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

APSC 169
Fundamentals of Sustainable Engineering Design
Project Report #2 - 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

Design Lab Section L2L
Team #3 Members:

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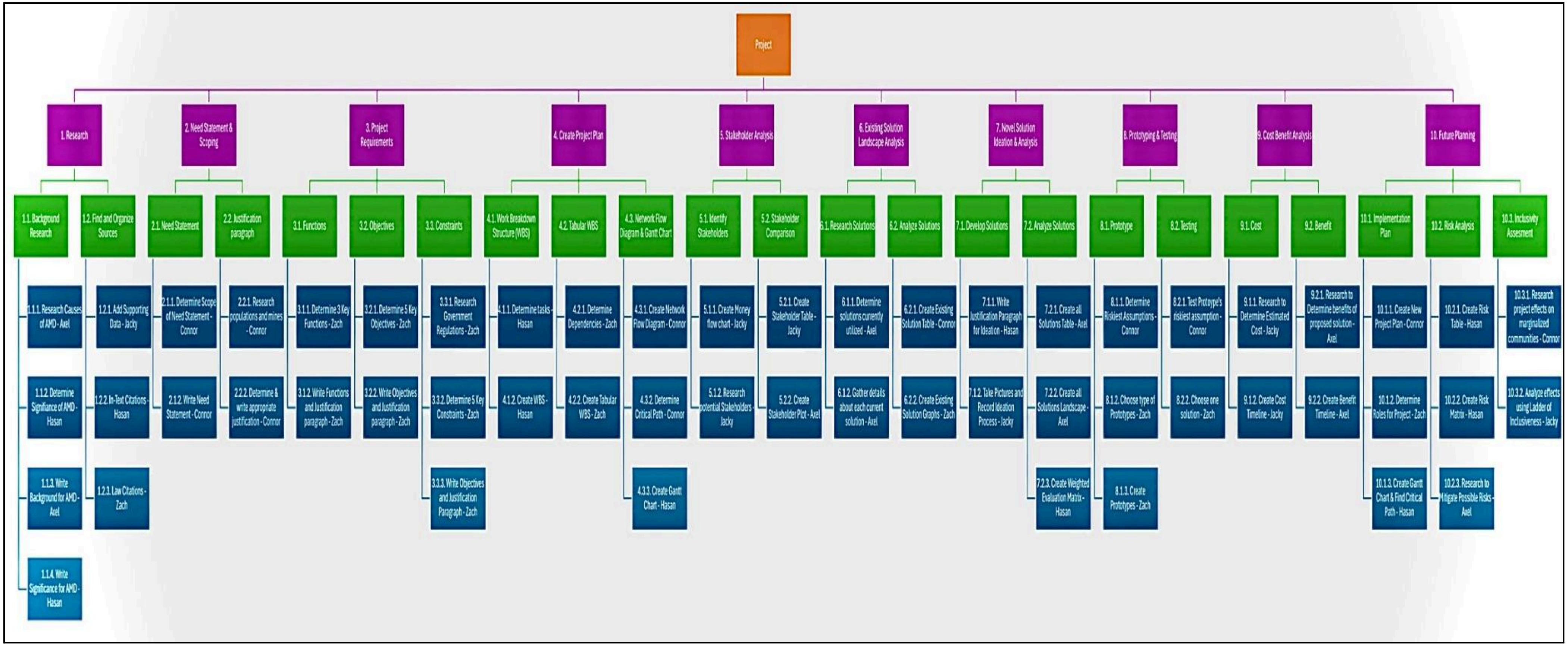
Identifying Team Strengths, Abilities and Interests

Name	**Interests**	**Strengths**	**Technical Abilities**
Hasan	Utilizing technology to improve environmental conditions.	Communicating with others and maintaining a strong work ethic.	Electronics development (soldering, circuit design), constructing and designing.
Connor	Impact of water quality on the aquatic environment and agricultural land.	Organization skills and communicating ideas with others.	Drafting sketches for possible solutions.
Axel	Interested in implementing electronics into designs	Speaks Indonesian, pays attention to small details.	CAD in Fusion360, CAM through 3D printing.
Jacky	Research the problem of water pollution.	Thinking critically and working well under pressure.	Programming in Java.
Zach	Law and Legal Stuff.	Can read French, as well as good art organization and coordinating.	Video editing, Woodworking.

Graphical Work Breakdown Structure



Tabular Work Breakdown Structure

WBS Code	Task Name	Dependencies	Owner	Time (Days)
1.1.1	Research Causes of AMD	N/A	Axel	2
1.1.2	Determine Significance of AMD	N/A	Hasan	3
1.1.3	Write Background for AMD	N/A	Axel	2
1.1.4	Write Significance for AMD	N/A	Hasan	3
1.2.1	Add Supporting Data	1.1	Jacky	2
1.2.2	In-Text Citations	1.1	Hasan	2
1.2.3	Law Citations	3	Zach	2
2.1.1	Determine Scope of Need Statement	N/A	Connor	2
2.1.2	Write Need Statement	2.1.1	Connor	2
2.2.1	Research populations and mines	2.1	Connor	2
2.2.2	Determine & write appropriate justification	2.2.1	Connor	2
3.1.1	Determine 3 Key Functions	1.1	Zach	1
3.1.2	Write Functions and	3.1.1	Zach	2

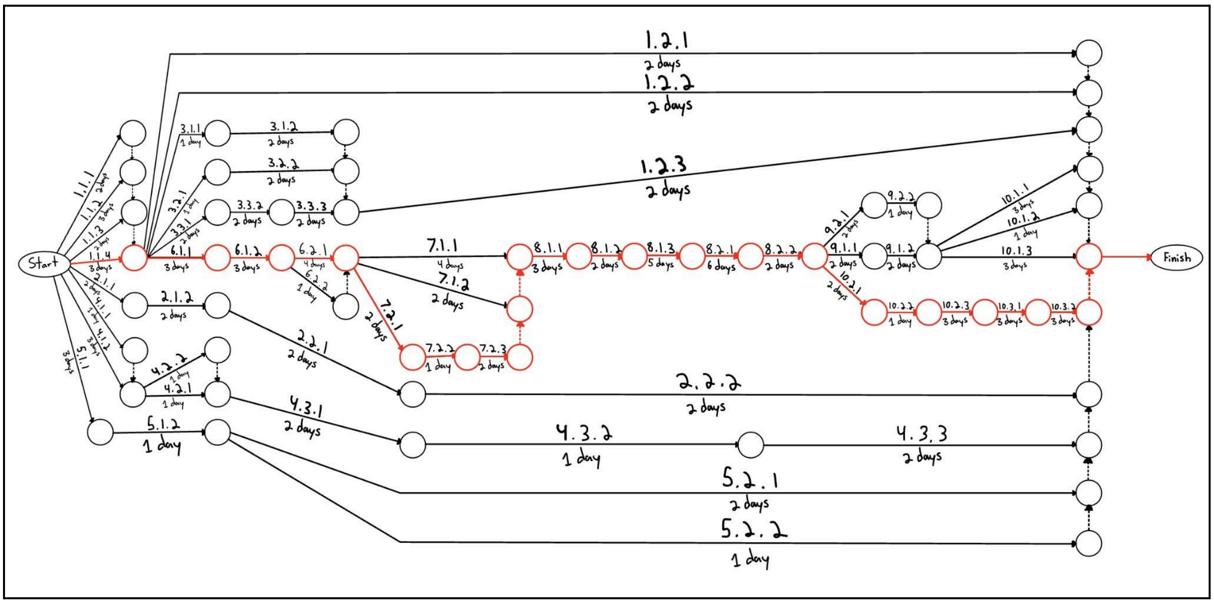
	Justification paragraph			
3.2.1	Determine 5 Key Objectives	1.1	Zach	1
3.2.2	Write Objectives and Justification paragraph	3.2.1	Zach	2
3.3.1	Research Government Regulations	1.1	Zach	2
3.3.2	Determine 5 Key Constraints	3.3.1	Zach	2
3.3.3	Write Constraints and Justification Paragraph	3.3.2	Zach	2
4.1.1	Determine tasks	N/A	Hasan	1
4.1.2	Create Graphical WBS	N/A	Hasan	3
4.2.1	Determine Dependencies	4.1	Zach	1
4.2.2	Create Tabular WBS	4.1	Zach	1
4.3.1	Create Network Flow Diagram	4.2	Connor	2
4.3.2	Determine Critical Path	4.3.1	Connor	1
4.3.3	Create Gantt Chart	4.3.2	Hasan	2
5.1.1	Research potential Stakeholders	N/A	Jacky	3
5.1.2	Create Money flow chart	5.1.1	Jacky	1

5.2.1	Create Stakeholder Table	5.1	Jacky	2
5.2.2	Create Stakeholder Plot	5.1	Axel	1
6.1.1	Determine solutions currently utilized	1.1	Axel	3
6.1.2	Gather details about each current solution	6.1.1	Axel	3
6.2.1	Create Existing Solution Table	6.1	Connor	4
6.2.2	Create Existing Solution Graphs	6.1	Zach	1
7.1.1	Write Justification Paragraph for Ideation	6	Hasan	4
7.1.2	Take Pictures and Record Ideation Process	6	Jacky	2
7.2.1	Create all Solutions Table	6	Axel	2
7.2.2	Create all Solutions Landscape	7.2.1	Axel	1
7.2.3	Create Weighted Evaluation Matrix	7.2.2	Hasan	2
8.1.1	Determine Riskiest Assumptions	7	Connor	3
8.1.2	Choose types of	8.1.1	Zach	2

	Prototypes			
8.1.3	Create Prototypes	8.1.2	Zach	5
8.2.1	Test Protoype's riskiest assumption	8.1	Connor	6
8.2.2	Choose one solution	8.2.1	Zach	2
9.1.1	Research to Determine Estimated Cost	8.2	Jacky	2
9.1.2	Create Cost Timeline	9.1.1	Jacky	2
9.2.1	Research to Determine benefits of proposed solution	8.2	Axel	2
9.2.2	Create Benefit Timeline	9.2.1	Axel	1
10.1.1	Create New Project Plan	9	Connor	3
10.1.2	Determine Roles for Project	9	Zach	1
10.1.3	Create Gantt Chart & Find Critical Path	9	Hasan	3
10.2.1	Create Risk Table	8.2	Hasan	2
10.2.2	Create Risk Matrix	10.2.1	Hasan	1
10.2.3	Research to Mitigate Possible Risks	10.2.2	Axel	3

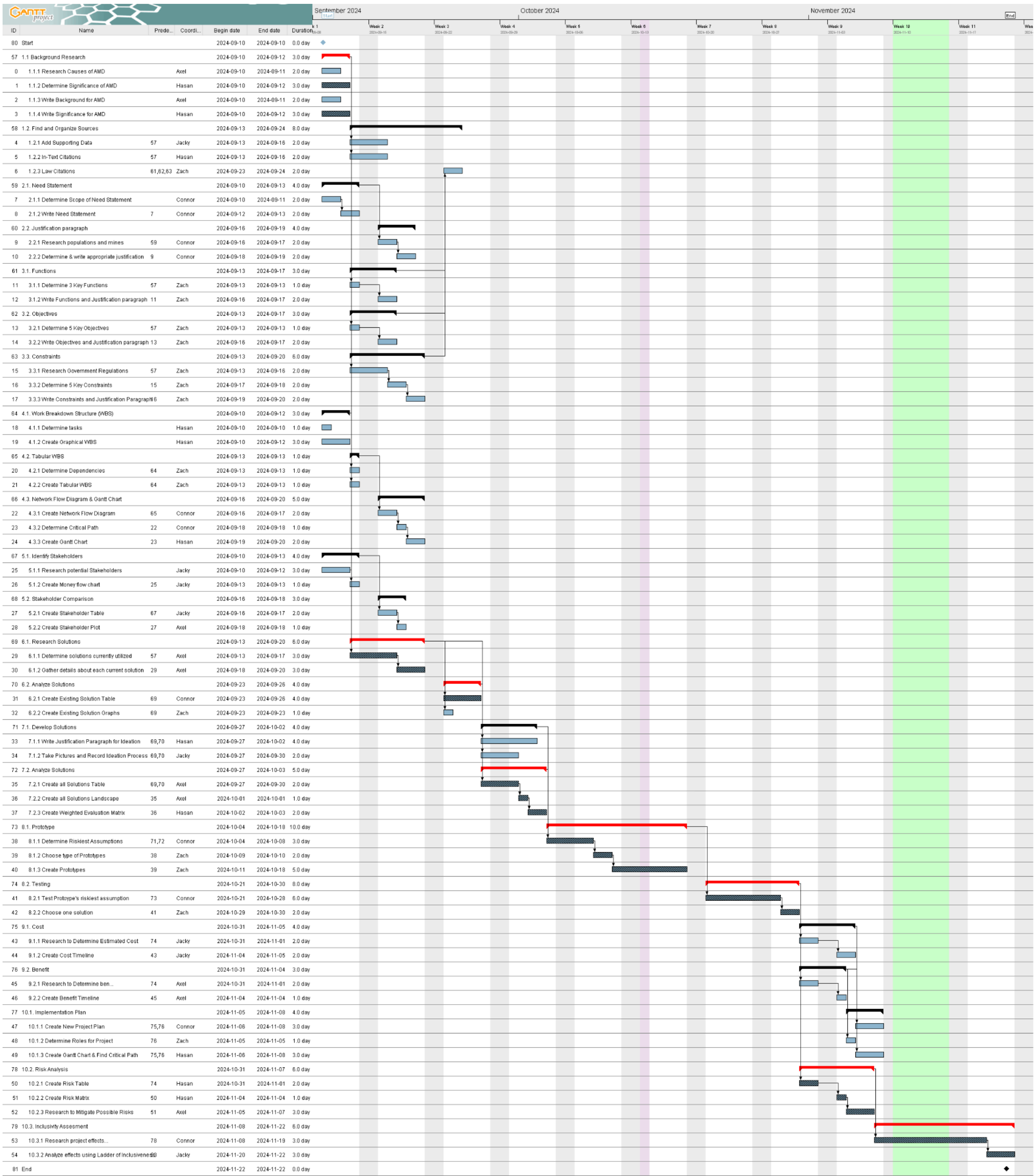
10.3.1	Research project effects on marginalized communities	10.2	Connor	3
10.3.2	Analyze effects using Ladder of Inclusiveness	10.3.1	Jacky	3

Network Flow Diagram



This network flow diagram is specified as an Activity on Arrow diagram. In addition, the diagram start date is on September 10th and it is completed by November 22nd. The diagram states the topics worked on referring to their designated WBS code and the time to complete said task is provided in the unit of days. The critical pathway, the longest pathway to complete the project, is highlighted in red and sums up to 48 days of work.

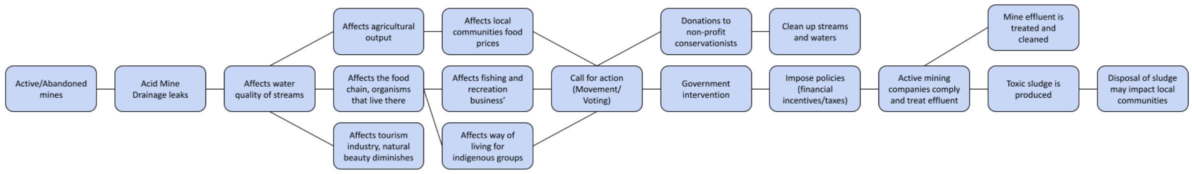
Gantt Chart



ID	Name	Prede...	Coordi...	Begin date	End date	Duration
80	Start			2024-09-10	2024-09-10	0.0 day
57	1.1 Background Research			2024-09-10	2024-09-12	3.0 day
0	1.1.1 Research Causes of AMD		Axel	2024-09-10	2024-09-11	2.0 day
1	1.1.2 Determine Significance of AMD		Hasan	2024-09-10	2024-09-12	3.0 day
2	1.1.3 Write Background for AMD		Axel	2024-09-10	2024-09-11	2.0 day
3	1.1.4 Write Significance for AMD		Hasan	2024-09-10	2024-09-12	3.0 day
58	1.2. Find and Organize Sources			2024-09-13	2024-09-24	8.0 day
4	1.2.1 Add Supporting Data	57	Jacky	2024-09-13	2024-09-16	2.0 day
5	1.2.2 In-Text Citations	57	Hasan	2024-09-13	2024-09-16	2.0 day
6	1.2.3 Law Citations	61,62,63	Zach	2024-09-23	2024-09-24	2.0 day
59	2.1. Need Statement			2024-09-10	2024-09-13	4.0 day
7	2.1.1 Determine Scope of Need Statement		Connor	2024-09-10	2024-09-11	2.0 day
8	2.1.2 Write Need Statement	7	Connor	2024-09-12	2024-09-13	2.0 day
60	2.2. Justification paragraph			2024-09-16	2024-09-19	4.0 day
9	2.2.1 Research populations and mines	59	Connor	2024-09-16	2024-09-17	2.0 day
10	2.2.2 Determine & write appropriate justification	9	Connor	2024-09-18	2024-09-19	2.0 day
61	3.1. Functions			2024-09-13	2024-09-17	3.0 day
11	3.1.1 Determine 3 Key Functions	57	Zach	2024-09-13	2024-09-13	1.0 day
12	3.1.2 Write Functions and Justification paragraph	11	Zach	2024-09-16	2024-09-17	2.0 day
62	3.2. Objectives			2024-09-13	2024-09-17	3.0 day
13	3.2.1 Determine 5 Key Objectives	57	Zach	2024-09-13	2024-09-13	1.0 day
14	3.2.2 Write Objectives and Justification paragraph	13	Zach	2024-09-16	2024-09-17	2.0 day
63	3.3. Constraints			2024-09-13	2024-09-20	6.0 day
15	3.3.1 Research Government Regulations	57	Zach	2024-09-13	2024-09-16	2.0 day
16	3.3.2 Determine 5 Key Constraints	15	Zach	2024-09-17	2024-09-18	2.0 day
17	3.3.3 Write Constraints and Justification Paragraph	16	Zach	2024-09-19	2024-09-20	2.0 day
64	4.1. Work Breakdown Structure (WBS)			2024-09-10	2024-09-12	3.0 day
18	4.1.1 Determine tasks		Hasan	2024-09-10	2024-09-10	1.0 day
19	4.1.2 Create Graphical WBS		Hasan	2024-09-10	2024-09-12	3.0 day
65	4.2. Tabular WBS			2024-09-13	2024-09-13	1.0 day
20	4.2.1 Determine Dependencies	64	Zach	2024-09-13	2024-09-13	1.0 day
21	4.2.2 Create Tabular WBS	64	Zach	2024-09-13	2024-09-13	1.0 day
66	4.3. Network Flow Diagram & Gantt Chart			2024-09-16	2024-09-20	5.0 day
22	4.3.1 Create Network Flow Diagram	65	Connor	2024-09-16	2024-09-17	2.0 day
23	4.3.2 Determine Critical Path	22	Connor	2024-09-18	2024-09-18	1.0 day
24	4.3.3 Create Gantt Chart	23	Hasan	2024-09-19	2024-09-20	2.0 day
67	5.1. Identify Stakeholders			2024-09-10	2024-09-13	4.0 day
25	5.1.1 Research potential Stakeholders		Jacky	2024-09-10	2024-09-12	3.0 day
26	5.1.2 Create Money flow chart	25	Jacky	2024-09-13	2024-09-13	1.0 day
68	5.2. Stakeholder Comparison			2024-09-16	2024-09-18	3.0 day
27	5.2.1 Create Stakeholder Table	67	Jacky	2024-09-16	2024-09-17	2.0 day
28	5.2.2 Create Stakeholder Plot	27	Axel	2024-09-18	2024-09-18	1.0 day
69	6.1. Research Solutions			2024-09-13	2024-09-20	6.0 day
29	6.1.1 Determine solutions currently utilized	57	Axel	2024-09-13	2024-09-17	3.0 day
30	6.1.2 Gather details about each current solution	29	Axel	2024-09-18	2024-09-20	3.0 day
70	6.2. Analyze Solutions			2024-09-23	2024-09-26	4.0 day
31	6.2.1 Create Existing Solution Table	69	Connor	2024-09-23	2024-09-26	4.0 day
32	6.2.2 Create Existing Solution Graphs	69	Zach	2024-09-23	2024-09-23	1.0 day
71	7.1. Develop Solutions			2024-09-27	2024-10-02	4.0 day
33	7.1.1 Write Justification Paragraph for Ideation	69,70	Hasan	2024-09-27	2024-10-02	4.0 day
34	7.1.2 Take Pictures and Record Ideation Process	69,70	Jacky	2024-09-27	2024-09-30	2.0 day
72	7.2. Analyze Solutions			2024-09-27	2024-10-03	5.0 day
35	7.2.1 Create all Solutions Table	69,70	Axel	2024-09-27	2024-09-30	2.0 day
36	7.2.2 Create all Solutions Landscape	35	Axel	2024-10-01	2024-10-01	1.0 day
37	7.2.3 Create Weighted Evaluation Matrix	36	Hasan	2024-10-02	2024-10-03	2.0 day
73	8.1. Prototype			2024-10-04	2024-10-18	10.0 day
38	8.1.1 Determine Riskiest Assumptions	71,72	Connor	2024-10-04	2024-10-08	3.0 day
39	8.1.2 Choose type of Prototypes	38	Zach	2024-10-09	2024-10-10	2.0 day
40	8.1.3 Create Prototypes	39	Zach	2024-10-11	2024-10-18	5.0 day
74	8.2. Testing			2024-10-21	2024-10-30	8.0 day
41	8.2.1 Test Protoype's riskiest assumption	73	Connor	2024-10-21	2024-10-28	6.0 day
42	8.2.2 Choose one solution	41	Zach	2024-10-29	2024-10-30	2.0 day
75	9.1. Cost			2024-10-31	2024-11-05	4.0 day
43	9.1.1 Research to Determine Estimated Cost	74	Jacky	2024-10-31	2024-11-01	2.0 day
44	9.1.2 Create Cost Timeline	43	Jacky	2024-11-04	2024-11-05	2.0 day
76	9.2. Benefit			2024-10-31	2024-11-04	3.0 day
45	9.2.1 Research to Determine ben...	74	Axel	2024-10-31	2024-11-01	2.0 day
46	9.2.2 Create Benefit Timeline	45	Axel	2024-11-04	2024-11-04	1.0 day
77	10.1. Implementation Plan			2024-11-05	2024-11-08	4.0 day
47	10.1.1 Create New Project Plan	75,76	Connor	2024-11-06	2024-11-08	3.0 day
48	10.1.2 Determine Roles for Project	76	Zach	2024-11-05	2024-11-05	1.0 day
49	10.1.3 Create Gantt Chart & Find Critical Path	75,76	Hasan	2024-11-06	2024-11-08	3.0 day
78	10.2. Risk Analysis			2024-10-31	2024-11-07	6.0 day
50	10.2.1 Create Risk Table	74	Hasan	2024-10-31	2024-11-01	2.0 day
51	10.2.2 Create Risk Matrix	50	Hasan	2024-11-04	2024-11-04	1.0 day
52	10.2.3 Research to Mitigate Possible Risks	51	Axel	2024-11-05	2024-11-07	3.0 day
79	10.3. Inclusivity Assesment			2024-11-08	2024-11-22	6.0 day
53	10.3.1 Research project effects...	78	Connor	2024-11-08	2024-11-19	3.0 day
54	10.3.2 Analyze effects using Ladder of Inclusivenes	53	Jacky	2024-11-20	2024-11-22	3.0 day
81	End			2024-11-22	2024-11-22	0.0 day

Stakeholder Analysis

Cycle of flow and use of money:

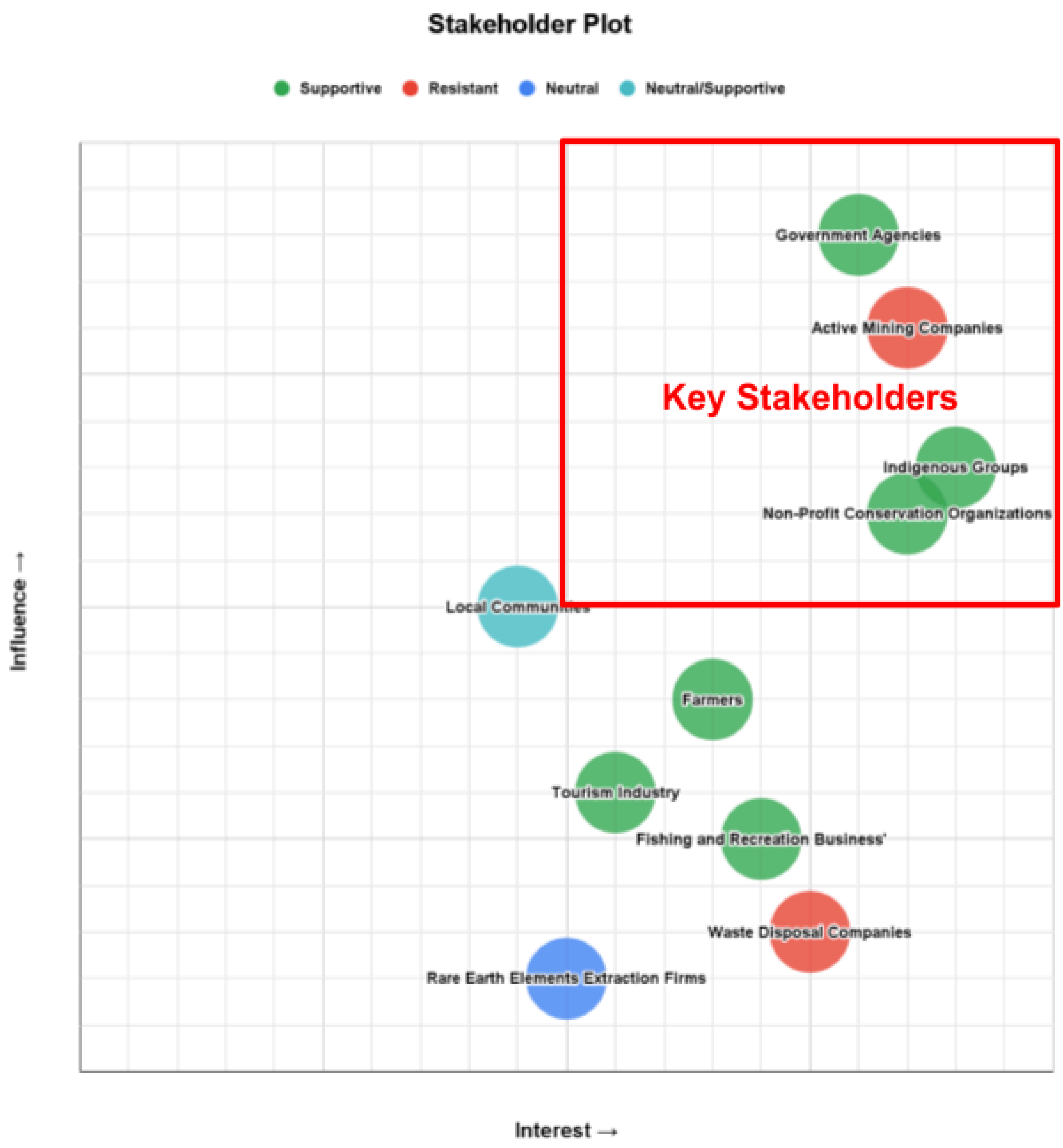


Stakeholder table:

Stakeholder	Impact	Interest	Influence
Government Agencies	Supportive	High	Very High
Active Mining Companies	Resistant	Very High	High
Non-Profit Conservation Organizations	Supportive	Very High	Medium/High
Tourism Industry	Supportive	Medium	Low
Fishing and Recreation Business'	Supportive	High	Low
Indigenous Groups	Supportive	Very High	Medium/High
Rare Earth	Neutral	Medium	Very Low

Elements Extraction Firms			
Local Communities	Neutral/Supportive	Medium	Medium
Farmers	Supportive	Medium/High	Medium/Low
Waste Disposal Companies	Resistant	High	Very Low

While most of the stakeholders are fairly logical and self explanatory, some require additional justification. For instance, active mining companies are likely to resist these environmental efforts as any new technology may prove costly compared to what they actively utilize, which will threaten their profits. In fact, it is an observed effect that companies do not want to take major risks by adopting a novel solution (SOURCE). It is only once the technology has been proven and largely accepted that they will support the project. Until that point, they may lobby against the effort in order to preserve the status quo. Their high influence comes from their ability to establish the infrastructure for these projects, as well as a potentially strong lobbying power. Another stakeholder that requires further clarification is rare earth element extraction firms. In the filtration of AMD, sludge often comes about as a byproduct of the treatment process. This sludge can contain highly concentrated amounts of metals and rare earth elements. With rare earth elements being critical due to their use in many high-tech industries, firms exist with the sole purpose of extracting these rare earth elements to meet the demand (Mwewa et al., 2022). While still a relatively new operation, some of these extraction firms have begun to extract these rare earth elements from AMD sludge, albeit still at a pilot scale (Mwewa et al., 2022). Consequently, the discovery of this technology has yet to truly impact the REE industry as a whole, which is why REE extraction firms are fairly neutral with some interest in the development of this technology.



Current Solutions Description

Currently, there are six primary methods for treating mine effluent (Mosai et al., 2024)—with various innovations and technologies within each method. Those methods are adsorption, sulphate-reducing bacteria, membrane technologies, freeze crystallization, precipitation technologies and ion exchange. It is important to note that of the six methods mentioned above, each method has a myriad of respective solutions and technologies developed by different companies. Moreover, while only 6 methods will be discussed below, there are further methods such as electrochemical technology (Management and Mitigation of Acid Mine Drainage in South Africa, n.d. p.255), which have been proposed to help deal with AMD. However, solutions of the like are in a very early stage and not enough research has been conducted on them.

1. Adsorption

Adsorption involves the use of natural or modified materials such as zeolite or manure compost to attract and bind contaminants from mining effluent. Absorbents are often preferred in studies as minimal waste is produced and the adsorbent itself can often be reused. However, most studies into adsorbent technology happen on a small scale, as the amount of adsorbents required to treat AMD is impractical (Mosai et al., 2024 p.4). Thus the large-scale feasibility is still unclear.

2. Sulfate-reducing bacteria (SRB)

SRBs are microorganisms which increase the alkalinity of AMD and facilitate the precipitation of metal sulfides allowing them to be easily filtered out. The process is an easy, efficient, and cost-effective method to address AMD. However, it requires careful control of environmental conditions to operate optimally (Mosai et al., 2024 p.5). Thus, the majority of

SRB technology has only been applied on a small scale, although some companies have managed to commercialize the process at a large scale (Mosai et al., 2024 p.5).

3. Membrane technologies

Membrane technologies implement a semi-permeable membrane to separate contaminants from mine effluent based on the particle's charge and size. The three most studied technologies are reverse osmosis, nanofiltration, and ultrafiltration, which can remove ~0.1-1 nm, ~1-10 nm, and ~10-100 nm sized particles respectively (Mosai et al., 2024 p.7). While membrane technologies have been proven to remove high rates of contaminants, the primary difficulty involves energy consumption and membrane fouling—the build-up of solute on membrane pores, causing blockages (Mosai et al., 2024 p.7).

4. Freeze crystallization

Freeze crystallization is a comparably simpler process in which mine effluent is frozen and then contaminants are separated from the ice that has formed. The ice is then extracted and allowed to melt back into pure water, leaving the contaminants behind to be disposed of (Mosai et al., 2024 p.10). While it is possible to recover high rates of water, the energy requirements required to execute this technology—especially in warmer climates—are impractical.

5. Precipitation technologies

Similar to SRBs, precipitation technologies involve adding chemicals like limestone to precipitate out the dissolved contaminants so that they can be filtered out. Precipitation technologies are cost-effective and have now been patented and applied on a pilot scale

(Mosai et al., 2024 p.11). However, the process generates sludge, an additional byproduct that must then be disposed of.

6. Ion exchange

Ion exchanges typically use resins that replace harmful ions with less harmful ones. This method allows for the recovery of precious metal and also involves minimal sludge. Ion exchange has been commercialized on a large scale. However, common problems include the high maintenance costs in replacing and or maintaining the ion exchange resin—if not dealt with, resins may aid bacterial growth, contributing to the contaminants in the water (Mosai et al., 2024 p.12).

Existing Solutions Table

As mentioned earlier, each method has a multitude of different solution technologies—thus it would be impractical to research and rate every single solution. Instead, the paramount solution for each method was picked and then used to extrapolate for all the other solutions that encompass a given method. The ratings on the existing solutions tables were ranked from very low to very high, and the justifications are provided below. It is also important to note that a perfect comparison of solutions was nearly impossible, as all are in different stages of development, with some papers describing a solution in full-scale operation, while others addressed smaller pilot projects. Additionally, variations in capacity, climate, years of operation, and region are additional factors further complicating the process. Thus, best judgment was used for the ratings of each solution.

The 6 selected techniques were rated in nine categories. Firstly, the upfront costs for the solution. Upfront costs included costs for land, equipment and construction. The second category was how much benefit each solution provided. This was more subjective as there was no one way to measure it. Based on research and inferences, they were ranked by factoring in the additional benefits they offered. Thus, this category included not just water purity, but also other functions a treatment may serve, such as being able to extract minerals from the collected sludge to be resold, or the ability to produce pure drinkable water. Third, the solutions were rated on how harmful they were to the environment. This distinction factored in their efficiency in removing heavy metals and sulphur, their impact on the pH of the water, and the amount of byproduct produced. Fourthly, the societal benefit of each solution was analyzed. Broadly, this entailed researching the impact each solution had on potential stakeholders; examples include the production of irrigation water for farmers, increased cleanliness that promotes tourism, and clean water resulting in reduced government fines. The remaining five ratings come from the five project objectives. Each solution was rated on how well it could maximize the variety of heavy metals that can be treated, maximize sulphate removal*, maximize the rate of purification, minimize the human control needed, and minimize operating costs. The ratings can be seen in the Existing Solutions Table below.

*It should be noted that the former objective to “Minimize contaminants in water” was replaced in favor with “Maximize Sulphate Removal” as the former set of objectives did not have a sulphate removal target.

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**
Adsorption (Open	Medium/ Low	Medium/ Low	Medium	Medium	Low	Low	< 20L/s Medium	Very Low	Very Low

Limestone Drains)	(2)		(2,3)		(2,3)	(1)	(2)	(2)	(2)
Sulfate Reducing Bacteria (Bioreactor)	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)
Membrane Technologies (Reverse Osmosis)	High (12, 16)	High	Low (11, 14)	High	Very High (14)	Very High (17)	46 L/s Medium/ High (13)	Medium (13)	High (15)
Freeze Crystallization (Pipe Freeze)	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)
Precipitation Technologies (SAVMIN)	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)
Ion Exchange (Selective Cation Exchange)	Medium (25)	Medium/ High (25, 27)	Low (25)	Low	Medium/ Low (25, 27)	Low (26)	18.93 L/s Medium (25)	Medium/ High (25)	Medium/ High (25)

Footnotes:

Absorption

(1) Silva et al., 2012, p. 54

(2) Taylor et al., 2005

(3) Fuchida et al., 2020

SRB

(4) Ayangbenro et al., 2018

(5) Bai et al. 2013, p. 822

(6) Cohen, 2006, p. 1155

(7) Di et al., 2022, pp. 8783-8783

(8) Johnson & Hallberg, 2005, p. 11

(9) Mosai et al., 2024

(10) Silva et al., 2012, pp. 46, 54

Membrane

(11) Agboola, 2019, pp. 1389-1400

(12) Herber, 2024

(13) Organization of American States, n.d.

(14) Kapepula & Luis, 2024

(15) León-Venegas et al., 2023

(16) Osipi et al., 2019 s. 13; pp. 305-324

(17) Zhu et al., 2022

Freeze Crystallization

(18) More & Mahlangu, 2024

(19) Water Resources Management VII. n.d.

(20) Mosai et al., 2024

Precipitation Technologies

(21) Management and mitigation of acid mine drainage in South Africa. n.d.

(22) Naidoo & Govender-Ragubeer, n.d.

(23) LORAX, 2003

(24) Mosai et al., 2024

Ion Exchange

(25) IRTC Mining Waste Team, n.d.

(26) Can, et al., 2020

(27) Mosai et al., 2024

Justification for Existing Solution Ratings

Absorption:

For the removal technique of Absorption, the most promising solution was selected as Open (or Oxic) Limestone Drains (OLD for short). This specifically was chosen due to its widespread use and the availability of data surrounding it. OLDs are river beds coated in large amounts of limestone (Taylor, et al., 2005., p. 16). As the water flows along, the metals and minerals in the water react with the limestone and precipitate out as a solid (Taylor, et al., 2005). However, due to the time it takes for the reaction to occur, most OLDs have to be built at an angle less than 10° so the water does not flow too fast (Taylor, et al., 2005, p. 16). It was noted that OLDs have medium to low upfront costs. Estimates put OLD construction costs anywhere between \$5,000 - \$200,000 Australian dollars (Taylor, et al., 2005, p. 15). This large range is likely due to the varying amounts of land needed. As mentioned earlier, OLDs have to be built at a slight incline so the metals in the water have time to react with the limestone (Taylor, et al., 2005, p. 16). Because of this additional requirement, a lot of land is required. With that said, limestone is a relatively cheap resource (Taylor, et al., 2005, p. 17), which offsets the cost of the land, therefore giving it medium/low upfront costs.

OLDs have little benefit outside of water purification, so they warrant a medium/low impact. As for environmental impact, it is somewhere in the middle. If a limestone drain is not maintained, the precipitate of these toxic heavy metals will remain in the water. As well as this, some metals like Zn, Cd, and Pb are hardly treated (Fuchida, et al., 2020, Table 1). However, studies show that the pH of the water typically increased to a range of 7.5 - 8.0 after flowing through an OLD (Taylor, et al., 2005, p. 17). On top of this, it has been shown that aquatic life had returned to places where OLD treatment was used (Taylor, et al., 2005. p. 17). Because of this, OLDs have an average environmental impact, as they improve conditions, but do not go above and beyond. This is similar to their societal impact - the effluent water quality suffices, but could be better. As touched on earlier, OLDs do not remove a large quantity of heavy metals (Fuchida, et. al., 2012), which is why it was classified as a “low” rating. Unfortunately, OLDs do not filter much sulfate either, with only 23 mg removed per gram of limestone (Silva et al., 2012, p. 54). Combine that with the fact that OLDs do not seem to be effective when sulphate concentrations are above 1.2-2.0 M (Silva et al., 2012, p. 54), and it becomes clear that they are useful, but only in certain ideal conditions. With that said, OLDs have a solid flow rate, reaching up to speeds of 20L/s depending on the angle (Taylor, et al., 2005, Table 6). Where Open Limestone Drains shine though, is with their automaticity. Besides occasional maintenance, OLDs are completely passive (Taylor, et al., 2005, p. 17). This also means OLDs have low operating costs as maintenance is minimal and limestone is cheap (Taylor, et al., 2005, p. 17). That is why both these categories were given a very low rating.

Bioreactors:

Bioreactors are the leading solution that utilizes Sulfate Reducing Bacteria (SRB). Bioreactors can take many forms, but they all share the same general principles: AMD is pumped into a chamber filled with SRB (Bai, et al., 2013, p. 819) and then discharged. The problem with bioreactors is they can vary greatly in size, meaning it is hard to gauge the upfront costs to construct one. However, reports have stated that construction costs are a downside noting they are “considerable” (Johnson, et al., 2005, p. 11). The SRB bioreactor has a similar environmental impact to the Limestone drains, though it does a more thorough job removing heavy metals from the water, removing up to 99% Copper, 86% Iron and 52% Manganese in some studies (Bai, et al., 2013, p. 822). However, bioreactors produce sludge as a byproduct of removal (Bai, et al., 2013, p. 819), which is detrimental to the environment (Silva, et al., 2012, p. 46). As for societal impact, and general benefit, again it is right up the middle. It cleans the water but does not do anything beyond that to distinguish itself. SRB bioreactors target a similar range of heavy metals to OLDs, focusing primarily on Cd, Cu, Fe, Mn, Ni, and Zn (Ayangbenro et al., 2018, Table 1). Where bioreactors fare better is with treating sulphate. Bioreactors can treat waters with a higher sulphate concentration; one study notes that they brought a 61% decrease in the concentration (Bai, et al., 2013, p. 822). Larger scale bioreactors can purify up to 116L/s, which is much higher than other solutions(Mosai, et. al., 2024, p. 6). However, bioreactors are more active than OLDs, as they require frequent maintenance to prevent them from clogging (Cohen, 2006, p. 1156), which is why it was given a medium rating. Finally the bioreactor’s operating costs are medium/low because most reports state that SRB bioreactors are cost-effective (Ayangbenro et al., 2018).

Reverse Osmosis:

The third treatment type, membrane technologies, was represented by reverse osmosis filtration (RO). Reverse osmosis works by forcing water molecules through a semipermeable membrane using high amounts of pressure (Ighal et al, 2022, p 45). This causes pure water to flow through while trapping all other contaminants. Upfront costs of an RO plant vary with its size. An architect wrote that a distillation plant could range between $1,000 - $2,500 per cubic meter (Herber., 2024), while membranes can cost about $40 per square meter (Osipi, et al., 2019, Table 3), making them an exorbitantly expensive option, which was reflected in the rankings. As for benefits, RO treatment has one of the greatest: it releases pure drinking water (Kapepula, et al., 2024). That means the water is perfect for all environments and functionalities, completely minimizing the environmental impacts of AMD. That is why it was ranked positively in the benefit, environmental impact, and societal impact columns. However, depending on the size of the plant, it can cost between $2.01 - $6.05 per cubic meter of water produced as well as using 8.03 kWh/m^3 of water purified (León-Venegas, et al., 2023, p. 8). That is quite a high resource use, which is why it was rated as high cost. And although RO plants can treat up to 4,000m^3 per day or 46 L/s. (Organization of American States, n.d.), other treatment options can double that, which is why it was only rated at a medium. Finally, the amount of human control needed was rated as medium. According to the Organization of American States, RO plants producing 4,000m^3/day only need 3 full-time staff members (Organization of American States, n.d.).

Pipe Freeze Technology:

For the fourth treatment, freeze crystallization was represented by the pipe freeze technology. In a report of a 100 kilogram/hour pipe freeze plant in South Africa, 1.5 million ZAR—approximately 120,000 CAD—was required as upfront costs for capital equipment, construction costs, utilities and so on (More & Mahlangu, 2024)—thus the upfront costs were rated very high. In the same source, it was mentioned that the pipe freeze plant was able to output drinking water fit for consumption. However, it still faced challenges in addressing the sludge produced as a waste product. For those reasons, both the benefit and societal impact were rated very high, alongside the environmental impact being rated high as well. As for the amount of sulphate and heavy metals removed, because it was incredibly low (as pipe freeze more so focuses on removing inorganic brines and salts), it is often prefiltered first by another technology like RO before the effluent is processed (Management and mitigation of acid mine drainage in South Africa. n.d. p.10). Thus, it was rated very low for both the variety of heavy metals treated, alongside the sulphate that is removed. It is reported that freeze crystallization technology can filter out 1500 litres an hour, which is quite low when compared to other technologies. This delay is largely based on the time taken to freeze the effluent (More & Mahlangu, 2024). Although limited chemical additives are required in the process, the operating costs and human control required are still very high, particularly because of the costs of the toxic waste that needs to be disposed of, which in South Africa, costs 2,500 ZAR (200 CAD) for every meter cubed of waste. That cost is in addition to the amount of electricity required to freeze such large amounts of AMD, and the labour required to maintain and observe the plant (More & Mahlangu, 2024).

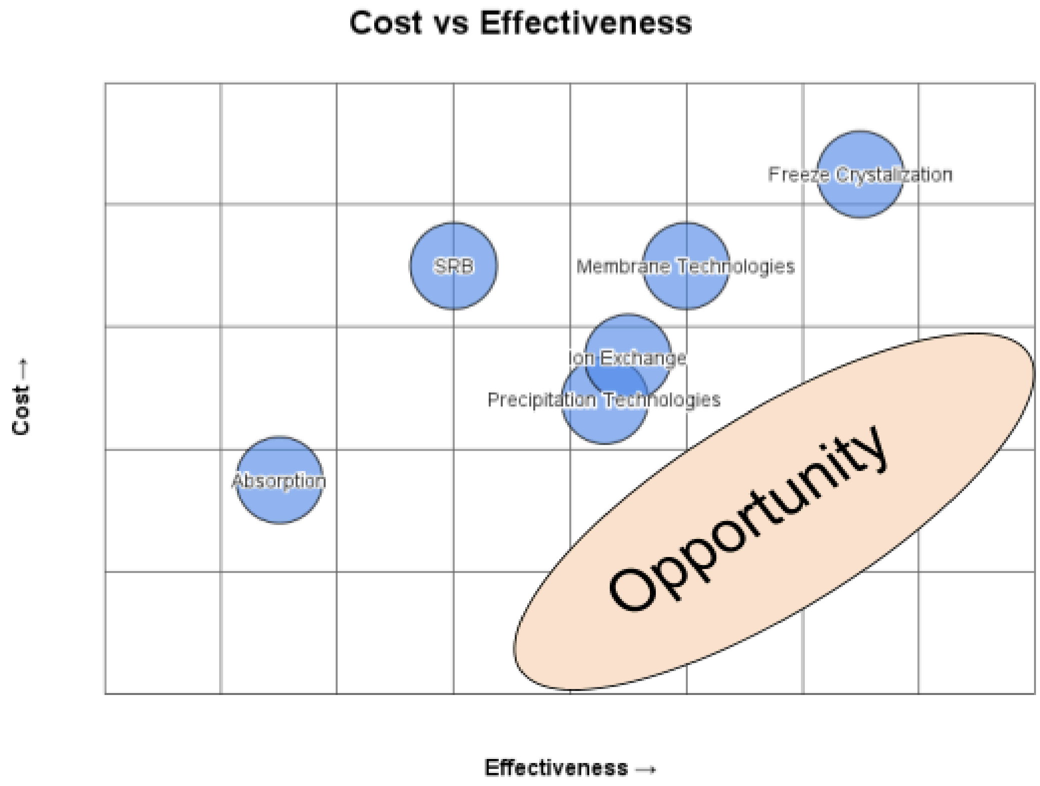
SAVMIN:

For precipitation technologies, it seems that the paramount solution in this field is a technology called SAVMIN developed by Mintek, an organization based in South Africa (Mosai et al., 2024). In one particular SAVMIN plant, which on average processed 1000 cubic meters of waste daily, the capital cost amounted to 310,000 USD (LORAX, 2003). While it is a pretty expensive solution upfront, the purification rate of 20 megalitres a day makes it the cheapest option when looking at cost per litre purified (Mosai et al., 2024). Thus upfront costs were rated medium and rate of purification was rated very high. Moreover, because SAVMIN can operate at ambient temperatures, without an environment needing to be created, this cuts down on the upfront costs required to build the plant, as well as the operating costs in terms of electricity—it is said that ($0.17 USD/$m^3$ of waste) is required to operate the electricity of the plant, and for this reason operating costs were rated medium/low (LORAX, 2003). An additional benefit of SAVMIN technology is that in its sludge produced, lots of precious metals can be recovered and sold to REE extraction firms, which is the reason why its benefit was rated medium/high (Management and mitigation of acid mine drainage in South Africa. n.d.). However, this production of potentially harmful sludge that must be dealt with is also the reason why it scored highly for environmental impact—although it produced a lot of sludge, some of the reagents used in the process were recycled, so a very high rating was not given (Naidoo & Govender-Ragubeer, n.d.). It is reported that almost all metals can be targeted and filtered out of AMD with the exception of monovalent ions. These ions are not particularly relevant in AMD, but it is still important to consider their presence, as they may be detrimental in other situations. Their continued presence prevents the rating from being very high, and rather it is just high (Naidoo & Govender-Ragubeer, n.d.). As for sulphate removal, it is reported to bring down concentrations to 69 milligrams per liter, which is well below the potable drinking water requirement of 200 milligrams per liter. For this reason sulphate removal was rated very high, and the societal impact was also rated medium/high (LORAX, 2003). Lastly, SAVMIN was rated medium for human control, as it is quite an autonomous process, but still requires labourers to maintain and dispose of the sludge produced (Management and mitigation of acid mine drainage in South Africa. n.d.).

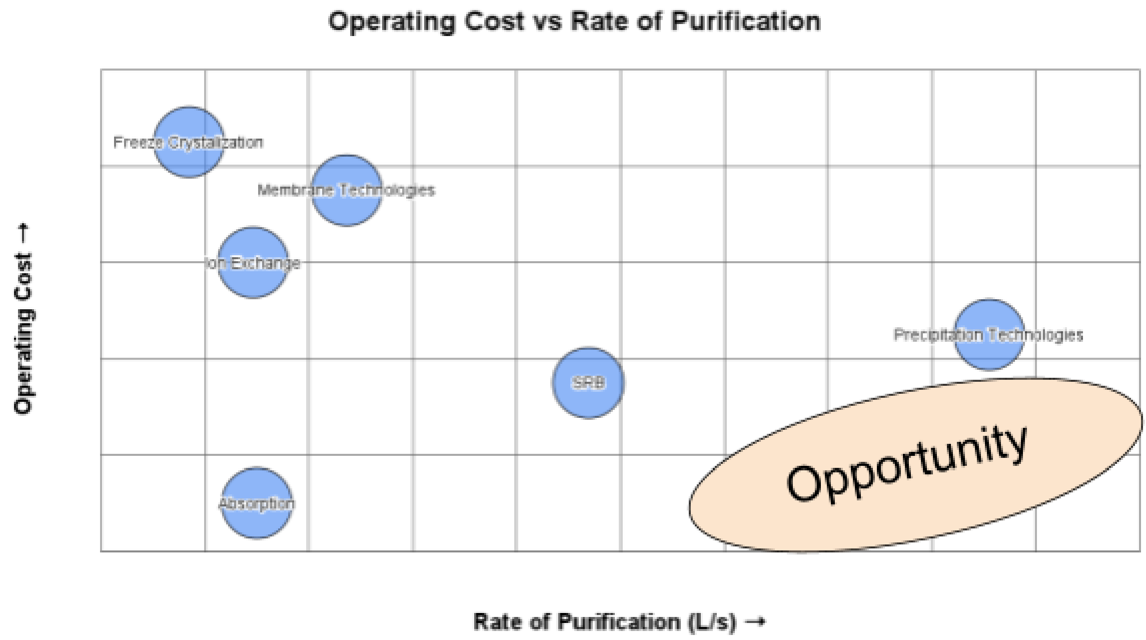
Selective Cation Exchange:

For the evaluation of ion exchange, the Soudan mine selective cation exchange case study from Minnesota was considered. Unlike the aforementioned solutions, construction in this case study only consisted of a room and some tanks, as opposed to industry scale plants (IRTC Mining Waste Team, n.d.). Relative to the costs, the fact that this solution can be implemented with minimal construction and quick installation—for permanent or temporary applications—justifies the upfront costs being medium and the environmental impact being low (IRTC Mining Waste Team, n.d.). Moreover, the metals recovered from the minimal sludge produced were used as a granular additive in cement. This not only reinforces the rating for the environmental impact but can also be used to justify the high/medium rating for the benefit, as it provides a way to recuperate some of the ongoing operational costs (IRTC Mining Waste Team, n.d.). In this case study, it is noted that the operating costs average $150,000 USD a year while purifying an average of 60 gallons a minute. This steep price is due to the ongoing operational costs associated with the resin regeneration and fouling that need to be changed at least twice a week (IRTC Mining Waste Team, n.d.). It is for these reasons both the operating costs and human control needed were rated medium/high. Whilst the case study operated at an average of 60 gallons per minute, its maximum rate of purification is 300 gallons per minute, and in relation to the aforementioned solutions, it was rated medium in comparison (IRTC Mining Waste Team, n.d.). Additionally, it was noted that although the removal efficiencies varied between 95 to 99%—depending on how saturated the resin was (IRTC Mining Waste Team, n.d.)—it would only achieve these rates at low concentrations of heavy metals—generally the more complex the mixture, the more limiting the solution became in removing these heavy metals. In other words, it only really works at low concentrations, and consequently, it was rated medium/low from the heavy metals being treated (Mosai et al., 2024). Furthermore, the ion exchange alone is not particularly known for removing sulphates as it achieves an efficiency of only 60-70%, bringing sulphate levels down to between 1000-1500 milligrams per litre; acceptable for irrigation but not discharge into public streams—this justified the rating given for the societal impact and sulphate removal objectives, both of which being low (Can, et al., 2020).

Solution Landscapes



The solution landscape between cost and effectiveness displays where each solution is on the plot relative to each other. The "cost" on the y-axis of the landscape refers to the upfront cost which is displayed on the existing solutions table. Similarly, the "effectiveness" on the x-axis of the landscape refers to maximizing benefit which is also shown on the existing solutions table. In terms of the solutions, absorption is presented as the lowest in cost and it is also the solution that is least effective. In addition, freeze crystallization is the most effective solution but has the highest cost. With the other solutions falling somewhere between the first two, this leaves an opportunity for innovation shown in the bottom right of the landscape plot striving for low cost and high effectiveness. The data used for the landscape plot is taken from the previously mentioned existing solutions table.



The solution landscape plot of operating cost vs rate of purification (measured in L/s) links the two categories together to display possible opportunities for innovation. The ideal corner for this landscape, where there is possible opportunity, is located in the bottom right. The ideal corner is where operating costs are lowest and the rate of purification is the highest. Data for this plot is derived from the existing solutions table previously featured in this report. In terms of the solutions plotted, precipitation techniques hold the highest rate of purification but have higher operating costs compared to other solutions. Inversely, absorption has the lowest operating cost but it has a lower rate of purification than other solutions.

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Appendix A: Meeting Minutes

APSC 169 Team 03 Meeting Minutes

Date: Monday, September 24th, 2024

Location: ART 110

Time: 10:00 am – 12:00 pm

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

Regrets: N/A

Note-Taker: Axel Bendl

Points of discussion:

- Introduction to design lab 3
- Working on identifying team strengths, abilities and interests
- Beginning the work breakdown structure table

Task:	Assigned to:	Additional Conditions:
	Connor	
	Hasan	
Create tabular WBS	Zach	
	Axel	
	Jacky	
Complete team strengths and interests	Everyone	

Next meeting: Monday, September 24th 2024; 12:30am – 12:45pm - Whatsapp Call

Meeting adjourned: 12:00pm

APSC 169 Team 03 Meeting Minutes

Date: Monday, September 24th, 2024

Location: Whatsapp Call

Time: 12:30 pm – 12:45 pm

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

Regrets: N/A

Note-Taker: Axel Bendl

Points of discussion:

- Reviewing the report 1 feedback, evaluating what could have been done better and room for improvement in second report
- Made comments for every piece of TA feedback

Task:	Assigned to:	Additional Conditions:
	Connor	
	Hasan	
	Zach	
Create feedback document	Axel	
Research potential stakeholders	Jacky	
	Everyone	

Next meeting: Tuesday, October 1st 2024; 10:00am – 12:00pm - ART110

Meeting adjourned: 12:45pm

APSC 169 Team 03 Meeting Minutes

Date: Tuesday, October 1st, 2024

Location: ART 110

Time: 10:00 pm – 12:00 pm

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

Regrets: N/A

Note-Taker: Axel Bendl

Points of discussion:

- Introduction to design lab 4
- Starting graphical work breakdown structure
- Assigning tasks to each member

Task:	Assigned to:	Additional Conditions:
Network flow diagram	Connor	
Graphical work breakdown structure, Gantt Chart	Hasan	
	Zach	
Gather details about current solutions	Axel	
Money flow chart	Jacky	
	Everyone	

Next meeting: Tuesday, October 7th 2024; 12:30 pm – 1:15 pm - Library

Meeting adjourned: 12:45pm

APSC 169 Team 03 Meeting Minutes

Date: Monday, October 7st, 2024

Location: Library

Time: 12:30pm – 1:15pm

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

Regrets: N/A

Note-Taker: Axel Bendl

Points of discussion:
- Going over what needs to be done, and what has been completed so far
- Assigning further tasks to each member

Task:	Assigned to:	Additional Conditions:
	Connor	
	Hasan	
Existing solutions table	Zach	
Existing solutions table	Axel	
Create stakeholder table	Jacky	
	Everyone	

Next meeting: Friday, October 11st 2024; 5:30pm – 6:00pm - Whatsapp Call

Meeting adjourned: 1:15pm

APSC 169 Team 03 Meeting Minutes

Date: Friday, October 11st, 2024

Location: Whatsapp Call

Time: 5:30pm – 6:00pm

Present: Zach Boos, Hasan Mohammad, Jacky Zhou

Regrets: Axel Bendl, Connor Jones

Note-Taker: Axel Bendl

Points of discussion:

- Finish rough draft before monday, to do final edits before handing in
- Checking in with everyone, what needs to be done

Task:	Assigned to:	Additional Conditions:
Solution landscapes	Connor	
	Hasan	
	Zach	
Stakeholder plot	Axel	
Justification for stakeholders	Jacky	
	Everyone	

Next meeting: Monday, October 14th 2024; 12:30pm – 1:30pm - Whatsapp Call

Meeting adjourned: 6:00pm

APSC 169 Team 03 Meeting Minutes

Date: Monday, October 14th, 2024

Location: Whatsapp Call

Time: 12:30pm – 1:30pm

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

Regrets: Jacky Zhou

Note-Taker: Axel Bendl

Points of discussion:

- Proofread the full report
- Make edits where needed
- Make sure everyone is on the same page (Report is consistent)
- Ensure citations and formatting is correct

Task:	Assigned to:	Additional Conditions:
Solution landscape analysis	Connor	
Citations and formatting	Hasan	
Justification of existing solutions	Zach	
Justification of existing solutions	Axel	
	Jacky	
	Everyone	

Next meeting: Tuesday, October 15th 2024; 10:00am – 12:00pm - ART 110

Meeting adjourned: 1:30pm