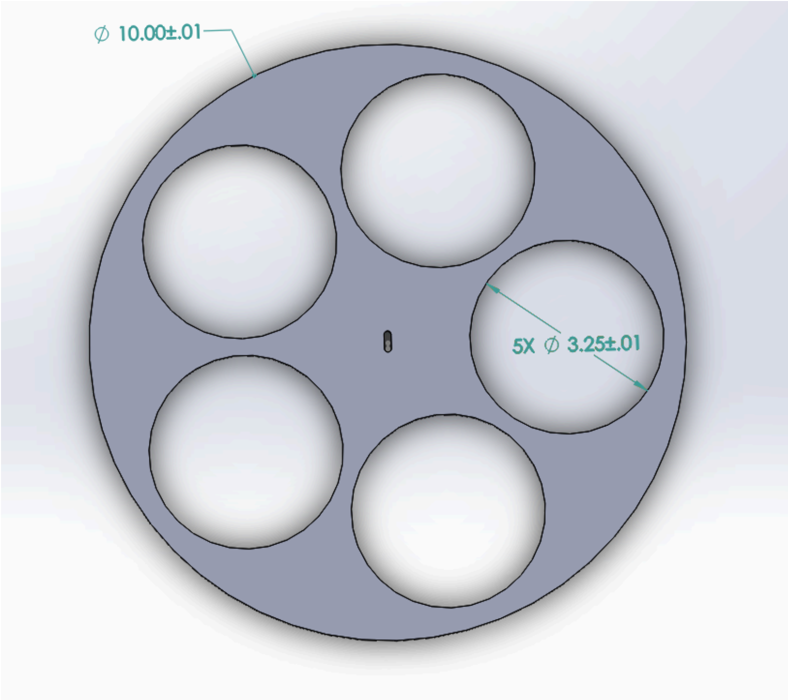

Figure 13: Second solidworks model of the rotary design

Prototype 2

Type: Feels-Like

Purpose: Demonstrate the feasibility of the membrane filter without pressurizing the incoming AMD. Additionally, determine the gradient at which it would need to be applied.

In a real life application, it is crucial that the incoming rate of AMD flow matches the effluent flow rate our solution is capable of in order to prevent flooding and overflow at the entrance of the solution. If the membrane filter is not permeable, the system will simply not work and lead to failure. Thus this prototype will determine whether an NF90 filter will allow for sufficient water flow utilizing only atmospheric pressure—and if so, at what angle?

It is important to consider the following equation for flow rate for the following line of reasoning (J Arcement & R Schneider, 1989):

$$Q = A \times v$$

$$Flow\ Rate = Cross\ Sectional\ Area \times Velocity$$

Under the assumption that the velocity of the stream leading out of an abandoned mine adit and the prototype is the same—as gravity is accelerating water molecules to its terminal velocity depending on the slope. It can be deduced that the flow rate of the solution is directly proportional to its cross sectional area, the calculations of such being showcased in Appendix D.

With the prototype flow rate being approximately equal to 0.5 mL per second—as per Appendix D, the objective of the prototype is to find the angle at which the model scale NF90 filter would allow for an effluent flow rate of 0.5 mL per second.

Figure 14: Releasing water into a tube containing the NF90 filter at a constant rate, to determine the necessary angle

Using a plastic pipette dropper, approximately 0.5 mL of water was dropped into the tubing containing the NF90 filter a second. This was conducted for a minute straight until approximately 30 mL of water had been used. This testing was repeated at different angles, namely: 5, 10, 15, 30, 45, and 60 degrees, yet the result was all the same—the water hardly passed through the filter, most of it just accumulating on the surface of the NF90 filter. At first, we believed that friction with the tubing caused the water to slow down to a point where its velocity was not enough to overcome the force required to pass through the membrane. So we repeated the test for a last trial, straight down at 90 degrees such that the water molecule doesn’t come into contact with the surface of the pipe, nevertheless the result was much the same.

We initially chose the NF90 filter because of its relative simplicity, in being able to completely remove all heavy metals whilst still being dissolved in the water. After this prototype, it’s evident that although this filter would’ve been the ideal membrane, its pores are simply too small for atmospheric pressure alone to push water through. For reference the pores in a NF90 range between 0.3-0.9 nanometers, whilst water has a molecular size of 0.282 nanometers, without an external pressure acting on the water, it is likely that the surface tension will prevail (Hilal et al., 2005).

Though the NF90 filter prototype would have been ideal, we had an alternative membrane in mind, that being the SFP-2880 ultrafilter. In comparison to the NF90, this filter has a much larger pore size at 30 nanometers. Though the larger openings imply a lower pressure required to push through the membrane, it also implies that heavy metals dissolved in the AMD will likely pass through (The Dow Chemical Company, 2013). In spite of that, it is still possible to filter out heavy metals if a pretreatment is administered to raise the pH of the AMD, allowing heavy metals to precipitate out of the water and clump together to form larger particles, that of which the ultrafilter is capable of separating (Mosai et al., 2024c).

Because the design prototype had a constraint of 100 CAD$, and purchasing another membrane filter went beyond our budget, we utilized Manning's Open Channel equation to simulate and determine whether or not the SFP-2880 filter was a feasible alternative.

The method for the calculations of Manning's Open Channel equations, alongside relevant coefficients come from the following publication J Arcement & R Schneider (1989), and all workings will be presented in Appendix B.

From the calculations shown in Appendix B, it is theoretically possible to use the SFP-2880 membrane to filter out heavy metals using the atmospheric pressure and water velocity alone. However, the channel leading up to the filters must be oriented at an approximate 75 degree slope.

From the findings of prototype 2, aspects of our design were changed. First and foremost, a pretreat was necessary as the SFP-2880 filter requires the heavy metals to precipitate out of the AMD in order to function correctly (Mosai et al., 2024c). Thus, a decision was made to bring limestone powder into this solution, where it can release the powder based on pH measurements taken at the base of the pipe. The limestone powder will be stored in a large container beside the mine adit and to the side of the channel, which will be dispersed through a secondary motor feed system. Because the limestone is now being dispersed with an active system, the limestone blocks along the columns of the channel were removed and replaced with concrete so that the system can more accurately respond to the changes in pH without having to account for a secondary neutralizing agent.

Selected Solution Detailed Description/Justification:

The chosen solution addresses the often exorbitant prices of environmental cleanup efforts, from the initial construction to the maintenance required for typical water treatment methods. Streams of water flowing from mine sites are targeted as they eventually lead into larger bodies of water, contaminating the water supply and harming wildlife. The solution requires a solid foundation constructed from reinforced concrete for the purpose of support. Concrete blocks are placed at an angle to funnel the water, which both builds pressure and creates a smaller stream. The number of concrete blocks needed will vary based on the specific conditions of the location, including the stream dimensions and the stream pressure. The funnelled water leads into a 3-foot inner-diameter and 4-metre-long pipe. The pipe diameter and length was determined to allow for a moderate water flow rate so the solution could be efficient without damaging the filters. The pipe will be constructed out of HDPE as it is able to withstand the harsh environments it will endure in nature without deteriorating significantly and is cost-effective, with a price of $1.84/kg (MatWeb, 2024). The pipe contains one set of five SFP-880 Ultrafilters that remove the heavy metal contaminants. The filter set consists of a carousel system that contains five filters and a water flow sensor. When the water flow sensor detects that the flow has dropped significantly below the average—which could imply flooding—the sensors will initiate the carousel revolution, effectively replacing the clogged filter with a new one. This system increases the time that the system can operate without manual maintenance, significantly reducing costs. The carousel itself will be constructed out of aluminum, with an overall diameter of 10 feet, and will contain 5 holes, each with a diameter of 3.25 feet. These will house the filters which interest the pipe. The extra 0.25 feet of space will be used to mount the filters to the carousel using large nuts and bolts, making the filters fully replaceable. This area will also house the rubber gasket that ensures a proper seal around the filter mechanism. The rotation is completed using a small motor mounted above the pipe, directly to the middle of the carousel. The power to drive the motor comes from a waterproof battery that is recharged using a small generator turbine placed within the pipe. Before water can enter the pipe, an elevated metal structure containing 5 tons of fine lime powder will dispense lime into the flowing water using a small motor, also powered by the battery. This is necessary to combat the sulphate in the water and increase the pH as the chosen filter requires a pH of 8 to correctly function. Powdered lime as opposed to limestone blocks allows the dispersion to be controlled with the assistance of a small pH meter placed at the entrance of the pipe. Manual maintenance tasks include replacing the used filters with new ones and removing any debris that has found its way into the system. In addition, debris and wildlife are prevented from entry into the system with stainless steel grates being installed at the intake and output stations. The carousel-design iteration was chosen over the linear-system design because it proved in the testing stage to better prevent water leaks during filter changes and has fewer moving parts, decreasing the likelihood of a failure that requires manual maintenance.

Diagram of Selected Solution

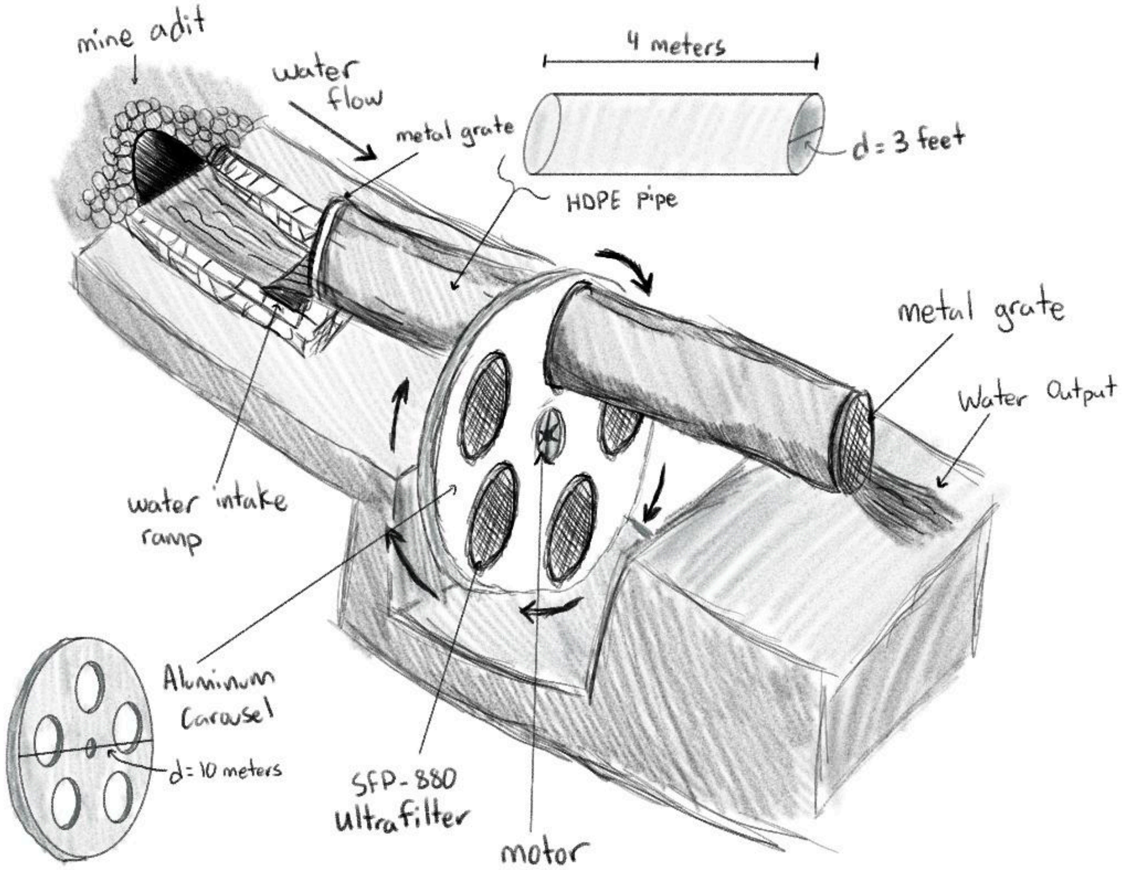

Figure 15: Diagram of final selected solution, showcasing how all parts work in conjunction to treat the water.

Pre-Cost Benefit Analysis Estimations

With reference to report 1, table 1, the governing bodies of the Pacific Northwest place strict limits on 6 heavy metals—aluminium, arsenic, copper, iron, lead, and zinc—in order to meet the freshwater concentration criterion (Bendl, et al., p.11, 2024). Each aforementioned heavy metal has a specific pH for which it precipitates out of the water, in order to precipitate out all of these heavy metals the pH of the incoming AMD must be raised to match the pH of the heavy metal which requires the most basic pH (Mosai et al., 2024c).

Table 2: Most efficient pH to precipitate respective heavy metals from water

Heavy Metal	Aluminum (Al)	Arsenic (As)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Zinc (Zn)
Optimal Precipitation pH	6[1]	4[3]	6.5[1]	Fe(III): 7[1] Fe(II): 4[1]	8[2]	8[1]

Footnotes:

[1]Balintova & Petrilakova (2011)

[2]Water Specialists Environmental Technologies (2024)

[3]Robins et al. (2001)

Table 2 shows that the pH we need to match the AMD to is 8, as this allows for all heavy metals to precipitate out and be caught by the ultrafilter.

Next we must determine the amount of limestone required to neutralize the AMD and reach a pH of 8. Because the amount of limestone required is dependent on the initial pH of the AMD—the pH of the AMD coming out of abandoned mines varies wildly—we will assume the worst pH scenarios to approximate conservative values of required limestone.

The typical pH of AMD coming from abandoned mines range between 2 to 6 (Rambabu et al., 2020). Whilst there is no statistic to describe the average pH of AMD coming from abandoned mines in the Pacific Northwest, after review of multiple AMD case studies in the region, we used our best judgement to choose a case study which seems to be representative of the AMD pH within the region—airing moreso on the extreme side of the pH range to give us more conservative values. This case study was conducted by the Canadian Ministry of Mines & Forests, in which the abandoned mine site had a pH of 2.3 (Spires & Hamblin, n.d.). With this information, we can calculate the amount of limestone required to increase the pH to 8 from 2.3 in a given year.

Method for the calculations shown in Appendix C, come from the following publication (*Size and Performance of Anoxic Limestone Drains to Neutralize Acidic Mine Drainage | U.S. Geological Survey*, n.d.).

Thus, from the calculations in Appendix C, it can be deduced that approximately five tonnes of calcium carbonate is needed to operate the average abandoned mine emitting AMD at a pH of 2.3 for an entire year.

[BLANK SPACE TO RETAIN TABLE FORMATTING BELOW]

Cost-Benefit Analysis

Table 3: Cost-Benefit Analysis

Item	Cost
Initial Construction Costs	$41,417.41
Initial Societal Costs of CO_2	$7,839.06
Maintenance (5 Years)	$6,250.00
Societal Costs of CO_2 in Maintenance	
Year 1	$2,072.86
Year 2	$2,152.28
Year 3	$2,184.05
Year 4	$2,223.76
Year 5	$2,263.47
Total Cost:	$66,402.89
Yearly Benefit (for Real GDP) (5 Years)	-$80,739,759.05
Total:	-$80,673,356.16

Table 4: Present Value Conversion

Item	Future/Annual Value	Present Value
Initial Construction Costs	—	$41,417.41
Initial Societal Costs of CO_2	—	$7,839.06
Maintenance	$1,250.00	$4,738.48
Societal Costs of CO_2 in Maintenance	$2,072.86	$8,147.70
Total Present Value of Costs	—	$62,142.65
Yearly Benefit (for Real GDP)	-$16,147,951.81	-$61,213,442.07
Total Present Value of Costs:	—	-$61,151,299.42

Cost-Benefit Timeline

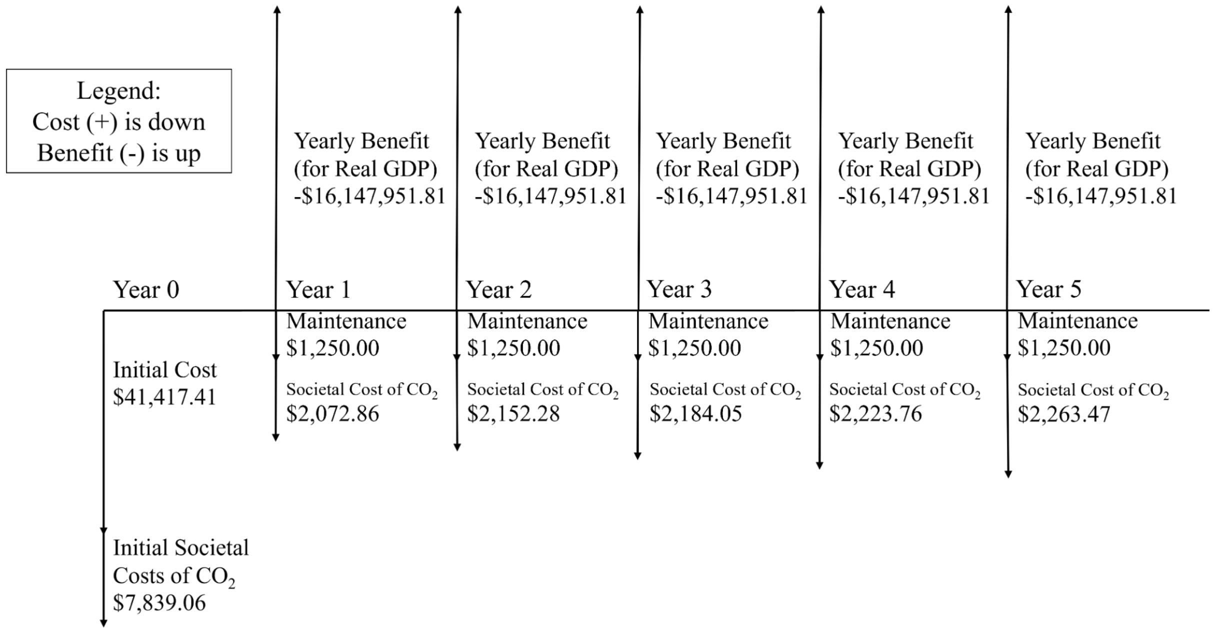

Figure 16: Cost-Benefit Analysis timeline showing costs over 5 years

Cost-Benefit Discussion

It was difficult to prepare a Cost-Benefit Analysis for the filtration project. There were many values that had to be researched or simply assumed to make it possible. So, from top-to-bottom, the values in the CBA will be described, referring to footnotes for certain pricing or mentioning any assumptions made. When it comes to the initial cost, it was mostly a sum of the needed materials from pricings compiled online. These materials were: a foundation with included excavation costs around $2,000[(1)], an Aluminium frame of $2,500[(2)], 4 feet of 3' diameter HDPE Pipe costing $260[(3)] total, 5 tonnes of Limestone powder, costing $120[(4)], 10 Filters costing $37[(5)] each, 50 feet of necessary electrical wires were $63.76[(6)], a $291.72[(7)] pH sensor, a $582[(8)] Flow Rate sensor, a $3,000[(9)] hydroelectric generator, a

\$28,000[10] 400V battery to store that electricity, a 25 HP motor to rotate the filters which cost \$3,509.93[11], two 3' diameter grates costing \$110[12] each and an assumed \$500 for the necessary gaskets and fasteners. Coming to a grand total of \$41,417.41 for initial costs.

The initial societal cost of CO_2 was calculated using several different values. While not all of these listed items had a known CO_2 footprint, multiple sources were used to get the best metric possible, this included the "Idemat" app. Once the total amount of CO_2 was added up, it was multiplied by the 2024 "Social cost of greenhouse gas emissions" metric created by the Government of Canada. It should be mentioned again that footnotes will be used to refer to exact sources for CO_2 quantities. A similar brand of filters produces 9.2kg of CO_2 per unit manufactured[a]. Because the system uses 5 filters, with an additional 5 for replacement, the total is 92 kg of CO_2. The aluminium frame holding the filters has a mass of 6,027kg, which, at a rate of 0.85kg of CO_2 per kg of Al[b], means a total of 5,122.95kg of CO_2 are produced. The electric motor didn't have a specific statistic, but it likely produced around 4,000kg of CO_2 when produced[c]. The 400V battery roughly produced 16,000kg of CO_2 during its production[d]. Limestone creates about 0.785kg of CO_2 for every kg produced[e]. Since 5,000kg are required, this means 3,925kg of CO_2 were produced. The HDPE Pipes produce 1.8kg of CO_2 for every kg of material used[f]. A foot of pipe weighs approximately 98.41 lbs[g] or 44.73kg, and 4 feet were used, bringing the total CO_2 produced for manufacturing to 321.4kg. Finally, the two grates were likely made of stainless steel, which produce 1.94kg of CO_2 per kg of material[h]. Each grate weighed 2.27 kg, meaning it produced 8.81kg of CO_2. In total, 29,470.16kg or 29.47 metric tonnes of CO_2 were produced in manufacturing this plant. When multiplied by the \$266 per metric tonne of CO_2 set by the Government of Canada, a total of \$7,839.06 of societal damage was caused (Government of Canada, n.d.).

Maintenance costs were calculated using the price of 10 filters and 10 tonnes of limestone as it is expected both assets will have to be replaced every 6 months. These prices end up being \$370 per year[5] and \$240[4] per year respectively. We also assumed that a labourer would have to replace these two things twice a year. It was assumed that the labourer would work 4 8-hour days at an arbitrary wage of \$20 per hour. This would bring annual maintenance costs to \$1,250. The CO_2 impact was calculated the same way as before meaning an amount of \$2,072.86 of societal damages are caused. However, the Government of Canada levies a 2% geometric increase on these damages each year, causing small hikes in these costs each year.

The final part of the cost benefit analysis was the return benefit for purifying the water. Going back to N.F. Gray's 1998 metric, a mine adit at minimum will flow 8.5 L/s. This can be expanded to 268,056,000 liters of water being filtered per year. This is important because in 2019, the Government of Canada reported that 16.6 cubic metres of water amounted to \$1,000 of real GDP (Government of Canada, 2019). This equates 16.6 m^3 of water to a \$1,000 benefit to the overall GDP. Converting the former statistic from liters to cubic meters, 268,056m^3, it can be calculated that this single filter adds a whopping \$16,147,951.81 to the national GDP. This number makes all other costs miniscule, which makes it very suspect as to how trustworthy this statistic is. Regardless, these were the numbers that made up our cost-benefit analysis. These numbers show the outstanding importance clean water is to our economy and environment as a whole.

For the present value equivalent of the cost-benefit analysis, we chose to look at a 5 year life cycle of the plant. It is unclear whether the plant can last longer without further testing, hence why 5 years was chosen. The interest rate was set at 10% mostly arbitrary, but was also done to reflect extreme opportunity costs taken when proposing such a plant be built. The final point to mention is that since the societal cost of carbon increases by 2% each year, the calculated value was treated as a geometric series when determining the equivalent present value. The calculations for determining these values are shown below.

Equation for Uniform Future Costs:

$$P = UT_{UP,i,n}$$

$$T_{UP,i,n} = \frac{[(1+0.10)^5 - 1]}{0.1(1+0.1)^5} = 3.79 \text{ (where } i = 0.10 \text{ and } n = 5\text{)}$$

$$P = UT_{UP,i,n} = \$1{,}250 \times 3.79 = \$4{,}738.48 \text{ AND } \$16{,}147{,}951.81 \times 3.79 = \$61{,}213{,}442.07$$

Equation for Geometric Future Costs:

$$P = GT_{GP,i,e,n}$$

$$T_{GP,i,e,n} = \frac{[(1+0.1)^5 - (1+0.02)^5]}{(0.10-0.02)(1+0.10)^5} = 3.93 \text{ (where } i = 0.10,\ n = 5 \text{ and } e = 0.02\text{)}$$

$$P = GT_{GP,i,e,n} = \$2{,}072.86 \times 3.93 = \$8{,}147.70$$

Footnotes:

(1) $2,000 was chosen from looking at what the estimates for a small scale foundation were. The lowest was $1,500, but I thought $2,000 seemed better.

How much does excavation cost? 2024. HomeGuide

https://homeguide.com/costs/excavation-cost

(2) The aluminium frame mass was based on the dimensions of a 10 ft diameter and a depth of 1ft. Aluminium has a density of 2,710kg/m^3 according to this source:

Density of Aluminium. (n.d.). Thyssen-Krupp.

https://www.thyssenkrupp-materials.co.uk/density-of-aluminium.html

From these numbers a mass of 6,027kg was calculated. This value was then multiplied by $0.40/kg to get $2,500. This ratio was provided by the "Idemat" app.

(3) This was based off the price provided by this website; stating HDPE costs $65/ft:
36" HDPE Pipe at 40' Long, (n.d.). National Salvage.
https://pdinationalsalvage.com/products/40ft-hdpe-pipe

(4) There was a calculation error with this one. The website says lime costs $24 per ton, but I read it as $24 per *tonne*, these are different. I wanted to acknowledge this error, while also not having to redo the calculations.
Screenings AG Lime. (n.d.). Fox Landscape Supply.
https://www.foxlandscapesupply.com/materials/screenings-ag-lime/

(5) These are different shaped filters, but are the same grade. They are just meant to be an estimate for this report clocking in at $370 for a pack of 10.
SFP-2880 Seawater RO Reverse Osmosis Membrane Filter Element. (n.d.). Made in China.
https://chinafilters.en.made-in-china.com/product/NOEAIvwolltX/China-SFP-2880-Seawater-RO-Reverse-Osmosis-Membrane-Filter-Element.html

(6) Standard wire used in vehicles; likely the grade needed for this project.
GearIT, 8 Gauge Wire, for Automotive Power/Ground, Battery Cable, Car Audio, RV, Amp, CCA Wire, Wire, Automotive Wire, Amp Kit, Battery Cables, Amp Wiring Kit, (25 feet Each- Black/Red). (n.d.). Amazon.ca.
https://www.amazon.ca/GearIT-Gauge-Translucent-Copper-Aluminum/dp/B09ND1LTM5/ref=asc_df_B09ND1LTM5/?tag=googleshopc0c-20&linkCode=df0&hvadid=706724917140&hvpos=&hvnetw=g&hvrand=10323522090779997250&hvpone=&hvpt

wo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9195845&hvtargid=pla-1872244571672&mcid=acf798d2c7b43c758a73b411a56dd7eb&gad_source=1&th=1

(7) *Heavy-Duty Combination pH Sensor For Submersible Applications*. (n.d.). Omega. https://www.omega.ca/en/control-monitoring/air-soil-liquid-and-gas/water-quality-sensors/p/7352-3-Series?srsltid=AfmBOooNs7eJEpjxOFcFk5jOrzJadpZsA2WA4ZWUHg3qp4gJp0pE3qm-

(8) *Paddle Wheel Flow Sensor – Signet 515, 10"-36" Pipe Diameter*. (n.d.). Streamline Filtration. https://www.streamlinefiltration.com/product/paddle-wheel-flow-sensor-signet-515-10-36-pipe-diameter/?srsltid=AfmBOor38byY9ZTp4mfyEKEw1Lf2rX-CdMFVf2iPiyVlDqqpkYcjoG2q

(9) This number was based on the lowball installation estimate listed at the bottom of the page.

A Guide to Hydro Power. (n.d.). Suneco. https://www.micro-hydro-power.com/A-Guide-to-Hydro-Power.htm

(10) The battery estimate was based off of the Tesla model Y 400V battery as I needed a battery powerful enough to run an electric motor.

Manansala, Joel. (2023). *Tesla Battery Cost: What You Need to Know*. Lectron. https://ev-lectron.com/en-ca/blogs/blog/tesla-battery-cost-what-you-need-to-know#:~:text=Tesla%20Model%20Y&text=Like%20the%20Model%203%2C%20it,estimated%20at%20$20%2C000%20to%20$28%2C000

(11) A 25 HP engine was determined because of a long string of math. The aluminium frame weighed 6,027kg. How much torque is required to move that weight. Using the formula Torque = mr^2a (setting acceleration to 1, and putting in the 10ft radius as 1.524m), I got Torque = 6,027 x 1.524^2 x 1 = 13,998 N*m. Then, as a group, we

agreed we only wanted one second delay between changing filters, meaning the wheel would have to spin at a rate of 12 RPM (because it only has to make ⅕ of the rotation to get to the next filter) in one second. I then used this online calculator:

Torque (Nm) to Horsepower (HP) Conversion Calculator. (n.d.). OhmSchool.com. https://ohmschool.com/torque-nm-to-horsepower-hp-conversion-calculator/

To convert the necessary torque to horsepower (so it would be easier to find an engine). The output ended up being 23.5894 HP, which I rounded to 25, allowing me to find this motor.

Baldor EM4103T. (n.d.). E Motors Direct. https://www.emotorsdirect.ca/item/baldor-em4103t?quantity=1&tab=specs-tab

(12) *Stanbroil 36 Inch Heavy Duty X-Marks Fire Pit Cooking Grill Grates with Support X Wire - Outdoor Round BBQ Campfire Grill Grid*. (n.d.). Amazon.ca. https://www.amazon.ca/Stanbroil-X-Marks-Cooking-Support-36-Inch/dp/B01EH2D274/ref=asc_df_B01EH2D274/?tag=googleshopc0c-20&linkCode=df0&hvadid=706745350762&hvpos=&hvnetw=g&hvrand=5575431753219081095&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9195845&hvtargid=pla-307180648708&mcid=6b7ac38c06513c958519892222975001&gad_source=1&th=1

(a) *CO2 Footprint of TAPP Water Filters certified by the EU*. (n.d.). Tappwater. https://tappwater.co/pages/co2-footprint-of-tapp-water-filters-certified-by-the-eu

(b) This statistic of 0.85kg CO_2 / kg Al was pulled from the “Idemat” app.

(c) This number talks about manufacturing an electric vehicle as a whole, but I just decided to use the full number.

R.B., Lakshmi. (2023). *The Environmental Impact of Battery Production for Electric Vehicles*. Earth.org. https://earth.org/environmental-impact-of-battery-production/

(d) Crawford, Iris. (2022). *How much CO_2 is emitted by manufacturing batteries?*. Climate Portal. https://climate.mit.edu/ask-mit/how-much-co2-emitted-manufacturing-batteries#:~:text=For%20illustration%2C%20the%20Tesla%20Model,kg%20(16%20metric%20tons).

(e) Fagervik, Markus. (n.d.). *Lime and CO2 – What's the big deal?*. Nordkalk. https://www.nordkalk.com/lime-and-co2-whats-the-big-deal/

(f) This statistic of 1.80kg CO_2 / kg HDPE was provided by the "Idemat" app with a reference to:

The Online Materials Information Resource. (2024). MatWeb. https://www.matweb.com/search/DataSheet.aspx?MatGUID=482765fad3b443169ec28fb6f9606660&ckck=1

(g) *36" HDPE Pipe at 40' Long*, (n.d.). National Salvage. https://pdinationalsalvage.com/products/40ft-hdpe-pipe

(h) There was a calculation error here as well. I only calculated the amount of carbon produced by 1 grate, not two. The mass of 4.54kg can be found on this page:

Stanbroil 36 Inch Heavy Duty X-Marks Fire Pit Cooking Grill Grates with Support X Wire - Outdoor Round BBQ Campfire Grill Grid. (n.d.). Amazon.ca. https://www.amazon.ca/Stanbroil-X-Marks-Cooking-Support-36-Inch/dp/B01EH2D274/ref=asc_df_B01EH2D274/?tag=googleshopc0c-20&linkCode=df0&hvadid=706745350762&hvpos=&hvnetw=g&hvrand=5575431753219081095&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9195845&hvtargid=pla-307180648708&mcid=6b7ac38c06513c958519892222975001&gad_source=1&th=1

and the statistic for 1.94kg CO_2 / kg of stainless steel was from the "Idemat" app.

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Appendix A: Meeting Minutes

APSC 169 Team 03 Meeting Minutes

Date: Tuesday October 29th, 2024

Location: ART Floor 1; Room #110

Time: 10:23 am – 11:50 am

Present: Axel Bendl, Zach Boos, Connor Jones, Hasan Mohammad

Regrets: Jacky Zhou

Note-Taker: Connor Jones

Points of discussion:

- Determined what tasks needs to be started
- Assigned tasks to group members

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Develop meaningful solution description	Hasan and Zach	none
Create Sketches	Connor	none
Test riskiest assumptions with low fidelity prototypes	All members	none

Next meeting: Monday November 4st, 2024; 12:30pm-2:00pm at the Library/online

We hope to share our progress on our tasks and make sure the report is on schedule for completion.

Meeting adjourned: 11:50am

APSC 169 Team 03 Meeting Minutes

Date: Monday November 4th, 2024

Location: UBCO Library / Online

Time: 12:30 am – 2:00 pm

Present: Zach Boos, Connor Jones, Hasan Mohammad, Jacky Zhou

Regrets: Axel Bendl

Note-Taker: Connor Jones

Points of discussion:

- Determined what tasks needs to be started
- Assigned tasks to group members

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Develop meaningful solution description	Hasan and Zach	none
Create Sketches	Connor	none
Test riskiest assumptions with low fidelity prototypes	All members	none

Next meeting: Tuesday, November 5th, 2024; 10:25 am - 11:50 am.

We hope to share our progress on our tasks and make sure the report is on schedule for completion along with discuss the topics of the lecture.

Meeting adjourned: 1:54pm

APSC 169 Team 03 Meeting Minutes

Date: Tuesday November 5th, 2024

Location: ART Floor 1, Room #110

Time: 10:25 am – 11:50 am

Present: Axel Bendl, Zach Boos, Connor Jones, Hasan Mohammad, Jacky Zhou

Regrets: N/A

Note-Taker: Connor Jones

Points of discussion:
- Confirmed tasks
- Assigned new tasks to group members
- Discussed lecture topic
- Discussed low fidelity prototype designs

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Cost Benefit Analysis And additional justification.	Jacky, Zach, Connor	none
Medium fidelity Prototypes	Axel and Hasan	none

Next meeting: Friday, November 15th, 2024; 3:15 am - 4:25 am.

We hope to share our progress on our tasks and make sure the report is on schedule for completion.

Meeting adjourned: 11:50pm

APSC 169 Team 03 Meeting Minutes

Date: Friday, November 15th, 2024

Location: ART Floor 1 / Online

Time: 3:15 pm – 4:25 pm

Present: Axel Bendl, Connor Jones, Hasan Mohammad, Jacky Zhou

Regrets: Zach Boos

Note-Taker: Connor Jones

Points of discussion:
- Confirmed tasks
- Assigned new tasks to group members
- Discussed medium fidelity prototype designs and test results

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Cost Benefit Analysis	Jacky, Zach, Connor	none
Medium fidelity Prototypes	Axel and Hasan	none

Next meeting: Monday, November 18th, 2024; 12:30 pm - 2:00 pm.

We hope to share our progress on our tasks and make sure the report is on schedule for completion.

Meeting adjourned: 4:25pm

APSC 169 Team 03 Meeting Minutes

Date: Monday, November 18th, 2024

Location: Library / Online

Time: 12:30 am – 2:00 pm

Present: Axel Bendl, Zach Boos, Connor Jones, Hasan Mohammad, Jacky Zhou

Regrets: N/A

Note-Taker: Connor Jones

Points of discussion:

- Confirmed tasks
- Assigned tasks to finish report
- Discussed medium fidelity prototype test results and modifications

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Cost Benefit Analysis	All Group Members	none

Next meeting: Tuesday, November 19th, 2024; 10:00 am - 12:00 am.

Meeting adjourned: 2:05pm

Appendix B: Manning's Open Channel Equation Calculations

Equation for dynamic pressure, rho represents the density of AMD which is approximated to be the same as water at 1,000 kg per cubic meter, v represents the speed of the AMD.

$$P = \frac{1}{2}\rho v^2$$

$$v = \sqrt{\frac{2P}{\rho}}$$

In the specification sheet that DuPont created for the SFP-2880, it is stated that the maximum TMP pressure on the filter is 2.1 bar, while typical operating pressures occur account 1.4 bar (The Dow Chemical Company, 2013)

$$P_{filter} = P_{atmospheric} + P_{dynamic}$$

$$P_{dynamic} = 140,000\,Pa - 101,325\,Pa = 38,675\,Pa$$

Combining both equations we get that the velocity at which water is required to flow to permeate through the membrane is:

$$v = \sqrt{\frac{2\times 38,675}{1,000}} \approx 8.79\frac{m}{s}$$

With the velocity of the water being known, we can apply Manning's Open Channel equation to solve for the slope required to create this velocity. It is said that v represents the velocity of the water/AMD, n represents Manning's coefficient of roughness, and R represents the hydraulic radius, which is a fraction of the cross sectional area of the flow divided by the wetted perimeter.

$$v = \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

Solving for slope yields:

$$S = \left(\frac{v \times n}{R^{\frac{2}{3}}}\right)^2$$

Because it would be impractical to test for n and R, we will use approximations and assumptions. For instance allow n = 0.01 as this is the typical coefficient for a fairly smooth concrete base, we will also assume that the cross sectional area of the flow is to be a semicircle (J Arcement & R Schneider, 1989). Thus the hydraulic radius for a semicircle is:

$$R = \frac{\frac{\pi \times r^2}{2}}{\frac{2 \times \pi \times r}{2}} = \frac{r}{2}$$

R is written in terms of the radius of that semi circle, we can solve for this radius by considering the velocity of the AMD, which we said earlier was 8.79 meters per second, and the flow to be 0.6 liters a second (Kalin & Chaves, 2003).

$$Q = A \times v$$

$$A = \frac{Q}{v}$$

$$A = \frac{0.006}{8.79} \approx 6.83 \times 10^{-4} m^2$$

$$\frac{\pi \times r^2}{2} = 6.83 \times 10^{-4} m^2$$

$$r = \sqrt{\frac{6.83 \times 10^{-4} \times 2}{\pi}} \approx 0.020m$$

After we solve for the radius, we can plug this back into the equation R to get us the hydraulic radius, and then the slope.

$$R = \frac{0.020}{2} = 0.01m$$

$$S = \left(\frac{8.79 \times 0.01}{0.01^{\frac{2}{3}}}\right)^2 \approx 3.59$$

A slope of 3.59 is implicit of a 3.59 meter drop for every horizontal meter outwards, this angle can be solved using trigonometry.

$$cos(\theta) = \frac{1}{3.59}$$

$$\theta = cos^{-1}\left(\frac{1}{3.59}\right) \approx 73.8° \cong 75°$$

Appendix C: Yearly Limestone Requirement Calculations

Using the statistic that 0.6 liters of AMD flow out an abandoned mine adit a second, we can calculate the volume of AMD that is emitted in a year (Kalin & Chaves, 2003).

$$Volume_{year} = 0.6\frac{L}{s} \times 31,556,952\frac{s}{year} \approx 18,934,171\ L$$

At respective pH's we can determine the hydrogen ion concentration, which we can then use to calculate the total moles of AMD [H+] that need to be neutralized (*Size and Performance of Anoxic Limestone Drains to Neutralize Acidic Mine Drainage | U.S. Geological Survey*, n.d.).

$$At\ pH\ 2.3:\ [H^{+}] = 10^{-2.3}\frac{mol}{L}$$

$$At\ pH\ 8:\ [H^{+}] = 10^{-8}\frac{mol}{L}$$

$$\Delta pH:\ [H^{+}] = 10^{-2.3}\frac{mol}{L} - 10^{-8}\frac{mol}{L}$$

$$18,934,171\ L \times (10^{-2.3}\frac{mol}{L} - 10^{-8}\frac{mol}{L}) \approx 94,895\ mol$$

The neutralization reaction between limestone (calcium carbonate) and AMD can be represented as follows:

$$CaCO_3 + 2H^{+} \rightarrow Ca^{2+} + H_2O + CO_2$$

It's observed that the molar ratio between limestone and AMD is:

$$\frac{CaCO_3}{H^{+}} = \frac{1}{2}$$

Thus, the required moles of limestone to complete the reaction is:

$$\frac{1}{2} \times 94,895\ mol \approx 47,448\ mol$$

This amount of moles corresponds to a given amount of mass in kilograms:

$$47,448\ mol \times 100.09\frac{g}{mol} \times \frac{1}{1000}\frac{kg}{g} \approx 4,749\ kg \cong 5,000\ kg$$

Appendix D: Scaled Down Prototype Flow Rate Calculations

With reference to the first prototype, we are aware that our radius is $\frac{1}{24}$th of a foot (0.5 inches), whilst the final product is speculated to have a radius of 1.5 feet. Additionally, the typical flow rate of AMD from abandoned mines averages to 0.6 litres per second (Kalin & Chaves, 2003). With this information, proportionalities can be used to find the approximate flow rate for our prototype.

$$Flow\ Rate\ (Q) \propto Surface\ Area\ (A)$$

$$\frac{Prototype\ Flow\ Rate}{0.6} = \frac{\pi\times(\frac{1}{24})^2}{\pi\times(1.5)^2}$$

$$Prototype\ Flow\ Rate = \frac{\pi\times(\frac{1}{24})^2}{\pi\times(1.5)^2} \times 0.6 = \frac{1}{2160}\frac{L}{s} \approx 0.46\frac{mL}{s} \cong 0.5\frac{mL}{s}$$