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FACULTY OF APPLIED SCIENCE, SCHOOL OF ENGINEERING

APSC 169
Fundamentals of Sustainable Engineering Design
Project Report #3 - 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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Review of the Need Statement

“A way to purify contaminated water runoff originating from abandoned mining operations located in the Pacific Northwest”

Upon exploring this research project, we have found that our need statement should be revised. Though much of it remains the same, a decision was made to narrow the scope of it by replacing the opening phrase, “A way to address…” with “A way to purify…”. This was done to emphasize the idea that the goal is to create a physical solution that will purify the waters that are contaminated by AMD. The original opener can suggest a more passive role; perhaps implying a view from the sidelines. With this subtle change to the need statement, the purpose of this project will be more clearly communicated.

Ideation

Figure 1: The flow diagram of the process followed during ideation

First, we decided to break our solution into three functional and three structural categories based on our functions defined in Project Report #1 and research of other solution techniques. The three structural categories we came up with were: water intake, water containment, and required maintenance. The three functional categories we decided on were: heavy metal removal, sulphate removal and waste removal.

Now that our criteria were defined, the initial ideation process began with an initial open brainstorming session within the group. We all discussed unique ideas for water intake solutions. The method did bring about some interesting designs for water intake systems that could prove to be useful for novel solutions. The below figures elaborate and illustrate some of our ideas from this initial brainstorming session.

Water Intake Brainstorming ideas:

1. Ramp Collection:

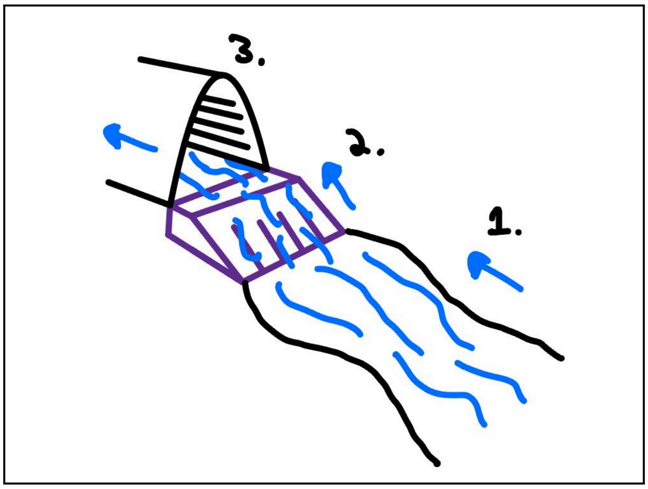

Figure 2: An illustration showcasing a small ramp used to funnel and direct water

This provides a method for intaking water for treatment without consuming energy and requires no human assistance. In Figure 2, step 1 demonstrates natural flow in areas such as rivers and streams. Water is then guided using a ramp to funnel the water into a pipe, shown as shown in step 2. Finally, the function to direct the water from the pipe towards a treatment process is shown in step 3.

2. Water Pump:

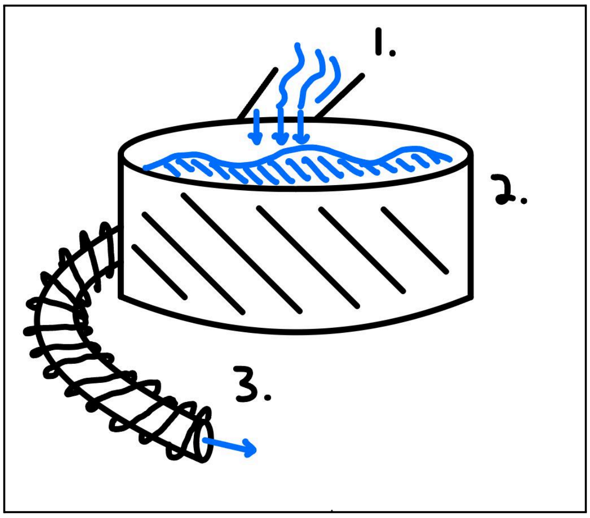

Figure 3: An illustration demonstrating the "water pump" method, which utilizes a tank and pipe combination

This idea would create a controlled flow of water to intake for water treatment. Step 1 displays water flowing from natural streams or creeks. The water from these natural pathways is gathered in a collection tank, as shown in step 2. Finally, a water pump is used to transport water from the collection tank to a treatment process.

3. Water wheel

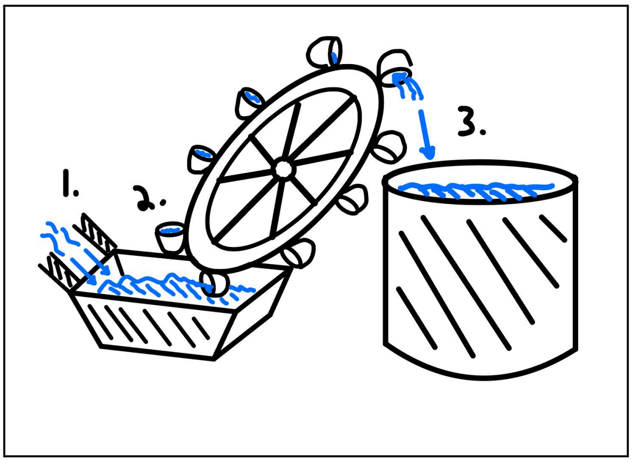

Figure 4: An illustration showcasing the "water wheel" solution, which uses a wheel to transport water over a large area

This idea uses a water wheel as a way to intake water for water treatment. In step 1 of Figure 4, water is directed from a natural stream or creek into a collection tank. Steps 2 and 3 showcase the water being collected and transported over a distance to a secondary treatment container. This method would supply water to the treatment tank at a consistent rate while opening up a wide range of additional uses that the wheel could be applied towards.

4. Water Tank Flow

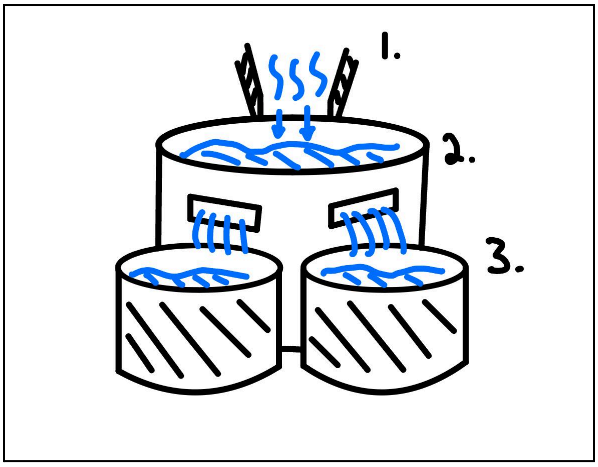

Figure 5: An illustration showcasing the "Water Tank Flow", an option to divert water into various smaller tanks

The water tank flow idea is implemented as a way to intake water for treatment with a controlled water rate without the use of external energy. Step 1 in Figure 5 showcases the collection of water from a natural stream or creek into a collection tank. Next, steps 2 and 3 represent a dam-like method of supplying water from the collection tank to the treatment tanks.

In our next meeting, we took a very different approach as we sat around the table trying silent brainstorming. We did a modified version of brainwriting 5-3-1, this consisted of all of us having a stack of sticky notes and setting a timer for 15 minutes instead of the usual 5 minutes. In that time, we tried to write, or draw, three unique, but general, solutions for treating AMD based on our previous research into other designs and techniques. Then when time was up, we passed the sticky notes in a clockwise direction around the table to the next person. We then had another 15 minutes to write down responses or improvements to the design ideas we were given. After that 15 minutes was up, we passed the sticky notes once more for the second and final round of writing improvements. This, again, lasted 15 minutes. Once we finished, we had a sharing session where we read aloud each of the ideas with their improvements. As a group we discussed these designs and further improved upon them to refine them. We came up with several ideas, like a carousel filtration system, distillation setups and automated maintenance to name a few. With that said, all the sticky notes used during this brainstorming session are included in Appendix C.

Before our next meeting, we each individually created a functional/structural decomposition of four of the six AMD treatment solutions addressed in Project Report #2. The four we chose were: absorption, sulphate reducing bacteria, precipitation technologies, and freeze crystallization. We did this because the following meeting saw us using the Heuristic Ideation Technique (HIT) to generate more ideas. In this meeting, we created two HIT charts, one combining absorption and freeze crystallization.

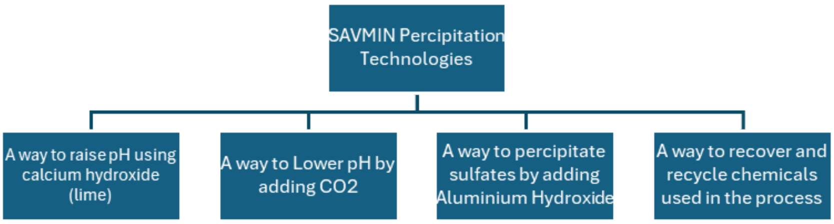

Figure 6: Functional Breakdown of SAVMIN Precipitation

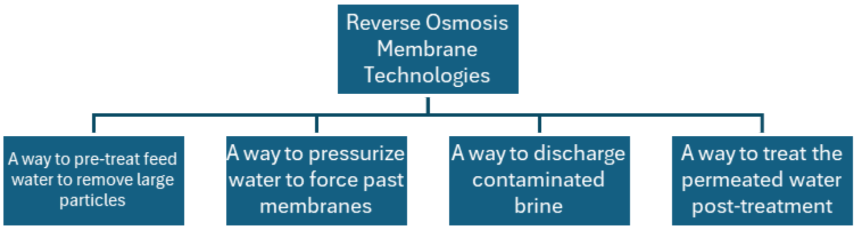

Figure 7: Functional breakdown of Reverse Osmosis

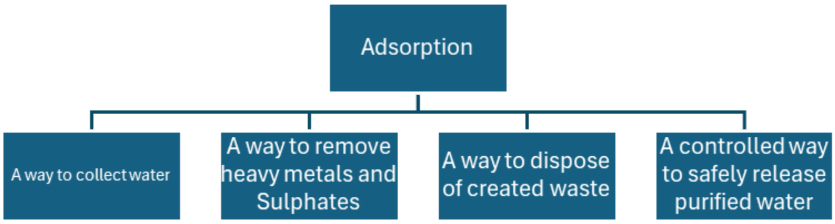

Figure 8: Functional breakdown of Adsorption

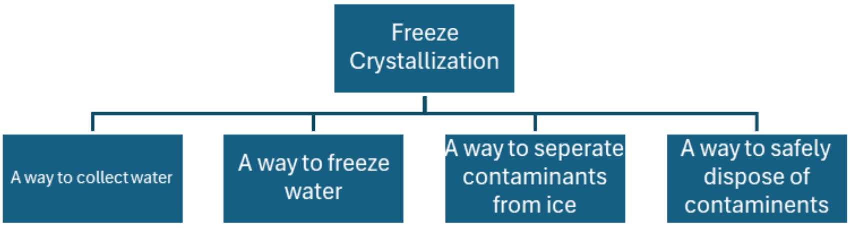

Figure 9: Functional breakdown of Freeze Crystallization

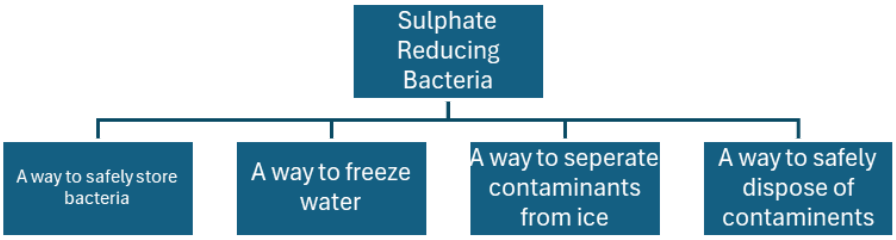

Figure 10: Functional Breakdown of Sulphate Reducing Bacteria

Table 1: Heuristic Ideation Technique (HIT) Chart #1:

Absorption and Freeze Crystallization

Absorption □ Freeze □	**Limestone Precipitate Metals from Water**	**Settling Tank for Waste Collection**	**Filter for water outlet**	**Slow Water Flow**
Collect Water	Collect water with limestone	Collect water in a settling tank	Collect filtered water	Collect water slowly
Freezes Water	Freezes water with precipitates precipitated already	Freeze waste for collection	Filter water before frozen	Freeze water with controlled flow
Separates Contaminants	Separates contaminants using limestone	Separates contaminants in settling tank	Filter out contaminants from water	Separate contaminants using slow flowing water
Disposes Contaminants	Limestone disposal system	Dispose contaminants out of settling tank	Dispose contaminants with a filter	Use slow water flow to dispose contaminants

Table 2: Heuristic Ideation Technique (HIT) Chart #2:

Precipitation and Sulfate-Reducing Bacteria (SRB)

Precipitation □ SRBs □	**Collect and discharge sludge**	**Precipitate heavy metals by adjusting pH (Lime and**	**Precipitate sulphates with aluminium hydroxide**	**Recover and recycle chemicals**

		CO_2)		
Converts SO_4 - H_2S	Converts sludge to H_2S	Changing pH for optimal SRB performance	Precipitates SO_4 using $Al(OH)_3$ and SRBs	Converts chemicals to H_2S
Continuous flow	Discharge sludge with a continuous flow	Precipitate heavy metals at a constant flow	Precipitate sulphates with a continuous flow	A continuous flow of chemical effluent to a recovery area
Uses a limestone pretreatment	Uses a limestone pretreatment to collect and discharge sludge	Precipitates heavy metals in pretreatment	Precipitates sulphates with aluminum hydroxide during the pretreatments	Recover chemicals in the pretreatment
Uses several chambers	Uses different chambers to collect and discharge sludge	Precipitates different heavy metals in different chambers	Uses several chambers to precipitates sulphates	Uses several chambers to recycle chemicals

All though a lot of these solutions were outrageous and can't be considered, a variety of these ideas from Tables 1 and 2 were then put into a morph chart to help form our six proposed novel solutions:

Table 3: Morph chart breaking down various required functions and offering varying approaches for each

Functions	**1**	**2**	**3**	**4**	**5**	**6**
Water Intake	Water Wheel	Ramp Collection	Water Pump	Water Tank Flow	Mine adits	
Heavy Metal Removal	Electrocoagulation	Precipitation	Filters/Membranes	Ion exchange	Wetlands	Distillation
Sulphate Removal	Sulphate Reducing	Calcium hydroxide	Limestone river bed	Distillation	Freeze crystalliz	

	Bacteria	(lime)			ation	
Type of Containment	Tank	Multi-Tanks	Dam	Constant flow	Waterfall system	Tubes/Pipes
Maintenance/ Waste Removal	Carisoul Filter Replacement	Manual Maintenance	Machine Learning (AI) Cleaners	Floodgate Sensors for waste release	Separate External Waste Containment	Wetlands/ Nature

Novel Solutions

Novel Solution #1 - Distillation Solution:

Novel solution 1 addresses the problem of Acid Mine Drainage right at its source by taking a proven technology and applying it at the source. Water intake is done at mine adits to target water directly out of mining sites before it can contaminate any watersheds. Mine adits are beneficial by providing a steady flow of water towards treatment systems without requiring assistance from powered utilities such as water pumps. Moreover, the volume of wastewater that needs to be treated is less than the volume that would need to be treated if watersheds were contaminated. A portable water tank will be set up at each contaminated mine site, along with a wide array of solar panels and perhaps small wind turbines. All energy generated will be transferred to a large commercial battery to make the system truly portable. Heavy metals and sulphates will be removed from contaminated water with a distillation process, which would mean that pure potable water comes out the other end. Additionally, the secondary waste that comes about will be very concentrated, which allows for the reselling of rare earth elements. The treatment process starts with water entering a mobile distillation tank which is then heated using an electric heating element powered by the battery. Steam will travel to another tank where it condensates back to water and cools down; at this point, it can be released from the system using a floodgate. Physically, this solution will span multiple tanks with each tank consisting of an automated floodgate for waste collection and water removal. Finally, manual maintenance is required for this operation to stay efficient.

Novel Solution #2 - Automatic Solution:

Novel solution 2 addresses the often exorbitant prices of 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. Heavy metals are removed from the water by using a series of membrane filters that get progressively smaller through the system. 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 essentially 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

Novel Solution #3 - Large Scale Plant Solution:

This solution aims to purify a large volume of water quickly, making it useful to implement in locations with highly polluted and large waterways. A water collection tank takes in water from surrounding natural waterways and a water pump is utilized to move the water from the collection tank into the treatment system. Using a pump results in a controlled amount of water intake and controlled water flow. Next, ion exchange is chosen to extract heavy metals from the water and sulphate levels are reduced with the use of sulphate-removing bacteria. Water containment includes a combination of treatment tanks and connecting pipes. Manual maintenance is mandatory for continuous use, the primary maintenance is based around refilling and cleaning SRB and ion exchange treatment stations.

Novel Solution #4 - Dam Solution:

Solution 4 aims to be completely self-sufficient in terms of water purification and is suitable in mountainous areas that already have large amounts of Acid Mine Drainage contamination in the soil and watersheds. In this solution, water is collected through a small dam on the stream. It is diverted to a series of collection tanks, one set of which uses ion exchange and the other uses freeze crystallization. Ion exchange functions by adding a resin which binds to molecules, causing the harmful ones to precipitate into a form that can be collected. Likewise, Freeze crystallization uses extremely cold temperatures to freeze the water, making it easier to remove the contaminants. Although both these procedures require electricity, they can be powered completely on-site through a turbine placed in the dam, which effectively turns it into a hydroelectric generator. The tanks in which these processes occur will be connected via a waterfall system as a form of water transfer. Finally, maintenance is executed using a separate external waste containment.

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. Rather than utilizing large water treatment plants, it uses a naturally engineered environment to achieve the same effects. A combination of limestone blocks lining the water channels and 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.

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.

All Solutions Table

Table 4: All solutions tables containing ranks for all solutions, including both novel and existing options

Method (Solution)	Min. Upfront costs	Max. The benefit	Min. Environmental impact	Max. Societal impact	Max. Variety of heavy metals being treated	Max. Sulphate Removal	Max. Rate of purification	Min. Human control needed	Min. Operating costs
Open Limestone Drains (ES.1)	Medium/ Low (2)	Medium/ Low	Medium (2,3)	Medium	Low (2,3)	Low (1)	< 20L/s Medium (2)	Very Low (2)	Very Low (2)
Bioreactor (ES.2)	High (4,8)	Medium	Medium (5,10)	Medium	Medium (4,5)	Medium/ Low (5)	>115 L/s High (9)	Medium (6)	Medium/ Low (4,6,7)
Reverse Osmosis (ES.3)	High (12, 16)	High	Low (11, 14)	High	Very High (14)	Very High (17)	46 L/s Medium/ High (13)	Medium (13)	High (15)
Pipe Freeze (ES.4)	Very High (18)	Very High (18)	High (18)	High	Very Low (20)	Very Low (20)	0.42 L/s Very Low (18)	Very High (18, 19)	Very High (18)
SAVMIN (ES.5)	Medium (23)	Medium/ High (21)	High (21, 22, 24)	Medium /High	High (22)	Very High (23, 24)	231.48 L/s Very High (24)	Medium (21)	Medium/ Low (23, 24)
Selective Cation	Medium	Medium/ High	Low	Low	Medium/ Low	Low	18.93 L/s Medium	Medium/ High	Medium/ High

Exchange (ES.6)	(25)	(25, 27)	(25)		(25, 27)	(26)	(25)	(25)	(25)
Distillation (NS.1)	Medium/ High	Medium	Medium/ High	Medium / High	High	High	0.01 L/s Very Low	Low	Medium/ Low
Automatic (NS.2)	Medium/ High	Medium/ High	Medium	Medium /Low	High	High	< 20L/s Medium	Low	Low
Large Scale Plant (NS.3)	High (25)	Medium/ High (25, 27)	Medium (25)	Low	Medium/ Low (25, 27)	Low (26)	18.93 L/s Medium (25)	Medium/ High (25)	Medium/ High (25)
Dam (NS.4)	Very High	High	High	High	Medium/ Low	Low	Medium/ High	Medium/ Low	Medium
Natural (NS.5)	Medium/ Low	Medium	Medium	Medium	High	Medium	< 20L/s Medium	Very Low	Very Low
Small Scale Precipitation (NS.6)	Medium	Medium/ High	Medium/ High	Medium /High	High	Very High	Medium/ High	Medium	Medium/ Low

Footnotes:

For all relevant footnotes, please refer to Report 2, Existing Solutions Table (Bendl et al., p.17, 2024)

It is important to note that for many novel solutions based on existing solutions, many statistics for the existing solution were considered and then extrapolated onto the novel solutions with minor tweaks. This is because it is difficult to theorize statistics for novel solutions that have never been implemented before.

Justification

The first Novel Solution, an adaptation of distillation, is positioned at the mine and uses distillation to purify the water. It was given a medium/high score when it came to upfront costs. Although no exact figure could be found on upfront costs of a distillation unit, the costs of solar panels and wind turbines are a lot. In 2020, the average cost to install a solar panel in the US was $2.39CAD/watt and the solution requires thousands of watts (Fraas and O'Neill, p. 14, 2023). This is because distillation plants use, roughly, 7 - 27 kWh/m^3 of water treated (Denfoss, 2021). For the sake of this hypothetical situation, it can be assumed the distillation process only requires 7 kWh/m^3 (or 7 kWh/1,000L). Based on a study by NF Gray, mine adits can have a highly variable flow rate and the one covered in his study fluctuated between 8.5 L/s and 37.3 L/s (Gray, 1998). Assuming the minimum rate of 8.5 L/s was consistent across all mines in the Pacific Northwest, that would mean the process would require 0.0595 kWh/s or 5,141 kWh/day. Now, solar panels only produce as much electricity as there are hours of sunlight. Using a Peak Sun Hours Calculator (Beale, 2022) to find the average peak sunlight hours in the capital cities across all 6 regions of the Pacific Northwest and averaging them together, it was found that, on average, the PNW receives about 3.71 hours of peak sun each day. Putting this amount through a “Solar Panel Daily kWh Production Calculator” (How many kWh…, n.d.), which multiplies the average peak sun hours by the wattage of the solar panels (in this case, 400W) and then multiplies it by the conversion factor of 0.00075 to get the daily kWh production. This ends up being 1.11 kWh/day, which pales in comparison to the amount 5,000+ kwH needed daily. As such, either operating costs will be high as this energy will need to be purchased from somewhere else, or upfront costs will be very high. It was decided that for the sake of portability, all the necessary solar costs would be put upfront rather than as operational costs. Batteries would also be needed to store the power generated from solar panels. These batteries can range in price, with advancements in technology, the price has dropped to approximately $112.64 CAD/kWh (Cicconi and Kumar, p. 12, 2023).

Moving on from cost, this solution has a minimum impact on the environment. Although distillation does produce a sludge (Diao, et al., 2022), this sludge can be removed, allowing for a cleaner effluent to be released. This gives it the added societal impact of recovering raw materials that may have been lost in the effluent otherwise. Distillation also removes all heavy metals (Distillation Treatment…, n.d.) and sulphates (Sulfate In Well Water, 2024) due to the water evaporating, thus leaving the debris and sludge behind. However, this purity comes at the cost of water flow rate. Many distillation plants can only process 40 L/h or 0.01 L/s. (Armenta-Deu, C. 2004) This makes it by far one of the slowest treatment methods, which is no good if water is flowing into it at 8.5 L/s. It also requires low amounts of human operation, only having the sludge cleaned out every once and a while. With all this said, it was given a medium ranking on benefit as the final quality of water is pure and the sludge can be refined into raw materials. However, this solution still has its drawbacks of high upfront costs and slow purification rates. This solution is good for abandoned mines with little effluent draining out.

The second novel solution aims to be fully automatic, which earns it a low rank for the amount of human control needed. It also has low operational costs as it does not require electricity to operate. However, it will be costly to build upfront. Not only do you have to factor in all the building supplies and gears, but membranes can cost about $40/m^2 (Osipi, et al., 2019) which begins to add up fast. With that said, since this solution can hold multiple membranes at a given time, they do not have to be replaced often thus hardly impacting operating costs. It is predicted that the water flowing out from the membranes will be high quality, although not as high quality as other solutions seen in Table 4, resulting in an average score. The solution would undoubtedly filter out large amounts of heavy metals and sulphates without significant adverse effects on the environment, earning it its respective scores as seen in Table 4. Where this solution lacks is in its flow rate, as it will likely not flow at a fast rate through the membrane, especially once the membrane begins to clog. It also does not have any outstanding societal impacts to stakeholders which nets it a medium/low rating. Overall, the general benefit of solution 2 was rated as medium/high because it is fully automatic but does not have the greatest flow rate.

The third novel solution, a large-scale treatment plant, combines ion exchange technologies with sulphate-reducing bacteria. These two were combined as sulphate cannot be treated effectively through ion exchange (Can, et al., 2020). Now seeing that it is mostly an ion exchange plant, it shares a lot of similar rankings to the ion exchange mentioned in Report 2: It has a low societal benefit, as it does nothing extra to stand out; it has a medium rate of purification, medium/low for heavy metal removal and a low for sulphate removal while requiring medium/high operational costs and amount of human control needed. However, this one will cost more as it needs SRB treatment chambers to be added in. Although this will increase the cost compared to a regular SRB plant, it will produce cleaner water in the end, giving it a medium/high benefit.

The fourth novel solution utilizes hydroelectric technology to be self-sustaining. This, unfortunately, has the drawback of having high upfront costs (Afgan and Carvalho, p. 745, 2002). However, it is worth it as it will lower the operational costs for freeze crystallization from very high to about medium. The lower operating cost in conjunction to the added purification efficiency through the addition of the Ion exchange undoubtedly increases the benefits and amount of contaminants removed. It also produces the same high environmental and societal impacts as regular freeze crystallization. It has the same rate of purification and needs human control as with the other freeze crystallization technologies as freeze crystallization is the limiting factor in speed. Overall, this solution was given a high benefit rating due to its self-sufficiency, minimal environmental impact, and amount of contaminants removed.

The fifth solution relies mostly on natural techniques. With the only real-built structures being the water wheel and water channels, upfront costs are medium to low. Seeing that this is almost fully autonomous, it has very low operating costs and human control. The only exception is when SRBs, fertilizers, and limestone have to be replenished, but these times should be few and far between. Seeing that the flow of the river will be slowed so the SRBs and lime can really mix with the water, this solution will likely have a medium flow rate. And since both treatments are not high-end, the water quality will be acceptable, likely for irrigation, but not for drinking. It will still have removed the majority of heavy metals and sulphates which is the goal at the end of the day (Sheoran, et al., 2006). It will have a medium societal impact, but also a medium environmental impact as creating artificial wetlands may subtly disrupt the surrounding ecosystem due to new plant types being introduced. Although the low cost and efficiency are great, the potential adverse environmental impacts result in it being rated as a medium in net benefit.

The sixth and final solution attempts to scale down existing precipitation technologies to a smaller scale. As such, the hope is that the technology will retain its water filtration quality and its societal and environmental benefits, as found in Report 2, but at a reduced upfront cost. This also will have its drawbacks, such as reducing the flow rate but requiring the same level of human control and maintenance costs. This is why the benefits were dropped from high to medium/high.

All Solutions landscapes

Figure 11: All solution landscape comparing cost and effectiveness

The solution landscape between cost and effectiveness demonstrates where existing solutions and the new novel solutions are on the plot relative to each other. Cost which is shown on the y-axis of the landscape is in reference to the upfront cost of the solution displayed on Table 4. Likewise, the x-axis represents effectiveness which is directly linked to maximizing benefit also shown in Table 4. To continue, the solution that has the lowest cost is the natural solution (Novel Solution #5). On the other hand, the two solutions with the highest cost are the dam solution (Novel Solution #4) and pipe freeze (Existing Solution #4). In addition, pipe freeze (Existing Solution #4) is the most effective while open limestone drains (Existing Solution #1) are the least effective. The opportunity plot in Figure 11 displays the ideal corner, which is located in the bottom right corner of the landscape, aiming to achieve low cost and high effectiveness. All data used for the solution landscape was derived from Table 4.

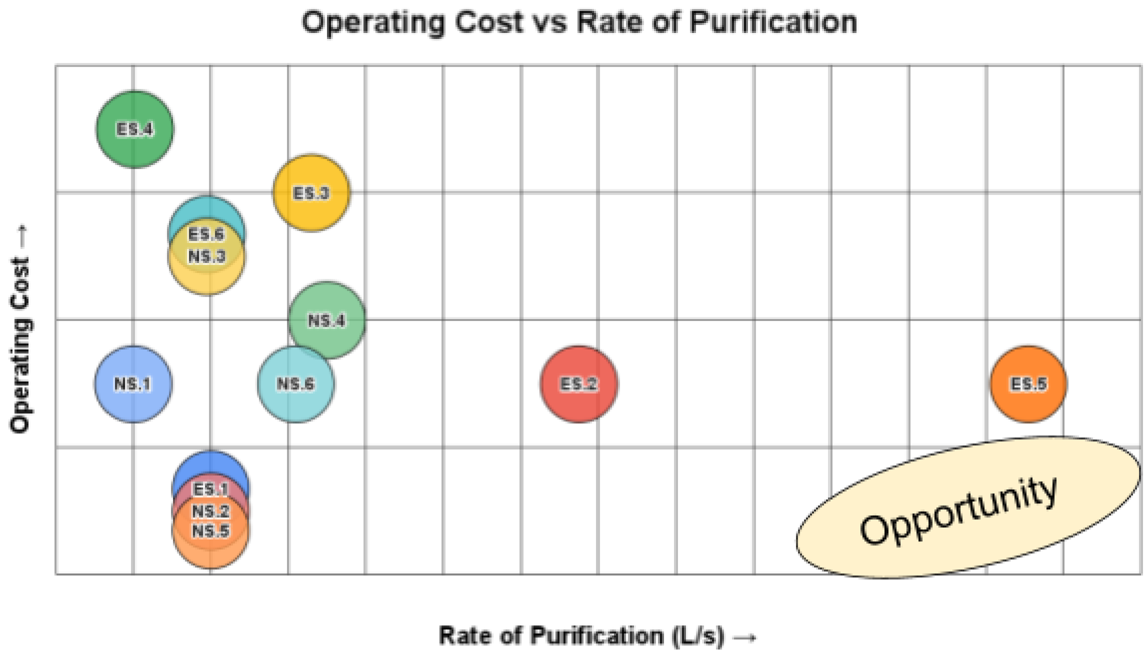

Figure 12: All solution landscapes comparing Rate of Purification vs Operating Cost

The solution landscape plot of operating cost against the rate of purification (measured in L/s) connects the two important aspects together and provides a visual of all the solutions relative to each other. The ideal corner for this landscape is located in the bottom right, where the rate of purification is the highest and operating costs are lowest. For the plotted solutions, SAVMIN (Existing Solution #5) has the highest rate of purification and pipe freeze (Existing Solution #4) has the lowest. In contrast, the three solutions with the lowest operating costs are open limestone drains (Existing Solution #1), the automatic solution (Novel Solution #2), and the natural solution (Novel solution #5). The highest operating cost goes with the pipe freeze solution (Existing Solution #4). Data for this landscape is derived from Table 4 referenced previously in this report.

Justification of Weights

Weights for the nine objectives in the summation matrix were determined through extensive group discussion and research on key decision-making methods, such as Multicriteria Decision Making. Based on the main functions and considerable original background research on the project report 1 (Bendl et al, 2024), minimizing environmental impact is the frontrunner in project importance. To add, discussion on this claim resulted in the group agreeing that environmental impact is the most important aspect. Furthermore, with consideration of stakeholder requirements and aspirations being a key piece of the project, the group discussed the importance of operational and upfront costs being the next most weighted aspects. Through research, the group found operational cost to be a more substantial component in the long run of the project compared to its upfront cost and is often the reason many companies and initiatives fail (Mourdoukoutas and Stefanidis, 2023). Because the target of our problem are abandoned mines at a mass scale, it is in the best interest to have a solution with a relatively low upfront cost. Related to that, government stakeholders would want to spend minimal operating costs on a solution for treating the water, as reported by BC journalists, “the province was short $753 million of the estimated cleanup cost in its last financial year”—meaning that cutting down on costs is vital for the support of the government (Anderson, 2024). Next, the group focused on the value of minimizing human requirement within these operating systems. The team came to the conclusion that automation is quite a paramount requirement as it increases efficiency of the operation while helping to minimize overall cost of workers. Expanding the variety of heavy metals being treated along with maximizing sulphate removal were the two next highest weighted parts of the summation matrix because these objectives are linked straight to water treatment, meaning that increasing these aspects would result in better water purification. Finally, maximizing the benefit, purification rate, and societal impact were weighted according to group decision based on what we believed to hold most importance to the goals we had set out for the project, project functions, and project relevance.

Weighted Summation Matrix

Objectives	**Min. Upfront costs**	**Max. The benefit**	**Min. Environmental impact**	**Max. Societal impact**	**Max. Variety of heavy metals being treated**	**Max. Sulphate Removal**	**Max. Rate of purification**	**Min. Human control needed**	**Min. Operating costs**	**Total**
Weights	**0.16**	**0.08**	**0.20**	**0.04**	**0.09**	**0.09**	**0.06**	**0.10**	**0.18**	**1.00**
Open Limestone Drains (ES.1)	0.091	0.034	0.067	0.027	0.026	0.026	0.034	0.086	0.154	0.545
Bioreactor (ES.2)	0.023	0.046	0.067	0.027	0.051	0.039	0.051	0.043	0.103	0.449
Reverse Osmosis (ES.3)	0.023	0.069	0.133	0.040	0.090	0.090	0.043	0.043	0.026	0.556
Pipe Freeze (ES.4)	0.000	0.080	0.000	0.040	0.013	0.013	0.009	0.000	0.000	0.154
SAVMIN (ES.5)	0.069	0.057	0.000	0.033	0.077	0.090	0.060	0.043	0.103	0.532

Selective Cation Exchange (ES.6)	0.069	0.057	0.133	0.013	0.039	0.013	0.034	0.029	0.051	0.438
Distillation (NS.1)	0.046	0.080	0.033	0.033	0.077	0.077	0.009	0.071	0.103	0.530
Automatic #1 (NS.2)	**0.046**	**0.069**	**0.067**	**0.040**	**0.077**	**0.077**	**0.034**	**0.086**	**0.154**	**0.650**
Large Scale Plant (NS.3)	0.023	0.057	0.067	0.013	0.039	0.026	0.034	0.029	0.051	0.339
Dam (NS.4)	0.000	0.069	0.000	0.040	0.051	0.026	0.034	0.057	0.000	0.277
Natural #2 (NS.5)	**0.091**	**0.046**	**0.067**	**0.020**	**0.077**	**0.051**	**0.034**	**0.086**	**0.154**	**0.627**
Small Scale Precipitation #3 (NS.6)	**0.069**	**0.057**	**0.033**	**0.033**	**0.077**	**0.090**	**0.034**	**0.043**	**0.103**	**0.540**

Example calculations for the weighted summation matrix is shown in Appendix B. Descriptive ratings of the solutions were converted into numerical values, also shown in Appendix B.

Analysis of Weighted Summation Matrix and Selected Novel Solutions

From the weightings and ratings, the summation matrix determined that novel solutions 2 and 5 took the top two spots, with a score of 0.650 and 0.627 respectively. This was to be expected because both solutions focussed on reducing operational costs, as well as increasing the autonomy, and lowering resources allocated towards the solution—all of which was weighted heavily. Even though both solutions have a large gap to the third place novel solution 6 (scored at 0.540), it is still being included for the prototyping and testing phase because of its uniqueness and important characteristics which were not reflected well by the set project objectives and weightings—these characteristics will be elaborated on further below.

“Automatic” Solution #2:

The strength of this solution resides in the minimal maintenance required to keep the project operating, due to the automatic replacement of membrane filters as they begin to foul—switching old filters with newer ones on a carousel of sorts. However, there are a few causes for concern with this automatic solution. First of all, the flow rate in the river will likely diminish as the membrane may serve as an impromptu dam, causing water to build up on one side if not enough pressure is applied to the membrane—testing must be done to determine if the pressure applied by the flow of smaller streams are adequate in passing through these membranes, additional testing must also be done to determine if the rate of incoming water is higher than the rate of effluent water. Furthermore, with the expensive costs of membranes, pretreatment must be conducted to remove any debris or particles which will result in fouling—testing must be done to find the optimal pretreatment method to keep the replacement of membranes at a minimum (Osipi, et al., 2019). Lastly, it is important to consider the wildlife, particularly fish, and how the construction of this solution may impede their movement along bodies of water. Thus, methods to allow fish to bypass the technology must also be considered and tested.

“Natural” Solution #5:

The biggest strength of this solution is its one-time upfront costs in the planting and construction of the wetlands and limestone waterways, which can then be used indefinitely with minimal maintenance and operating costs—a large pro as saving costs is vital in the creation of the solution. However, there are a few glaring problems which must be considered and or tested, the most prominent of which is that wetlands can not be built everywhere, due to challenging terrain as well as the ecosystem which they will likely disrupt—this may be detrimental to those who rely on the lands such as the indigenous peoples. Furthermore, of all the novel solutions, this is likely to be the least effective at removing sulphates and heavy metals as it is a passive process. Thus different plants must be tested to determine if they can meet the sulphate and heavy metal constraints outlined by each state's and province's respective governments as shown in report 1, table 1 (Bendl et al, pg.11, 2024).

"Small Scale Precipitation" Solution #6:

Although small-scale precipitation was rated the lowest of the three chosen solutions, there is a conspicuous benefit it holds over the other selected solutions, namely its portability factor. Because our scope resides within the wide expanse of the Pacific Northwest, the ability for this solution to be set up in any terrain is a major benefit that the previous two solutions failed to address. Because precipitation technologies are an incredibly effective technique in removing sulphates and heavy metals, this technology could be implemented right at the entrance of mine adits to treat AMD at the source. This runs the advantage of treating a smaller volume of AMD, meaning large plants do not need to be built, as well as not disrupting the ecosystem that encompasses a watershed. Moreover, like the other solutions, minimal electrical operating costs are required, and the operation can run at any ambient temperature in prop-up tanks of any size. Even so, of the three solutions, this solution would require the most frequent maintenance as a build-up of sludge would constantly need to be removed, as well as the replenishment of calcium hydroxide, carbon dioxide, and aluminum hydroxide compounds. Although this solution likely provides the largest benefit of the three aforementioned solutions, because our key stakeholder in this project is the government (abandoned mines are not owned by anyone), the larger maintenance and upfront costs associated with this solution is not ideal when working within the land reclamation budget. Thus, further theoretical testing into whether or not the solution is financially viable, alongside potential ways to recuperate some of the costs—perhaps reselling of rare earth elements concentrated within the sludge should be looked into. Additionally, not all mines are built with gravity-powered adits to allow for the collection of runoff AMD. Consequently, it means that this solution is not viable for every mine (particularly underground mines), or another method for collecting runoff AMD must be devised and prototyped.

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Appendix A: Meeting Minutes

APSC 169 Team 03 Meeting Minutes

Date: Tuesday Oct 15th, 2024

Location: ART Floor 1; Room #110

Time: 10:00 am – 11:50 am

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

Regrets: N/A

Note-Taker: Hasan Mohammad

Points of discussion:

- Discussion of ideation techniques
- Brainstorming of novel ideas
- Decomposition of current solutions
- Regrading Report 1

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Break down 1 novel solution each	All Members	
Email Dr. Eisenstein to inquire about regrading	Jacky	

Next meeting: Monday Ocotber 21, 2024; 12:30pm-2:00pm at the Library

Meeting adjourned: 11:50am

APSC 169 Team 03 Meeting Minutes

Date: Monday October21th, 2024

Location: Commons Building

Time: 12:30 pm – 2 pm

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

Regrets: N/A

Note-Taker: Hasan Mohammad

Points of discussion:

- Lots of brainstorming
- Used Sticky notes and 5-3-1 brainstorming to generate novel ideas and discuss their pros+cons

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Continue thinking about novel solutions!	All Members	

Next meeting: Monday September 16th, 2024; 12:30pm-2:00pm at the Library

We hope to decide what kind of mines to look into and what problems need to be solved there during our next meeting.

Meeting adjourned: 10:50am

APSC 169 Team 03 Meeting Minutes

Date: Tuesday October 22nd, 2024

Location: Art Room 110

Time: 10 am – 11:50 am

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

Regrets: Jacky Zhou

Note-Taker: Hasan Mohammad

Points of discussion:

- Finish breakdown of all existing solutions
- Create HIT charts 1 and 2
- Create Morph chart

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Finish Morph Chart	Hasan and Zach	
Finish HIT Charts	Connor and Axel	

Next meeting: Monday September 16th, 2024; 12:30pm-2:00pm at the Library

Meeting adjourned: 11:50am

APSC 169 Team 03 Meeting Minutes

Date: Wednesday, October 23rd, 2024

Location: Video Call

Time: 6:50pm-7:50pm

Present: Axel Bendl, Zach Boos, Connor Jones, Hasan Mohammad, Jacky Zhou
Regrets: N/A

Note-Taker: Hasan Mohammad

Points of discussion:
- Choose and refine the 6 novel solutions
- What are differentiating features of each solution?
- How can the solutions be made unique?

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Finish the last 2 solutions	Connor	
Finish Research for All Solutions table	Hasan and Zach	
Create Weighted Summation Matrix	Axel	

Next meeting: Monday September 16th, 2024; 12:30pm-2:00pm at the Library

We hope to decide what kind of mines to look into and what problems need to be solved there during our next meeting.

Meeting adjourned: 7:50pm

APSC 169 Team 03 Meeting Minutes

Date: Monday, October 28th, 2024

Location: COMS/Online

Time: 12:30pm-2:45pm

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

Regrets: Jacky Zhou

Note-Taker: Hasan Mohammad

Points of discussion:

- We need to make solutions more interesting and different - they all are similar
- What weights to assign each criteria
- What rankings should each solution get
- Formatting

Before our next meeting, we hope to do:

Task:	Assigned to:	Additional Conditions:
Finish Lab!	All Members	

Next meeting: Tuesday, October 29th, 2024; 10-12 Art 110.

Meeting adjourned: 2:45pm

Appendix B: Weighted Summation Matrix & Example Calculation

Descriptive Rating	Very Low	Low	Medium/Low	Medium	Medium/High	High	Very High
Numbered Rating	1	2	3	4	5	6	7

Descriptive Rating to Numbers	Min	Max	Min	Max	Max	Max	Max	Min	Min	Total
Weights	0.16	0.08	0.2	0.04	0.09	0.09	0.06	0.1	0.18	1
Example Calculation for ES 1	Medium/Low=...	Medium/Low=...	Medium=...	Medium=...	Low=...	Low=...	Medium=...	Very Low=...	Very Low=...	SUM...
ES 1	3	3	4	4	2	2	4	1	1	24
ES 2	6	4	4	4	4	3	6	4	3	38
ES 3	6	6	2	6	7	7	5	4	6	49
ES 4	7	7	6	6	1	1	1	7	7	43
ES 5	4	5	6	5	6	7	7	4	3	47
ES 6	4	5	2	2	3	1	4	5	5	31
NS 1	5	7	5	5	6	6	1	2	3	40
NS 2	5	5	4	3	6	6	4	1	1	35
NS 3	6	5	4	2	3	2	4	5	5	36
NS 4	7	6	6	6	3	2	5	3	7	45
NS 5	3	4	4	4	6	4	4	1	1	31
NS 6	4	5	5	5	6	7	5	4	3	44

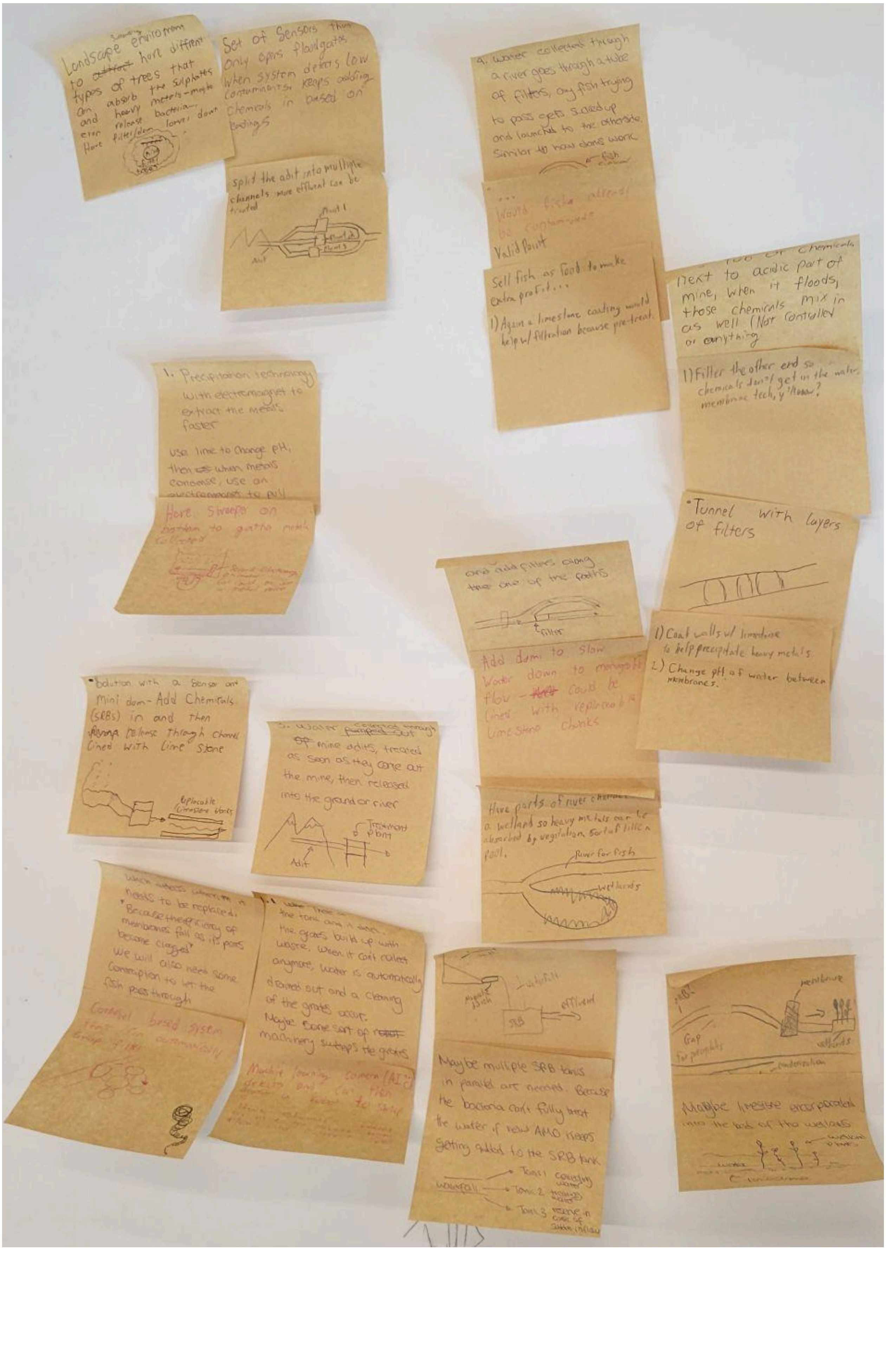
Normalizing Numbers	Min	Max	Min	Max	Max	Max	Max	Min	Min	Total
Weights	0.16	0.08	0.2	0.04	0.09	0.09	0.06	0.1	0.18	1
Example Calculation for ES 1	3/7=...	3/7=...	4/6=...	4/6=...	2/7=...	2/7=...	4/7=...	1/7=...	1/7=...	SUM...
ES 1	0.4285714286	0.4285714286	0.6666666667	0.6666666667	0.2857142857	0.2857142857	0.5714285714	0.1428571429	0.1428571429	3.619047619
ES 2	0.8571428571	0.5714285714	0.6666666667	0.6666666667	0.5714285714	0.4285714286	0.8571428571	0.5714285714	0.4285714286	5.619047619
ES 3	0.8571428571	0.8571428571	0.3333333333	1	1	1	0.7142857143	0.5714285714	0.8571428571	7.19047619
ES 4	1	1	1	1	0.1428571429	0.1428571429	0.1428571429	1	1	6.428571429
ES 5	0.5714285714	0.7142857143	1	0.8333333333	0.8571428571	1	1	0.5714285714	0.4285714286	6.976190476
ES 6	0.5714285714	0.7142857143	0.3333333333	0.3333333333	0.4285714286	0.1428571429	0.5714285714	0.7142857143	0.7142857143	4.523809524
NS 1	0.7142857143	1	0.8333333333	0.8333333333	0.8571428571	0.8571428571	0.1428571429	0.2857142857	0.4285714286	5.952380952
NS 2	0.7142857143	0.7142857143	0.6666666667	0.5	0.8571428571	0.8571428571	0.5714285714	0.1428571429	0.1428571429	5.166666667
NS 3	0.8571428571	0.7142857143	0.6666666667	0.3333333333	0.4285714286	0.2857142857	0.5714285714	0.7142857143	0.7142857143	5.285714286
NS 4	1	0.8571428571	1	1	0.4285714286	0.2857142857	0.7142857143	0.4285714286	1	6.714285714
NS 5	0.4285714286	0.5714285714	0.6666666667	0.6666666667	0.8571428571	0.5714285714	0.5714285714	0.1428571429	0.1428571429	4.619047619
NS 6	0.5714285714	0.7142857143	0.8333333333	0.8333333333	0.8571428571	1	0.7142857143	0.5714285714	0.4285714286	6.523809524

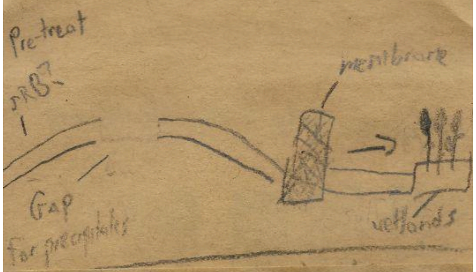
Adjusting for Max/Min	Min	Max	Min	Max	Max	Max	Max	Min	Min	Total
Weights	0.16	0.08	0.2	0.04	0.09	0.09	0.06	0.1	0.18	1
Example Calculation for ES 1	1-0.429=...	0.429=...	1-0.667=...	0.667=...	0.286=...	0.286=...	0.571=...	1-0.143=...	1-0.143=...	SUM...
ES 1	0.5714285714	0.4285714286	0.3333333333	0.6666666667	0.2857142857	0.2857142857	0.5714285714	0.8571428571	0.8571428571	4.857142857
ES 2	0.1428571429	0.5714285714	0.3333333333	0.6666666667	0.5714285714	0.4285714286	0.8571428571	0.4285714286	0.5714285714	4.571428571
ES 3	0.1428571429	0.8571428571	0.6666666667	1	1	1	0.7142857143	0.4285714286	0.1428571429	5.952380952
ES 4	0	1	0	1	0.1428571429	0.1428571429	0.1428571429	0	0	2.428571429
ES 5	0.4285714286	0.7142857143	0	0.8333333333	0.8571428571	1	1	0.4285714286	0.5714285714	5.833333333
ES 6	0.4285714286	0.7142857143	0.6666666667	0.3333333333	0.4285714286	0.1428571429	0.5714285714	0.2857142857	0.2857142857	3.857142857
NS 1	0.2857142857	1	0.1666666667	0.8333333333	0.8571428571	0.8571428571	0.1428571429	0.7142857143	0.5714285714	5.428571429
NS 2	0.2857142857	0.8571428571	0.3333333333	1	0.8571428571	0.8571428571	0.5714285714	0.8571428571	0.8571428571	6.476190476
NS 3	0.1428571429	0.7142857143	0.3333333333	0.3333333333	0.4285714286	0.2857142857	0.5714285714	0.2857142857	0.2857142857	3.380952381
NS 4	0	0.8571428571	0	1	0.5714285714	0.2857142857	0.5714285714	0.5714285714	0	3.857142857
NS 5	0.5714285714	0.5714285714	0.3333333333	0.5	0.8571428571	0.5714285714	0.5714285714	0.8571428571	0.8571428571	5.69047619
NS 6	0.4285714286	0.7142857143	0.1666666667	0.8333333333	0.8571428571	1	0.5714285714	0.4285714286	0.5714285714	5.571428571

Multiplying by Weights	Min	Max	Min	Max	Max	Max	Max	Min	Min	Total
Weights	**0.16**	**0.08**	**0.2**	**0.04**	**0.09**	**0.09**	**0.06**	**0.1**	**0.18**	**1**
Example Calculation for ES 1	0.16*0.571=...	0.08*0.429=...	0.2*0.333=...	0.04*0.667=...	0.09*0.286=...	0.09*0.286=...	0.06*0.571=...	0.1*0.857=...	0.18*0.857=...	SUM...
ES 1	0.09142857143	0.03428571429	0.06666666667	0.02666666667	0.02571428571	0.02571428571	0.03428571429	0.08571428571	0.1542857143	0.5447619048
ES 2	0.02285714286	0.04571428571	0.06666666667	0.02666666667	0.05142857143	0.03857142857	0.05142857143	0.04285714286	0.1028571429	0.449047619
ES 3	0.02285714286	0.06857142857	0.1333333333	0.04	0.09	0.09	0.04285714286	0.04285714286	0.02571428571	0.5561904762
ES 4	0	0.08	0	0.04	0.01285714286	0.01285714286	0.008571428571	0	0	0.1542857143
ES 5	0.06857142857	0.05714285714	0	0.03333333333	0.07714285714	0.09	0.06	0.04285714286	0.1028571429	0.5319047619
ES 6	0.06857142857	0.05714285714	0.1333333333	0.01333333333	0.03857142857	0.01285714286	0.03428571429	0.02857142857	0.05142857143	0.4380952381
NS 1	0.04571428571	0.08	0.03333333333	0.03333333333	0.07714285714	0.07714285714	0.008571428571	0.07142857143	0.1028571429	0.5295238095
NS 2	0.04571428571	0.06857142857	0.06666666667	0.04	0.07714285714	0.07714285714	0.03428571429	0.08571428571	0.1542857143	0.6495238095
NS 3	0.02285714286	0.05714285714	0.06666666667	0.01333333333	0.03857142857	0.02571428571	0.03428571429	0.02857142857	0.05142857143	0.3385714286
NS 4	0	0.06857142857	0	0.04	0.05142857143	0.02571428571	0.03428571429	0.05714285714	0	0.2771428571
NS 5	0.09142857143	0.04571428571	0.06666666667	0.02	0.07714285714	0.05142857143	0.03428571429	0.08571428571	0.1542857143	0.6266666667
NS 6	0.06857142857	0.05714285714	0.03333333333	0.03333333333	0.07714285714	0.09	0.03428571429	0.04285714286	0.1028571429	0.5395238095

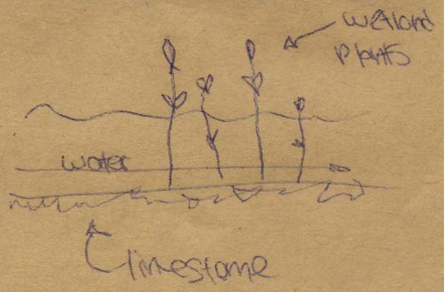
Final Table (3s.f.)	Min	Max	Min	Max	Max	Max	Max	Min	Min	Total
Weights	**0.16**	**0.08**	**0.2**	**0.04**	**0.09**	**0.09**	**0.06**	**0.1**	**0.18**	**1**
Example Calculation for ES 1	ROUND VALUES TO THREE SIGNIFICANT FIGURES									
ES 1	0.091	0.034	0.067	0.027	0.026	0.026	0.034	0.086	0.154	0.545
ES 2	0.023	0.046	0.067	0.027	0.051	0.039	0.051	0.043	0.103	0.449
ES 3	0.023	0.069	0.133	0.040	0.090	0.090	0.043	0.043	0.026	0.556
ES 4	0.000	0.080	0.000	0.040	0.013	0.013	0.009	0.000	0.000	0.154
ES 5	0.069	0.057	0.000	0.033	0.077	0.090	0.060	0.043	0.103	0.532
ES 6	0.069	0.057	0.133	0.013	0.039	0.013	0.034	0.029	0.051	0.438
NS 1	0.046	0.080	0.033	0.033	0.077	0.077	0.009	0.071	0.103	0.530
NS 2 (#1)	**0.046**	**0.069**	**0.067**	**0.040**	**0.077**	**0.077**	**0.034**	**0.086**	**0.154**	**0.650**
NS 3	0.023	0.057	0.067	0.013	0.039	0.026	0.034	0.029	0.051	0.339
NS 4	0.000	0.069	0.000	0.040	0.051	0.026	0.034	0.057	0.000	0.277
NS 5 (#2)	**0.091**	**0.046**	**0.067**	**0.020**	**0.077**	**0.051**	**0.034**	**0.086**	**0.154**	**0.627**
NS 6 (#3)	**0.069**	**0.057**	**0.033**	**0.033**	**0.077**	**0.090**	**0.034**	**0.043**	**0.103**	**0.540**

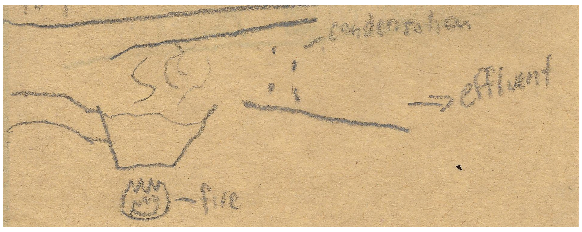
Appendix C: Sticky Note Brainstorming





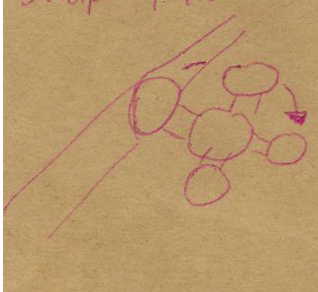
Maybe limestone encorporated into the bed of the wetlands

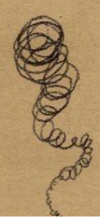




2.1 Each filter has a sensor which detects when ~~##~~ it needs to be replaced.
Because the efficiency of membranes fail as its pores become clogged
We will also need some contraption to let the fish pass through

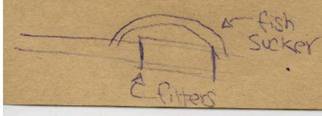
Carousel based system that can automatically swap filter





1.1 ~~Whe~~ There are sensors in the tank and it detects when the grates build up with waste. When it can't collect anymore, water is automatically drained out and a cleaning of the grates occur.
Maybe some sort of ~~robot~~ machinery sweeps the grates

4. Water collected through a river goes through a tube of filters, any fish trying to pass gets sucked up and launched to the otherside. Similar to how dams work



...
Would fishe already be contaminated?

Valid Point

Sell fish as food to make extra profit...

) Again a limestone coating would help w/ filtration because pre-treat.

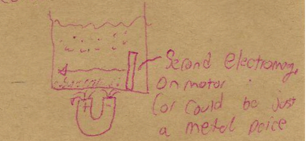
1. Precipitation technology with electromagnet to extract the metals faster

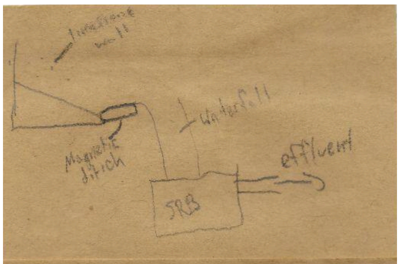
Use lime to change pH, then ~~so~~ when metals condense, use an electromagnet to pull

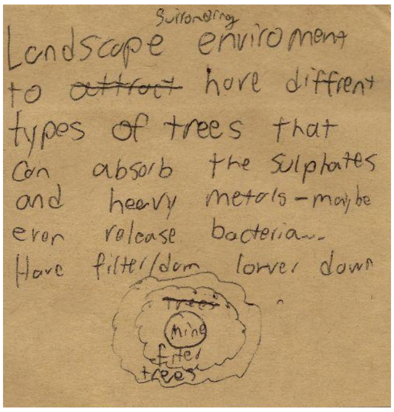
Machine learning camera (AI) detects and can then deploy a robot to sweep s

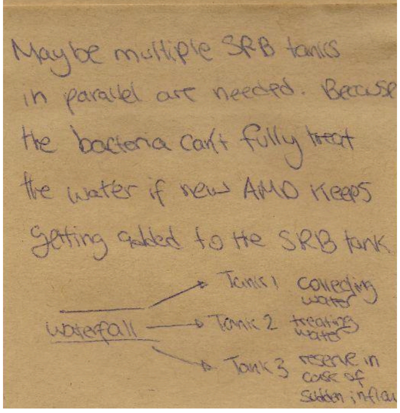
Have channels created in mine to ensure water flows into correct spot

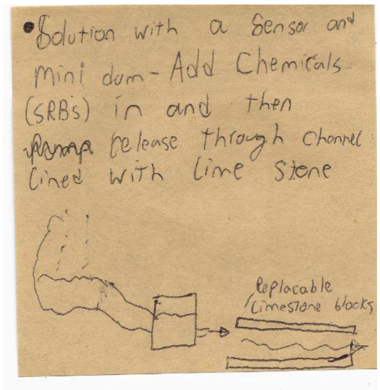
Have sweeper on bottom to gather metals collected



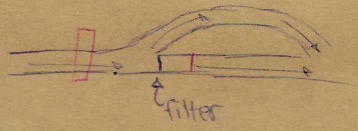

limestone wall
waterfall
Magnetic ditch
effluent
SRB


Landscape surrounding enviroment to ~~attract~~ have diffrent types of trees that can absorb the sulphates and heavy metals - maybe even release bacteria.
Have filter/dam lower down
~~Trees~~
Mine
filter
trees

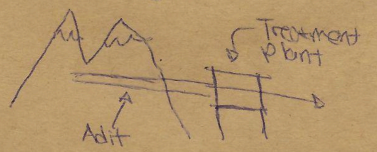

Maybe multiple SRB tanks in parallel are needed. Because the bacteria can't fully ~~treat~~ the water if new AMD keeps getting added to the SRB tank.
Tank 1 collecting water
waterfall
Tank 2 treating water
Tank 3 reserve in case of sudden inflow


Solution with a sensor and mini dam - Add Chemicals (SRBs) in and then ~~pump~~ release through channel lined with lime stone
Replacable limestone blocks

2. Create a slip stream along the rivers path and add filters along ~~the~~ one of the paths



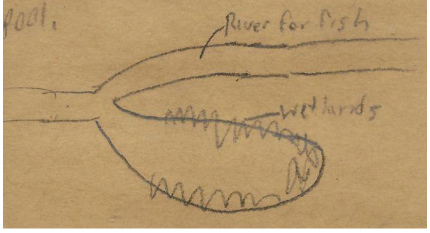
3. Water ~~pumped out~~ collected through ~~of~~ mine adits, treated as soon as they come out the mine, then released into the ground or river



Add dam to slow water down to manageable flow – ~~wall~~ could be lined with replaceable lime stone chunks

Set of sensors that only opens floodgates when system detects low contaminants, keeps adding chemicals in based on readings

Have parts of river channel into a wetland so heavy metals can be absorbed by vegitation. Sort of like a pool.



split the adit into multiple channels more effluent can be treated