Green Manufacturing Technology

Group Project

Sustainable Low Head River Dam

Implementation for Water Quality

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Abstract

Today's world is much focused on the harnessing of green energy sources mainly because of the drastic impacts posed by fossil fuel consumption. The existing SDG implementation guidelines also extensively promote the implementation of green practices in every possible scenario. Malaysia being an ever-expanding prosperous country, accordingly, eyeing on the subsidisation of Sustainable Manufacturing and in recent years there are lots of active emergence seen on grounds. Ensuring water security as well as marine ecosystem is also part of the campaign as it complements the establishment of SDG-6 and SDG-14. This project is influenced by the weir utilisation basically for the aeration of a typical low-DO enriched water reservoir. Oxygenating water sources through low-head-dams is one of the common techniques that could potentially secure the habitat for marine lives as well as provide cleaner water sources. The study has shown promising signs in increasing DO level in the on-site water sources, though the long-term effects are yet to be studied. This work will pave the way for further development in approaching a rather holistic sustainable green practice.

1. Introduction

1.1 Background

Following Malaysia's 2030 agenda of Sustainable Development plan that emulates the SDG's, Universiti Teknologi Malaysia has made efforts to localise the SDG agenda by introducing the sustainable development concept through various courses and projects. By utilising the student's engineers' passion for innovation and problem solving, the SDG implementation was adapted towards the lake located beside E07, in the Mechanical Engineering Faculty as illustrated in the figure below.

Figure 1-1 River, Faculty of Mechanical Engineering

This green manufacturing initiative looks towards improving water quality of the river by a sustainable innovation in order to align with SDG 6 and SDG 14 corresponding to water cleanliness and aquatic health.

1.2 Problem Statement

As illustrated in Figure 1, the river displayed signs of stagnating and slow flow rate. This stagnation primarily resulted in an increase in mosquito population around the riverbank. Furthermore, the river has a rainwater inlet which can cause an overflow downstream. Investigating the water quality further using an independent water study the following results were obtained as tabulated in the table below.

Table 1-1 River Water Quality Measurements

River Quality Measurements	
pH	6.78
Salinity (ppt)	0.06
Conductivity (ohm)	0.00937
DO (mg/l)	4.73
Temperature °C	27.9

Analysing the values, the temperature, salinity content and conductivity align with the expected values of a healthy river. However, in accordance with Malaysia's national water standards as shown in Figure 2, for a CLASS 1 (conservation of natural environment) the pH reading of the water is dangerously close to the lower threshold. Furthermore, the dissolved oxygen percentage shown is to be interpreted as a percentage of the expected oxygen value in mg/L ranging from 6.5 to 8. This indicates that the river has a drastically low dissolved oxygen (4.73 compared to 6.5)

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-

Figure 1-2 Malaysian National Water Standards

(doe.gov.my)

According to an established margin for dissolved oxygen, the lack of dissolved oxygen is the limiting factor for aquatic life to prosper within the body of water. The specific dissolved oxygen scale is as illustrated below.

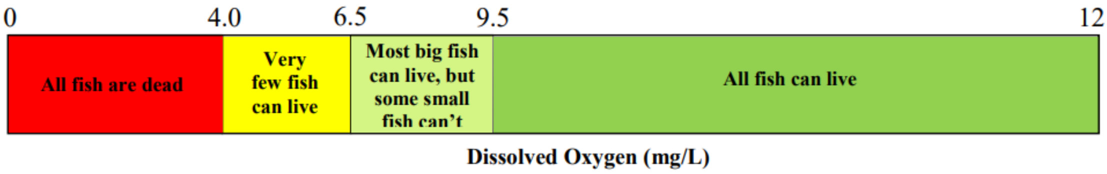


Figure 1-3 Dissolved Oxygen Standards

(doe.gov.my)

Hence, the primary problem statement was to establish a sustainable form of increasing the dissolved oxygen as well as the flow rate in the river through green policies and innovations.

1.3 Project Scope

The project scope for this river initiative is only limited to designing and developing a practical system prototype through green manufacturing strategies to counteract any immediate hurdles in river health- In this case, the lack of dissolved oxygen and slow flow rate. Furthermore, green policies should be suggested to accompany the prototype to establish a green initiative which ensures a lasting impact

2. Literature Review

2.1 Green Practices for the contribution to SDG 6 & 14

Innovative green based approaches can substantially ensure the objectives of SDG-6 and SDG-14. One study by Bhakta *et Al.* (2022) reviews miscellaneous environment friendly strategies, such as, reintroduction of after-use domestic/industrial water in the system process, systematic accumulation of rainwater, etc., and results from the study indicate encouraging prospects.

Present adoption of green practices, in line with SDG-6 implementation, concentrates on nature-based alternatives for urban water management. Study by Caparrós-Martínez *et Al.* (2020) discusses measures such as bioswales, permeable pavements, and green roofs and further investigates their usefulness in enhancing water quality and minimizing urban runoff.

Green Techniques are employed to reduce plastic pollution in marine ecosystems that facilitate contributing to the agenda of SDG-14. Ogunola *et Al.* (2018) analyzed different green based topics, such as biodegradable plastics, plastic recycling advancements, and zero-waste programs and results showed promising outcomes with respect to the conservation of marine environments.

Review by Das *et Al.* (2023) explores how circular economy principles might be used for water management and marine protection. The study discusses methods such as water recycling, resource recovery from wastewater, and sustainable aquaculture that holistically realise both SDG-6 and SDG-14.

On a similar note, a study by Delanka-Pedige *et Al.* (2021) examines environmentally friendly techniques for treating wastewater that exploits membrane bioreactors, artificial wetlands, and sophisticated oxidation techniques and connects them to the preservation of freshwater and marine ecosystems (SDG 6 & 14).

2.2 Green Practices for the contribution to SDG 6 & 14 in Malaysia

Innovative green based practices are frequently seen in Malaysia with regards to the achievement of SDG-6. Utami *et Al.* (2020) saw a rise in Malaysia's utilisation of membrane bioreactors and built wetlands. These methods have demonstrated potential in lowering water pollution and enhancing hygiene. Another study by Lee *et Al.* (2016) demonstrated that rainwater harvesting technologies have the potential to lessen stormwater runoff and ease water scarcity in Malaysian metropolitan areas.

On a collaborative note, the recent introduction of Malaysia's Integrated Water Resources Management (IWRM) strategy has made the enhancement in accessing clean drinking water and uplift the quality of the country's water resources, as Kamarudin *et Al.* (2019) pointed out. Although there has been progress, the survey discovered that problems still exist in rural regions.

In terms of SDG-14 green based implementation, Ramli *et Al.* (2022) examined Malaysia's management efforts for maritime protected areas (MPAs). They discovered that although MPAs have grown, there are still issues with community involvement and enforcement. Another study by Teh & Pauly (2018) focused on the application of ecosystem-based fisheries management while examining sustainable fishing methods in Malaysia. The report highlighted the need for improved monitoring and control of illegal fishing while noting increases in fish stocks.

The integration of green practices for both SDGs (SDG-6 and SDG-14) was investigated by the study from *Green Initiatives (SDG) in Malaysia: A Holistic Perspective* (2024), which depicted the interdependence of Malaysia's freshwater and marine ecosystems. The report emphasizes the necessity of managing water resources holistically. Enhancing public-private partnerships, raising community involvement, and utilizing technology for enforcement and monitoring are among areas where improvements can be made.

Although Malaysia has made strides toward implementing green practices for SDGs 6 and 14, numerous studies indicate that there is still need for improvement in areas like integrated ecosystem management, enforcement of marine protection, and rural water availability (Shahrir *et Al.* (2023).

2.3 Low Head Dams (Weirs) as Green Practice components for the contribution to SDG 6 & 14.

2.3.1 Overview Low Head Dams

A low head dam is an artificial structure that is built across a river or stream channel. It covers the entire bank of the channel. It is created with the intention of maintaining a constant flow of water over the top, spanning from one bank to another. If water levels rise downstream, a submerged hydraulic jump can form that generates an upstream directed current ("National Inventory of Low Head Dams," 2024).

These types of dams date back to the 1800s, when they were built in the U.S. to power grist mills and small industries. According to U.S. census data, there were over 65,000 water powered mill dams at that time. While many of these dams are still operating well, a noticeable number have either been destroyed or deteriorated. Hundreds more were built for other purposes, such as irrigation, mining, milling, water supply, and manufacturing. It was also done with the intention of diverting water to early navigation canals (Tschantz., 2014). Low-head dams (less than 4 m high) are common all over the world. In the U.S. alone, up to 2 million of these small hurdles break upriver ecosystems (Graf, 1993).

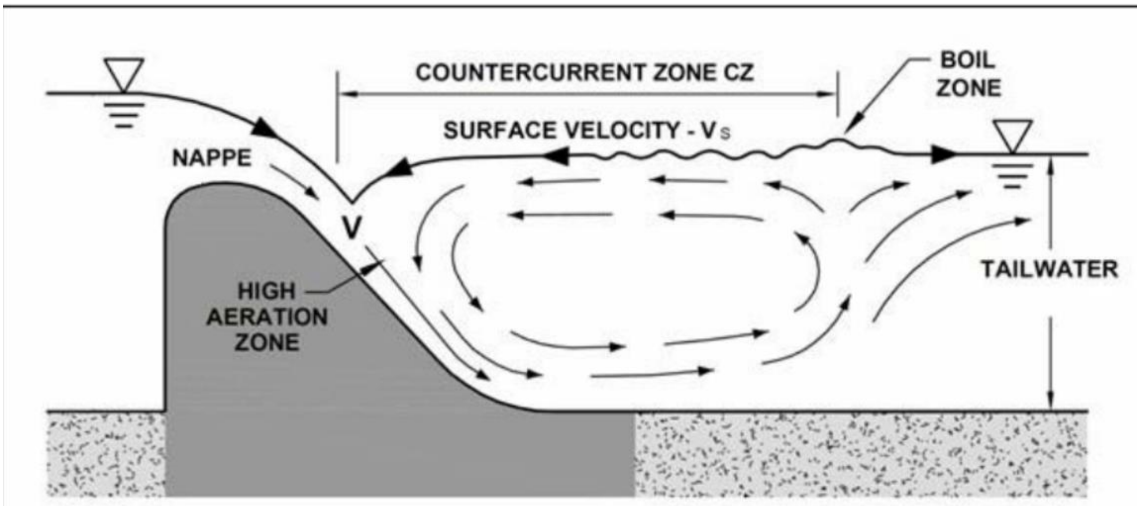


Figure 2-1 Schematic Elements of a Submerged Hydraulic Jump Downstream from Low Head Dam (Tschantz., 2014).

Figure 2.1 illustrates the formation of the hydraulic jump when the tailwater depth in the downstream channel exceeds the jump's subcritical sequent depth which is water depth after a hydraulic jump and is determined from the well-known Bélanger's momentum equilibrium equation that relates this depth to the incoming initial depth and Froude Number. A strong rotating current will produce due to that difference in depth.

2.3.2 Low Head Dams and Contribution to The SDG 6

Dams play a crucial role in the management of water resources, which is essential for achieving SDG 6's objective of ensuring the sustainable management of water. Dams maintain a steady water supply for agricultural, industrial, and home purposes, particularly in areas susceptible to droughts or erratic precipitation, by controlling river flows and storing water. The capacity to control the release and storage of water is crucial for maintaining the equilibrium between water supply and demand.

Low-head dams have an effect on the movement of nutrients and the composition of living organisms in rivers by creating a combination of stagnant (lentic) and flowing (lotic) water conditions. This impact is comparable to the impacts observed with larger dams (Bao et al., 2022; Bylak et al., 2017). Studies have shown that constructing multiple dams in a river, especially when they are placed in a sequence, can cause the concentration of dissolved reactive phosphorus to increase significantly in the river. The accumulation of nutrients frequently takes place in the higher sections of the water body, which can potentially result in river eutrophication. This is a phenomenon characterised by the abnormal growth of algae and other aquatic plants due to an excess of nutrients (Bao et al., 2018).

However, having large numbers of dams across the river could lead to changing the natural flow of rivers, creating slower-moving water that can hold more nutrients like phosphorus. This buildup can lead to excessive algae growth upstream, which consumes a lot of oxygen and creates dead zones where many aquatic organisms cannot survive. Additionally, these conditions favour a less diverse group of hardier species that can tolerate higher nutrient levels and lower oxygen. This change disrupts the natural balance and health of the river ecosystem (Ma et al., 2023) .

2.3.3 Low Head Dams and Contribution to The SDG 14

SDG 14 says that the goals should focus on a complete plan to protect and use the oceans, seas, and marine resources in a way that doesn't harm them. Some important goals are to cut down on all kinds of marine pollution, especially pollution that comes from land, and to protect and handle marine and coastal ecosystems in a way that doesn't hurt them too much by 2020. A big part of the goal is getting scientists to work together better to deal with the effects of ocean acidity. (“Goal 14: Life below water - The Global Goals,” 2024).

A study carried out by (Hitchman et al., 2018) addressed the broader implications of ecosystem management practices by exploring the varied impacts of habitat alteration due to human activities, specifically the construction and presence of low-head dams. The study included the collection of samples at ten locations, specifically five sites with low-head dams and five sites without dams, which were spread out along the Upper Neosho River and Cottonwood River(figure 2). The selection of sites was conducted meticulously, ensuring a mix of dammed and undammed locations, with a minimum separation of 5 km. This was done to guarantee that the undammed sites were situated beyond the geomorphological impact range of the dams, while still maintaining similar geomorphological features. This segregation facilitated efficient juxtaposition while circumventing any overlap in the zones affected by the dam. A Chi-square test was conducted to compare the mesohabitat between the Neosho and Cottonwood Rivers. The results indicated that there were no significant differences, suggesting that the habitat characteristics in both rivers are consistent.

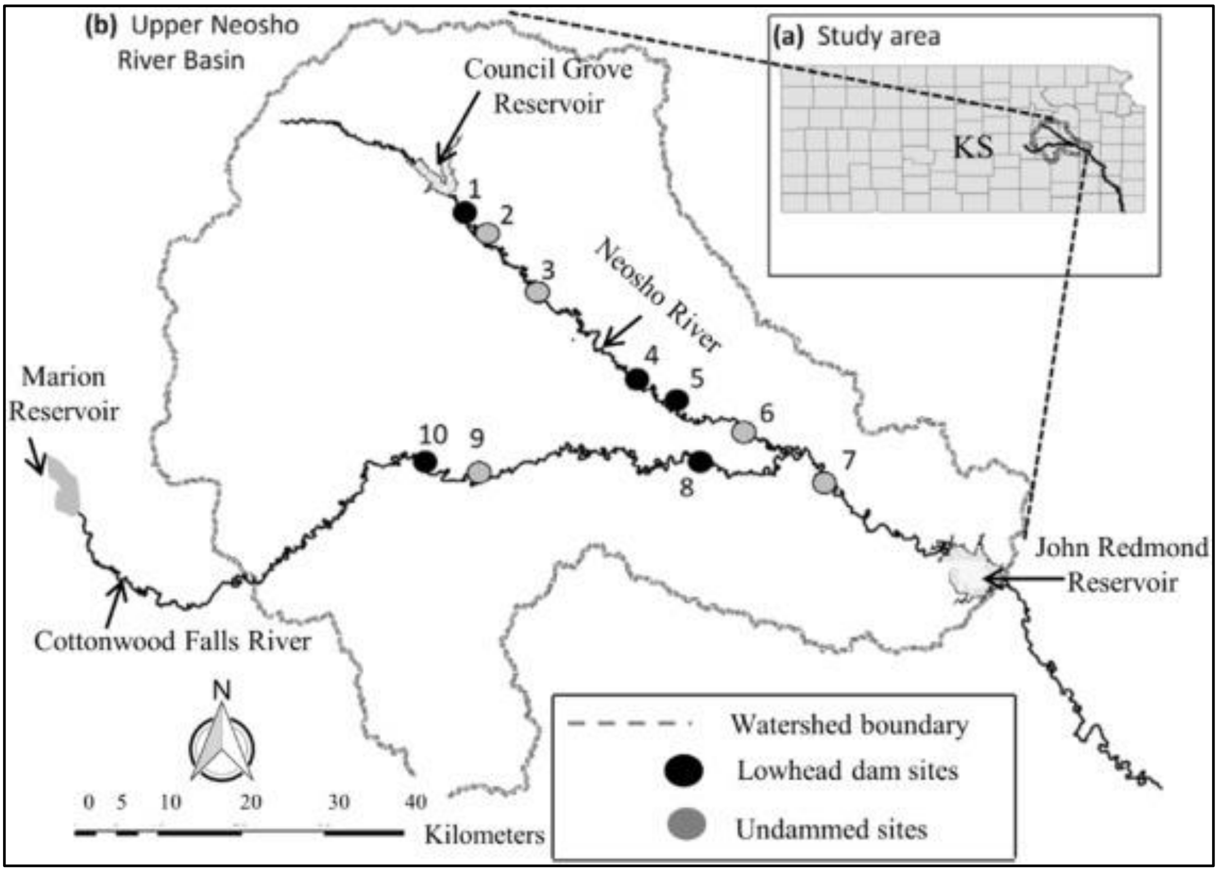


Figure 2-2 Map of Study Area

(a) Neosho River within the state of Kansas, and (b) 10 3-km sampling sites within the Upper Neosho River basin along the Neosho and Cottonwood Rivers, KS, below five low-head dam sites and at five undammed sites.

They found that while the average habitat diversity was similar across sites, dammed sites exhibited less variation in habitat diversity compared to undammed sites as shown in figure 3. Specifically, undammed sites demonstrated significantly greater variability in habitat diversity, indicating a richer and more diverse habitat. This suggests that low-head dams reduce the natural variability of stream habitats, as evidenced by a significant Chi-square test result ($\chi 2 = 50.57$, $p < 0.001$).

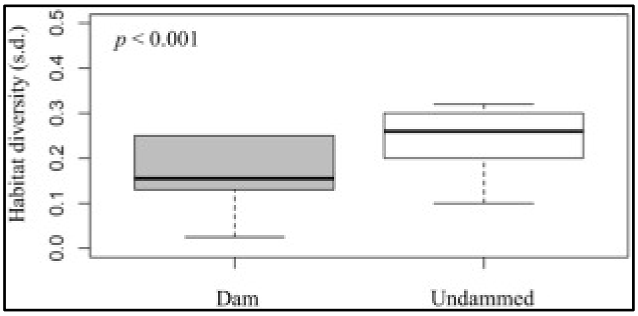


Figure 2-3 Comparison of standard deviation in habitat diversity at dammed (downstream) and undammed sites.

Data in figure above are the result of a bootstrapping procedure designed to quantify variation in habitat diversity. Data are represented by a boxplot in which the heavy horizontal line depicts the median, the box represents the 2nd and 3rd quartiles, and the whiskers show the 1st and 4th quartiles.

2.4 Low Head Dams (Weirs) for aerating of small to medium velocity water flows in line with SDG implementation.

2.4.1 Oxygen level in rivers and lakes

Dissolved oxygen (DO) in the rivers or lakes is a very crucial parameter that indicates how suitable that water environment is for the sea creatures. Phylogenesis and nonpoint sources can lead to nutrient enrichment in fresh systems, which in turn can cause a reduction in dissolved oxygen (DO). Human actions, such as the intentional discharge of harmful substances into bodies of water, have caused significant damage to the local aquatic ecosystems. Elevated nutrient concentrations, reduced water clarity, and the proliferation of pathogenic bacteria and viruses are signs of increasing prevalence of these pollutants in aquatic ecosystems [3].

2.4.2 Aeration

Aeration is a crucial operation in water treatment facilities for enhancing energy efficiency by raising the concentration of dissolved oxygen (DO) in water. It is noteworthy that aeration is one of the most energy-intensive procedures. Mechanical aeration is the process of agitating the surface of the water using devices such as impellers, propellers, or rotors, which are usually driven by motors. This technique improves the transfer of oxygen, which helps to facilitate the biological activities required for water purification. Mechanical aeration systems can be classified into three types according to their operation: low-speed radial flow, high-speed axial flow, and horizontal rotors with aspiration interfaces. The efficacy of these systems, as measured by the Standard Aeration Efficiency (SAE), is dependent on many elements such as the aeration equipment's design, tank shape, and power input ratio (Jia et al., 2016).

In addition, diffused aeration systems include blowers, air pipes, and diffusers, frequently employing fine-pore diffusers to optimize the air-water interface, in order to effectively transfer the necessary oxygen for biological processes in the water. The integration of mechanical and dispersed aeration systems is vital for preserving the well-being of aquatic ecosystems by guaranteeing sufficient oxygen levels.

2.4.3 Weir aeration

The use of weirs could increase the aeration process. This concept was studied by (Gameson, 1957) when he studied the effect of the weirs in the speed of the oxygen dissolved into the water. The phenomenon happens when the water falls over a weir, it will create a free-falling jet that entraps air as it plunges into the water. This will introduce bubbles into the water and following that will be the increase in the DO levels.

There are four different types of weirs which are triangular, rectangular, trapezoidal and semicircular studied by (Gameson, 1957). Each of them can have different techniques when dealing with the air. As for example if the weir has a triangular cross section, it is known for creating a pointed, narrow flow that can maximise the air entrapped due to higher velocities and more turbulent flow. If it has a rectangular cross section, this will offer a uniform flow over a wide area but it may have some limitations when it comes to the air entrapped.

Another approach by (singh et al., 2011) investigated the role of piano key weir (PKW) in enhancing oxygen levels in water. They found that there was efficient aeration due to the increase of the drop height. It is believed by (Baylar et al., 2000) that triangle notch weir has much better efficiency than other weirs in dissolving the oxygen into the water.

2.4.4 Weir, Aeration & SDG's (6, 14) in Malaysia Context

Weirs, sometimes known as low head dams, are frequently used in Malaysia to manage water resources. They are employed in the production of small-scale electricity, irrigation, and flood control. Weirs have been used in Malaysia since the colonial era, when numerous structures were constructed for irrigation in the early 20th century, according to Hezri (2018). A thorough examination of Malaysian weirs by Sidek *et Al.* (2016) resulted in the identification of over 150 noteworthy structures around the nation. They discovered that most of them are centered in the Kedah and Perak rice-growing regions.

Weirs have miscellaneous usages and can be adapted based on the suitability of the location, environment and available resources. According to the analytics of *Agriculture Water Services for Agribusiness* (2018), agricultural irrigation accounts for around 70% of the uses of weirs in Malaysia, particularly in rice-growing regions. On a different note, Shahrulnizam *et Al.* (2020) examined the function of weirs in mitigating floods, in the context of urban regions such as Kuala Lumpur and Penang. Although less common, 12 low head dams, mostly in Sarawak and Sabah, were identified by Koh & Lim (2010) as being utilized for small-scale hydropower generation.

The most crucial advantage of the establishment of weirs is their innate features to aerate the surrounding flow of water as well as air. Khdhiri *et Al.* (2014) studied the effects of weir aeration on water quality in Malaysian rivers. They found that potential weirs have been accounted for increased dissolved oxygen levels downstream of weirs, reduction in biochemical oxygen demand (BOD) and improved conditions for aquatic life. Findikakis's (2018) study also looked at the function of weirs in the Langat River basin. It has been discovered that carefully positioned weirs contributed to water security by helping to sustain water levels during dry seasons (SDG 6).

The significance of appropriate design of weirs in minimizing detrimental effects on aquatic ecosystems was also mentioned in numerous studies. Chong *et Al.* (2021) performed a comprehensive experimentation to investigate the effects of weirs on fish populations in Malaysian rivers. It has been estimated that properly planned fish channels could bring out satisfactory outcomes in sustaining connectedness for aquatic species, even when certain weirs functioned as obstacles to fish migration (SDG 14).

Weir aeration can comprehensively address both SDG-6 and SDG-14 as studies implicate. Malek *et Al.* (2022) investigated how aeration by weirs affected the Klang River's water quality. They saw increases in dissolved oxygen concentrations downstream of these structures, which was advantageous for estuarine and freshwater habitats (SDGs 6 and 14).

3. Methodology

3.1 Introduction

This section of the report serves as the detailed product design stage within the Green Design Process. Further Green Manufacturing design is discussed in section (5). The aim of this project is to produce a Weir Box - miniature prototype that will serve as a proof of concept to be realised in the real river. Considering the findings related to weir aeration and their impact on flow rate, a morphological chart is created to explore all the viable options. Hence, three concepts were generated and evaluated according to the criteria (listed in the Product Design Specification (PDS) statement of the full-scale weir dam) to determine the best weir box design.

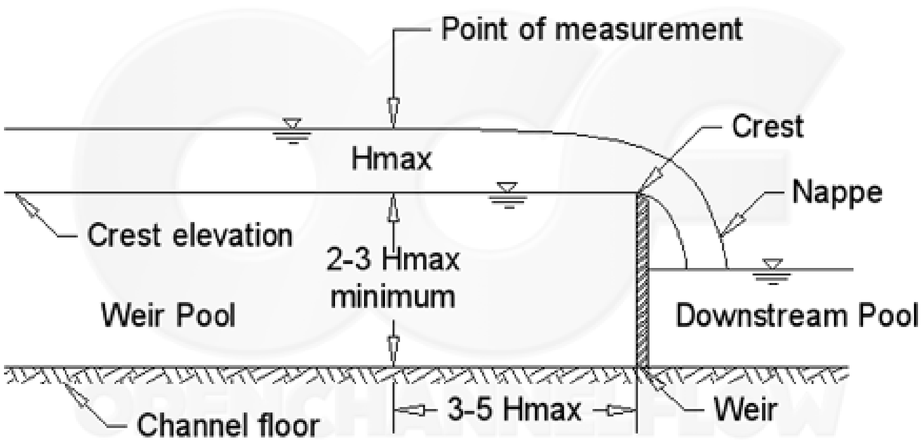


Figure 3-1 Standard weir technical specifications.

3.2 Product Design Specification

This statement presents a set of criteria that target different aspects of the weir dam. The following sections shall act as a guideline for the concept generation, evaluation and selection processes.

3.2.1 Performance

- The dam should increase the river flow rate, hence be effective in increasing the level of dissolved oxygen.
  - The weir plate's crest has to be a maximum of 3 mm thick to ensure optimum nappe and aeration.
  - The water drop height is 60% of downstream depth.
- The dam shall not disrupt the pre-existing ecosystem in the river.

3.2.2 Material

- The dam structure should be made of green materials.
- The dam's weir plate should be made of stainless steel or aluminium to maintain a sharp and burrless edge.
- The dam's material should be free of any toxic materials.

3.2.3 Lifespan

- The dam should last at least 5 years before needing to be renovated.
- The dam should be easy to identify points of deterioration after a long period of time.

3.2.4 Maintenance

- The dam's weir plate should be easily replaceable and/or repairable to keep sharp for optimal nappe effect of the water flow.
- The dam structure should be low maintenance.

3.2.5 Durability

- The weir plate should be reinforced, or heat treated at the edges to maintain a sharp edge for a longer time before needing replacement or resharpening.
- The dam structure should be able to hold the weir plate sturdily and withstand high water pressure.

3.3 Concept Generation

As previously mentioned, to enable the concept generation process, a morphological chart is created. Using the PDS statement as a guide, three concepts of a weir box prototype are generated for evaluation in the next step process.

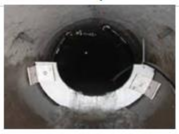
Function/Option	1	2	3	4
Weir Notch Shape	 V-Notch	 Rectangular	 Trapezoidal	 Semi-circular
Weir Angle	30°	45°	60°	90°
Water Flow	 Water Pump	 Water Hose	 Manual Water Circulation	
Box Material	Wooden Plates	Aluminium Sheet	Stainless Steel Sheet	Acrylic Glass Sheets

Figure 3-2 Prototype Morphological Chart

3.3.1 Concept 1 (3-3-2-3)

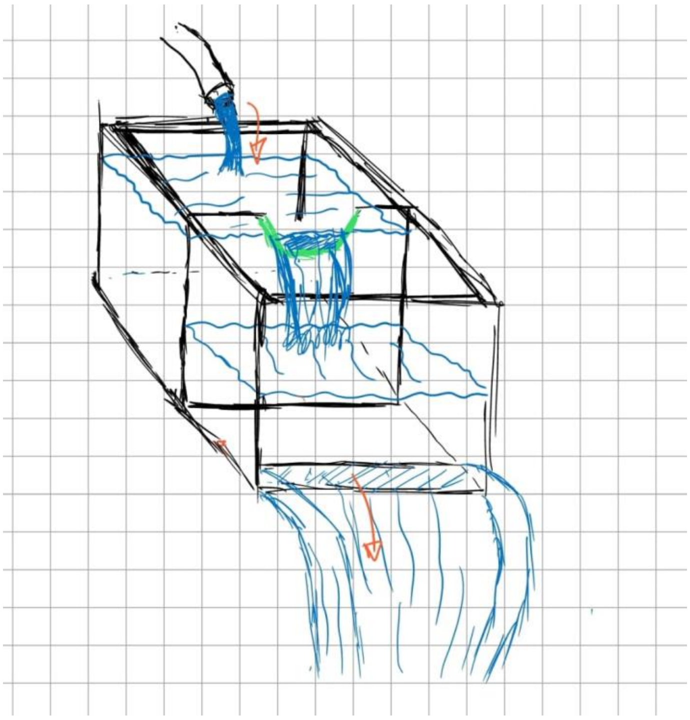


Figure 3-3 Concept 1 Sketch.

This concept uses a trapezoidal weir notch plate. Despite this shape being inferior to the V-notch shape, it is believed to be able to withstand higher water pressure than its counterpart given that there’s more area to counteract the force. According to Baylar et al. (2001), the oxygen transfer efficiency of the trapezoidal weir was measured at 0.41, which is not much of a difference than the V-shaped weir’s 0.48 efficiency (at a discharge of 1 l/s, and a drop height of 0.9 m).

The concept chooses an external water source to be used, such as a water hose, in providing the flow for the prototype's performance demonstration. Furthermore, the material used in fabricating the weir box was chosen to be aluminium sheet. This is due to its malleability at room temperature and relative strength.

3.3.2 Concept 2 (1-4-1-4)

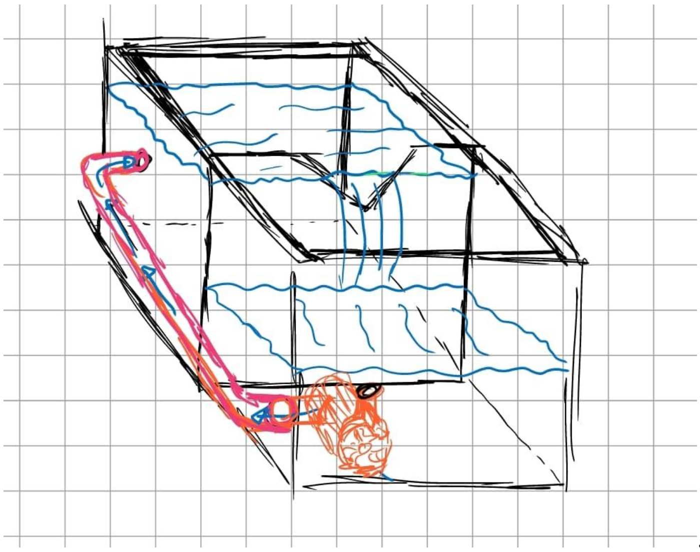


Figure 3-4 Concept 2 Sketch.

This concept features a V-shaped weir notch; which has proven to be the best among all the listed options. This type excels in both aeration efficiency and increasing the river’s flow rate. There are a plethora of angles that are commonly found in a V notch weir. The standard angles are 22-1/2º, 30º, 45º, 60º, 90º, and 120º. Ensuring the optimal performance angle should be calculated using the Kindsvater-Shen’s relation formula. This can also be done using sophisticated websites that consider more factors into calculating the angle. However, for simplicity of the design, ease of manufacturing and maintenance, and due to the lack of certain parameters that would be required to calculate the actual optimal weir notch angle, the angle used was a right angle. Besides that, the prototype concept being designed is less likely to be impacted by a relatively minute detail. Although it must be noted that this can have a noticeable impact on the performance of the weir at full scale.

Moreover, a water pump is used to circulate the water from the downstream to the upstream side in order to allow for the demonstration of the weir's functionality in a portable form factor. Finally, the material chosen to construct the weir box was acrylic glass. This is due to its cheap price and sufficiently strong properties. Using a clear material also has the added benefit of better presenting the flow of water over the weir notch.

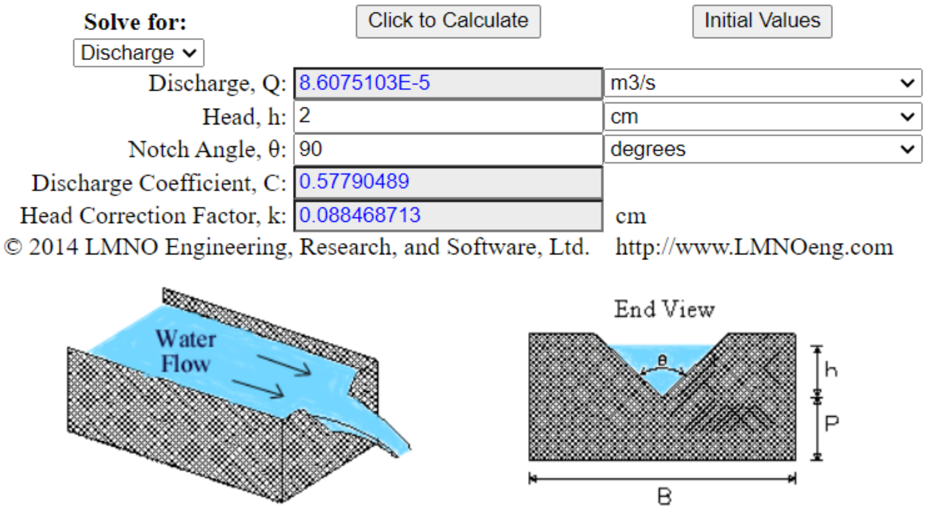


Figure 3-5 V Notch Weir Calculator website

(https://www.lmnoeng.com/Weirs/vweir.php)

3.3.3 Concept 3 (2-4-1-1)

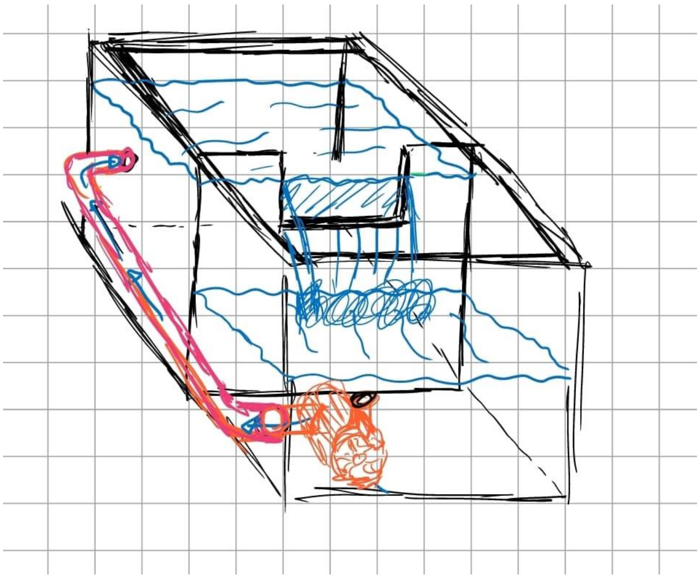


Figure 3-6 Concept 3 Sketch.

This concept focuses on ease of fabrication and convenience and neglects the difference in performance that might incur with that. The weir notch shape chosen was the rectangular notch, which not only has a lower cost of manufacturing and maintenance due to the simple shape, it also uses wooden plates as its material of choice for the structure of the weir box.

3.4 Concept Selection

In order to go forward with one out of the three concepts suggested in the concept generation phase, a process evaluation table must be constructed to score them in various aspects and criteria.

Table 3-1 Concept Evaluation

Criteria	Weighting Factor (W.F.)	Concepts					
		1		2		3	
		Score	Score × Weightage	Score	Score × Weightage	Score	Score × Weightage
Performance	0.3	8	2.4	9	2.7	6	1.8
Ease of Fabrication	0.1	6	0.6	8	0.8	9	0.9
Cost	0.15	6	0.9	8	1.2	9	1.35
Convenience	0.05	7	0.35	8	0.4	9	0.45
Ease of Maintenance	0.1	6	0.6	8	0.8	6	0.6
Ease of Assembly	0.1	7	0.7	8	0.8	8	0.8
Durability	0.1	9	0.9	8	0.8	6	0.6
Reliability	0.1	8	0.8	9	0.9	6	0.6
Total	1		7.25		8.4		7.1

As can be seen in table above, the third concept has scored the lowest despite scoring 9 in ease of fabrication, cost and convenience. This, however, would prove ineffective as it did not meet the criteria possessing the highest weighting factors. This was due to its wooden construction which lacked in reliability and durability as well as the inadequate performance of the rectangular weir notch when compared with its counterparts. Furthermore, the next best score was concept 1, scoring a decent 7.25. Due to its aluminium sheet construction, it has scored low in ease of fabrication and cost, being the most expensive compared to acrylic and wooden sheets. Despite aluminium being rust resistant, it is, however, prone to corrosion with time, which might impact its ease of maintenance. Lastly, concept 2 has scored the highest among them, hence it shall be the one considered into the next design process. It can be noticed that this concept did not score the highest in every category but was consistently rated a reasonable 8 due to its practical combination of functionality.

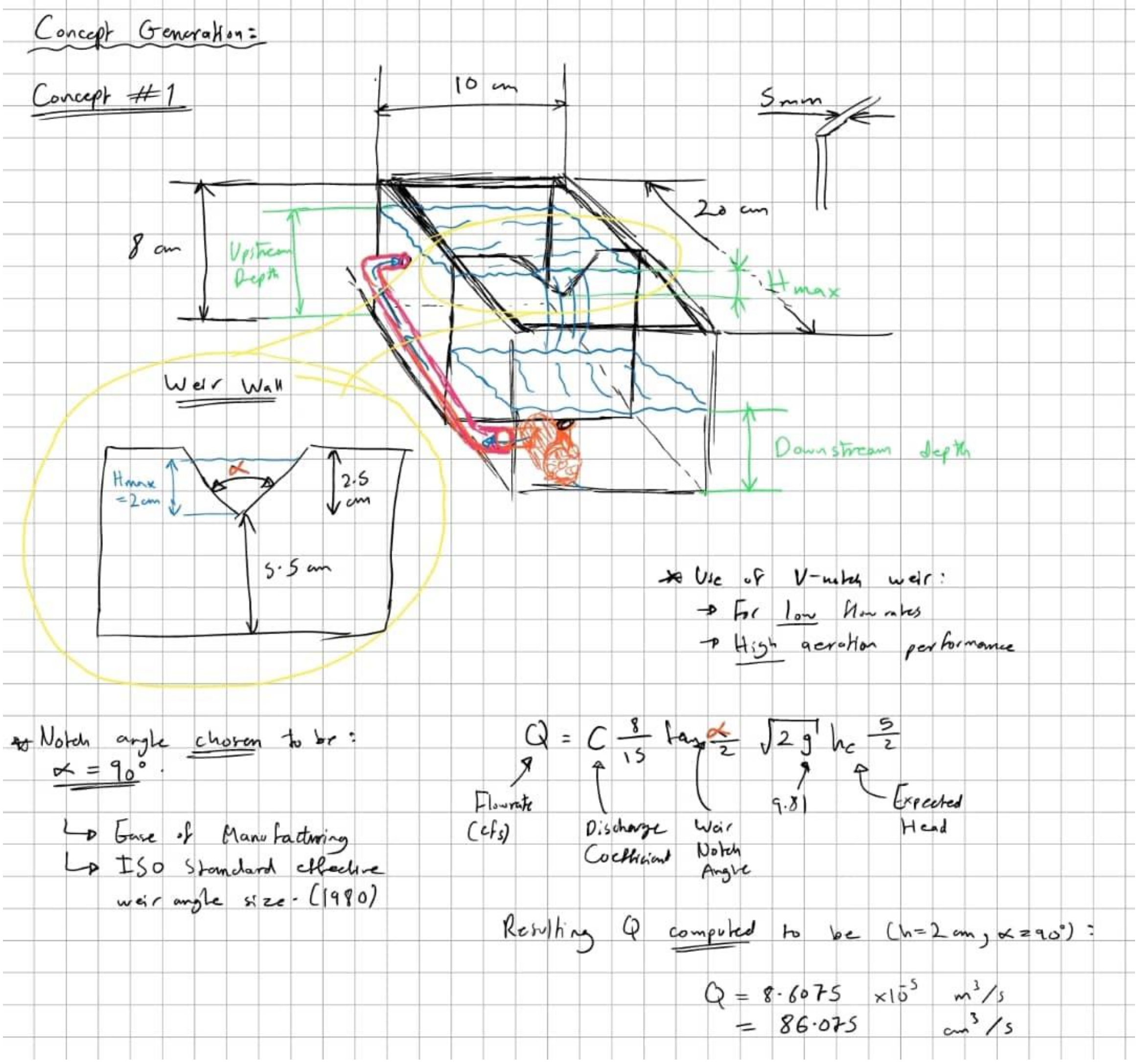


Figure 3-7 Sketch of the highest scoring concept - Concept 2.

4. Results

4.1 Prototype

This prototype developed to display the concept of a dam built in the river can help to enhance the water quality issue. This objective of this innovative solution is to increase the dissolved oxygen levels and improving the flow rate in the river

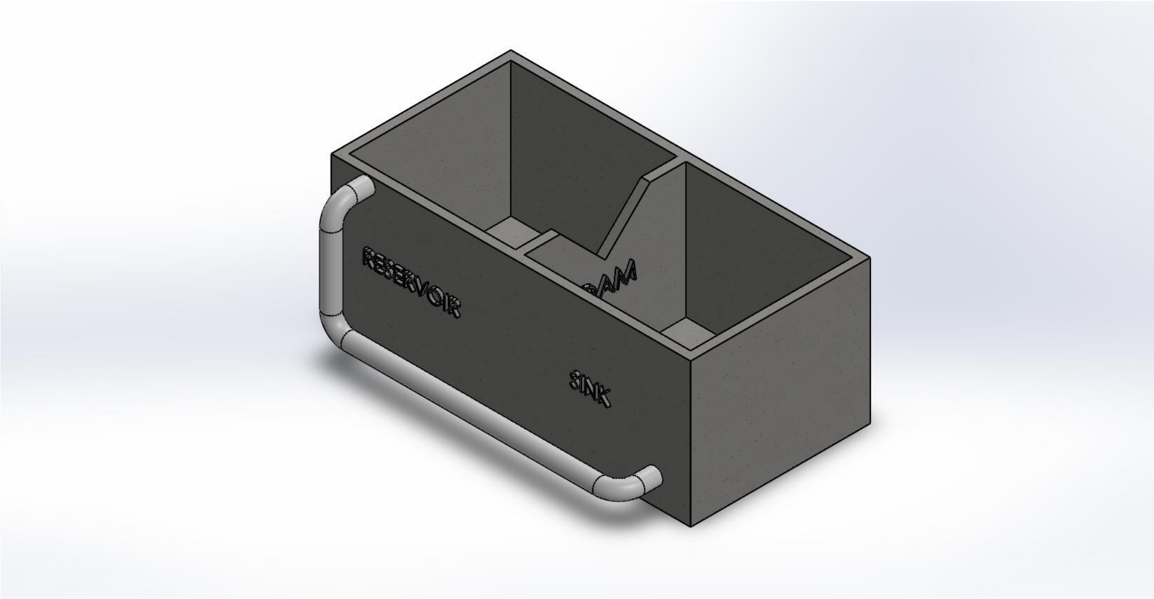


Figure 4-1 3D drawing of the dam prototype

The prototype boasts a simple design in explaining the concept simulation as it comes with three main compartments such as reservoir (river before dam), sink (river flow after dam), dam and piping with water pump to suck water from sink to reservoir back.

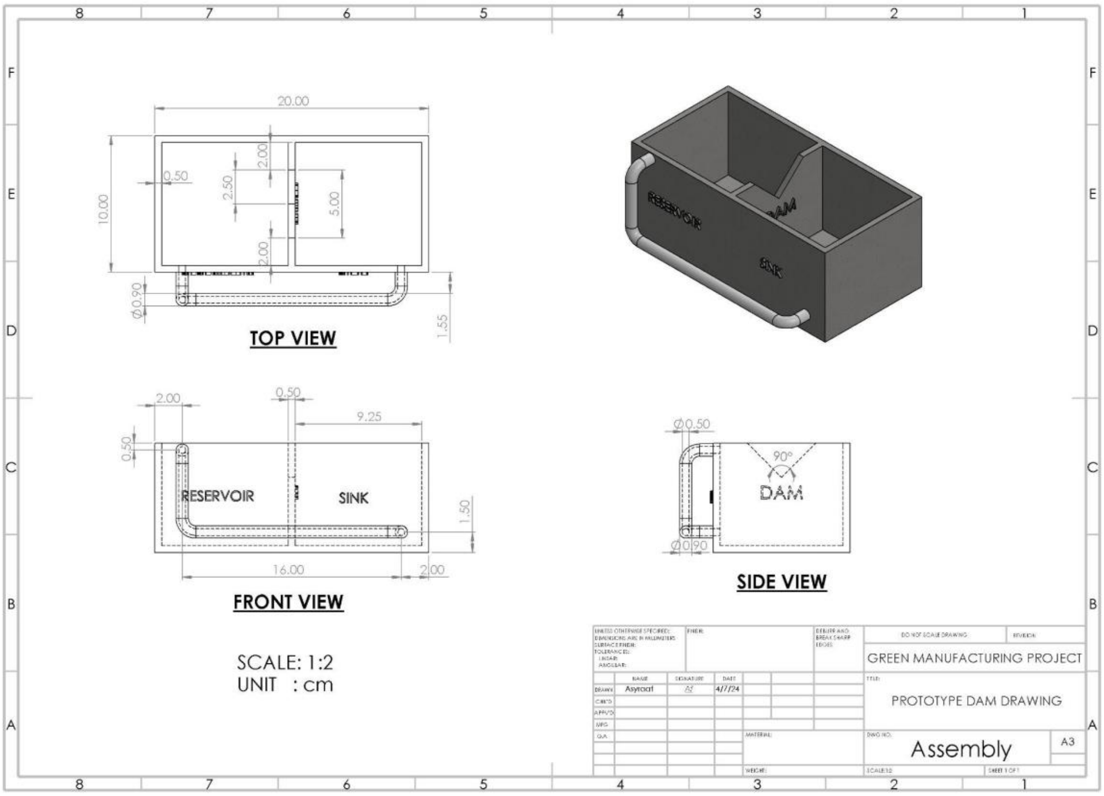


Figure 4-2 Dimensional layout for the prototype dam drawing

Incorporating this element included in the will give us a comprehensive overview on what innovative solution was made to improve water quality issues and promote sustainable development practices.

4.2 Costs and Limitations

The table below presents a detailed cost breakdown for developing the dam. The weir plate is constructed using recycled aluminium or stainless-steel plates, which are available for free from the UTM Mechanical Engineering lab. Meanwhile, to calculate the cost of the raw materials for the structure, which consists of sand, gravel, and cement, the dam is assumed to be trapezoidal in shape, as illustrated in the figure below. The dimensions of the dam are assumed to be 8 metres in length, 0.5 metres in height, with a long base of 0.7 metres and a short base of 0.5 metres. The total volume of the dam is then calculated to be 2.4 cubic metres.

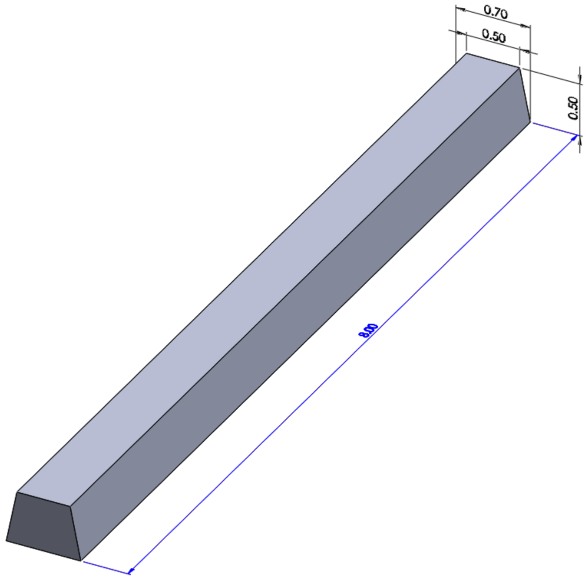


Figure 4-3 Assumed shape and dimension of the dam structure

For water-retaining structures like dams, reservoirs, and water tanks, it is crucial that the concrete be entirely impermeable to avoid water leakage. To ensure absolute watertightness, a mixture ratio of 1: 0.5 : 1 (cement : sand : aggregate) with a low water-cement ratio is frequently used (EasyMix Concrete, n.d.). The densities of cement, sand, and gravel are 1440 kg/m³, 1600 kg/m³, and 2400 kg/m³, respectively.

The total ratio of the concrete mix is calculated as follows:

$$Total\ Ratio\ =\ 1\ +\ 0.5\ +\ 1\ =\ 2.5$$

Next, the volume and weight for cement, sand, and gravel are calculated to determine the cost of each material.

$$Cement\ volume\ =\ \frac{1}{2.5} \times\ 2.4\ m^3\ = 0.96\ m^3$$

$$Cement\ weight\ =\ 1440\ kg/m^3\ \times\ 0.96\ m^3\ =\ 1382.4\ kg$$

$$Sand\ volume\ =\ \frac{0.5}{2.5} \times\ 2.4\ m^3\ =\ 0.48\ m^3$$

$$Sand\ weight\ =\ 1600\ kg/m^3\ \times\ 0.48\ m^3\ =\ 768\ kg$$

$$Gravel\ volume = \frac{1}{2.5} \times 2.4\ m^3 = 0.96\ m^3$$

$$Gravel\ weight = 2400\ kg/m^3 \times 0.96\ m^3 = 2304\ kg$$

Once the weight of each raw material is determined, the cost is calculated based on the price per kilogram, which can be found on Shopee. The expected total cost of the dam amounts to RM 4008.96, excluding manufacturing, design, and other associated costs.

Table 4-1 Expected total cost of the dam

No	Parts	Quantity	Price (RM) /1kg	Total Price (RM)
1	Recycled aluminium / stainless steel plate	1	-	FOC
2	Cement	1382.4 kg	0.90	1244.16
3	Sand	768 kg	0.90	691.20
4	Gravel / Aggregate rock	2304 kg	0.90	2073.60
Total				4008.96

However, there are some limitations with this model. For example, the use of recycled materials like aluminium or stainless steel, while environmentally beneficial, poses durability concerns over extended exposure to water and environmental conditions. These materials must undergo rigorous testing to ensure long-term resilience and operational reliability. Corrosion resistance, mechanical strength under various stress conditions, and susceptibility to environmental degradation (such as oxidation) are critical factors that need thorough evaluation to mitigate potential risks.

Furthermore, despite efforts towards sustainability, the dam's installation and operation could potentially impact low head river ecosystems. Issues such as habitat disruption during construction and altered flow patterns leading to sedimentation downstream need careful consideration and effective mitigation strategies. Thorough environmental impact assessments (EIAs) are essential to identify and address these potential impacts.

Implementing mitigation measures, such as sediment management plans and habitat restoration initiatives, can help minimise adverse effects on local biodiversity and ecosystem health.

4.3 Implementation

Implementing a Cemented Sand, and Gravel Dam (CSGD) for a low head river dam necessitates a methodical approach to ensure successful deployment and sustainable outcomes. The process begins with a thorough preliminary assessment and planning phase, evaluating potential sites along the river beside UTM’s Mechanical Engineering Faculty building based on geological stability, hydrological conditions, and environmental sensitivity. This initial feasibility study determines the technical, economic, and environmental viability of using CSGD to address issues such as stagnant flow rates and low dissolved oxygen levels.

Once a suitable site is identified, the design development phase commences. Engineers and hydrologists collaborate on detailed hydraulic and structural designs tailored to the specific site conditions. The hydraulic design focuses on optimising water flow dynamics and oxygenation within the river, incorporating features like spillways and aeration mechanisms to enhance ecological benefits. Simultaneously, the structural design ensures the dam can withstand local hydrological forces while minimising environmental impact.

Regulatory approvals and permits are pivotal milestones in the implementation process. Environmental impact assessments (EIAs) are conducted to evaluate potential impacts on biodiversity, water quality, and surrounding communities. Obtaining necessary permits from UTM Management, water resource agencies, and environmental regulators ensures compliance with national and regional standards for water quality and conservation.

Construction and implementation involve procuring materials such as locally sourced sand, gravel rock, alongside cement for dam construction. Sustainable construction practices are emphasised, including waste minimization, material recycling, and energy-efficient methods to reduce environmental footprint during the build phase. The CSGD is constructed according to approved designs, ensuring proper alignment of structural elements and hydraulic features to achieve desired performance outcomes.

Post-construction, a comprehensive monitoring and maintenance program is established to assess the dam’s effectiveness over time. This includes monitoring water quality parameters, flow rates, sediment transport, and biological indicators to evaluate ecological impacts and ensure the dam’s functionality. Regular maintenance inspections and proactive repairs help maintain structural integrity and operational efficiency, contributing to the long-term sustainability of the dam.

In conclusion, implementing a Cemented Sand, and Gravel Dam (CSGD) at UTM's Mechanical Engineering Faculty offers substantial benefits. By addressing stagnant flow rates and low dissolved oxygen levels in the adjacent river, the dam enhances water quality, supports local biodiversity, and promotes sustainable water management practices. This initiative aligns with UTM's commitment to sustainable development goals, fostering a resilient ecosystem and providing a practical learning environment for students in engineering and environmental sciences.

5. Discussion

5.1 Green Manufacturing Proposal

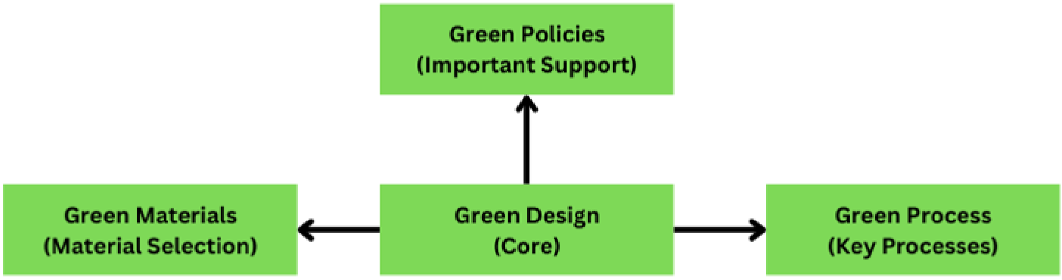


Figure 5-1 Green Proposal

Following the methodology which puts forth a conceptual effective system, the green manufacturing principles are essential to design a comprehensive proposal to ensure environmental impact of the weir is reduced. In this scenario, the figure above illustrates the four elements within this green proposal. Green design at the core refers to the amalgamation of green material selection, green policies and green process as is strategized while generating concepts.

Figure 5-2 Green Design Flowchart

5.1.1 Green Design

The Green design process starts by identifying the environmental goals required to achieve the desired outcome. As identified through the independent water study with results attached in the appendix, the river stream displayed a really low dissolved oxygen reading, as well as slow flowrate. Once these major problems were highlighted, literature was reviewed to identify the best environmentally friendly solution applicable to the current scenario.

It was determined that the simplest, natural and most effective way to resolve the problems with the river was by using Low-Head River dams or Weir for short. As described and discussed in section (2) of the report, Weirs control the river flow rate by forcing flow through a conformed cross-section. The river flow drops from elevation and is exposed to more air, increasing absorbed oxygen and flow rate. However, typical Weirs are harmful to the environment as they introduce rigid structures in a dynamic ecosystem.

To introduce green design, the proposal starts by defining the design goals and strategizing the required parameters as illustrated in the figure below.

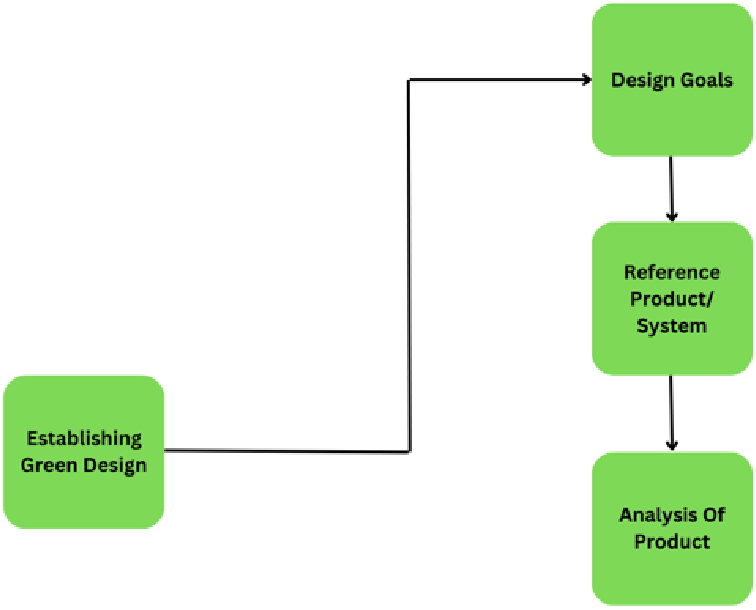


Figure 5-3 Green Design Schematic

The goals for this project are as defined previously, and summarised below:

- Design an environmentally friendly Weir
- Use natural and sustainable materials
- Improve aquatic health by introducing aquatic flora through new green production methods.

These goals and objectives have already been highlighted in detail in section (3). Reiterating these goals shows the relation within the green proposal. Hence, once the design goals are established, reference products are analysed. In this scenario, various practical weir designs used for river reformation were analysed to determine the best weir design that positively impacts DO% and flowrate- On this basis a few concepts were generated, and a final concept was chosen as finalised in section (3). The following design process was followed.

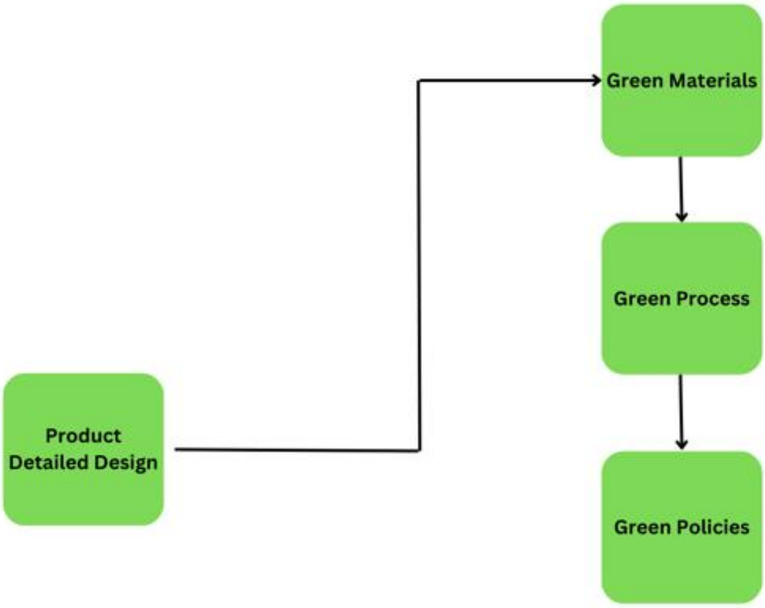


Figure 5-4 Product Design Process

5.1.2 Green Materials

In short, the product concluded a detailed design in section (3). Moving forwards, the material selection of the weir was necessary, unlike typical dam construction, the materials were required to be non-invasive and natural. (Jia et al., 2016) introduced an environmentally friendly dam constructed from natural cemented materials (CMD). This concept includes various types of dams, such as the cemented sand, gravel, and rock dam (CSGRD), the rockfill concrete (RFC) dam (also known as the cemented rockfill dam, CRD), and the cemented soil dam (CSD). The goal of this design was to create a safer and more economical dam while also being environmentally friendly for both the structure and the downstream area

These dam types utilise locally available materials such as sand, gravel, and rock, which are mixed with cement to form a durable and resilient structure. CSGRDs are particularly suitable for lower head dams due to their ability to withstand moderate water pressures and maintain stability over time. In addition, the tip or notch of the weir was designed to be stainless steel or aluminium to prevent erosion through water - This metallic component can be obtained through recycling scraps and casting process.

However, the initial prospect of just using natural materials was not enough, Hence, a new condition was added to utilise aquatic plants- Introducing biodiversity in the river. To accomplish this, a new technique was identified through a recent study (Li et al., 2022). The study suggests the use of planting concrete (PC). This specific blend of concrete solves the drainage issue by using stones with different grits and sizes mixed in- Allowing plants to absorb water from a soil bed implanted on top of the concrete base.

The addition of aquatic plants plays a vital role in water quality. Aside from using the weirs to boost dissolved oxygen and flow rate, aquatic plants serve to stabilise the water chemically. Plants act as nitrogen and phosphorus fixers - Absorbing excess nitrogen and phosphorus in the river preventing algal blooms. Furthermore, the plants also improve the aesthetics of the river by adding a certain green charm to the scenery.

Overall, the green material selection is summarised as follows:

- Natural materials (Sand, Gravel Rock and Cement) used to construct the dam.
- Recycled metallic scraps used for weir notch.
- Planting Concrete (PC) used to allow growth of aquatic plants at the dam wall.

5.1.3 Green Process

Green process mentioned involves the construction of the river dam in such a way that reduces waste and increases resource utilisation. As mentioned above, the best type of dam are CSGRD's (Cemented sand gravel and rock). By using local resources, the dam construction is often more cost-effective compared to traditional concrete dams, as they reduce the need for expensive imported materials and minimise environmental impact using local resources.

In addition, concerning the use of PC (Planting Concrete) a specific layering process is required to ensure that plants can grow. This layering is illustrated in the figure below.

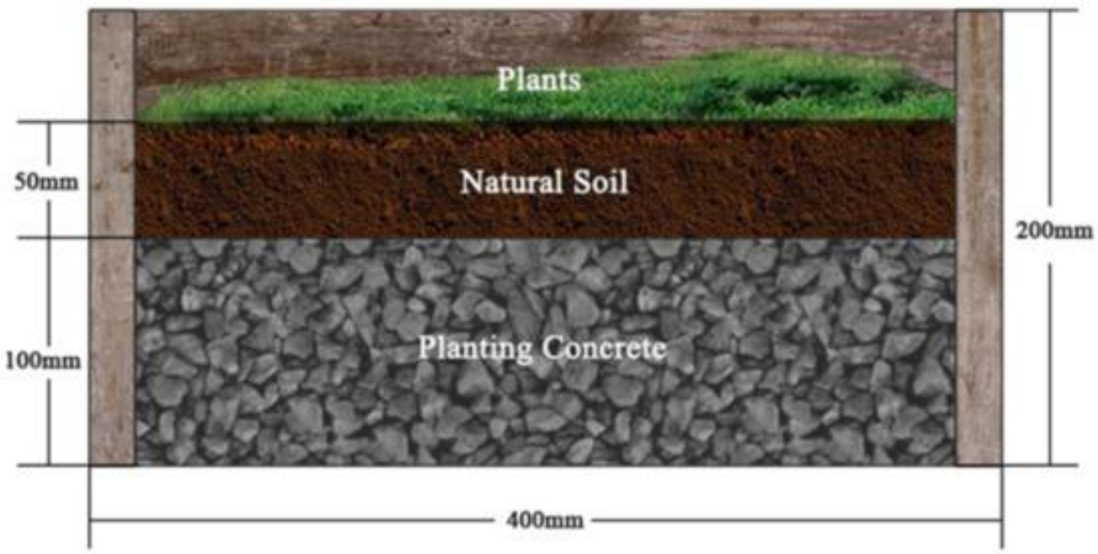


Figure 5-5 PC Layering Process

(Li et al., 2022)

As illustrated above, a layer of natural soil is added above the concrete layer to allow for plant growth. These production processes are necessary to follow to ensure the low-head dam operates effectively.

5.1.4 Green Policies

Accompanying the weir design are essential policies that ensure the green system works effectively. The aim of these policies is to act as supports for the overall green design. The suggested policies and justifications are as described and listed below:

1. Use of weirs in consideration with the topography of the river, from upstream to downstream. Weirs must be used conservatively along the length of the river.
2. Plant seeds used for the weir must be non-invasive and nitrogen fixing- Such as Azolla (water fern).
3. Weir notch must be used to bi-monthly monitor the flow rate and dissolved oxygen of the river.

These three policies cover the entirety of the green design. Firstly, the weir only has a limited effect area, and considering that the river stream stretches beyond it, it is probable that more than one weir can be used across the river width, however they must be spaced adequately to prevent stagnating water. The more weirs present introducing oxygen and increasing flowrate, the faster the recovery for the river ecosystem. Secondly, the aquatic plants to be planted into the concrete must be considered as invasive plants might hinder the recovery of the river. In this case, plants that are known to be stable and beneficial must be used- Such as Azolla (Water fern) which are nitrogen fixing and do not require many resources.

Lastly, the weir notch outlet area of the dam is very useful in measuring water parameters accurately, hence the river health must be monitored in case of any random changes that might result from introducing weirs.

5.3 Evaluation

Presenting the green design above, evaluating its benefits and adverse effects is necessary. This design has several benefits. The first and most outstanding advantage is the improvement in the level of dissolved oxygen that is available in the river. One of the known problems of water is low dissolved oxygen which is inimical to aquatic life, and the design of the dam tries to solve this problem through increasing the rate at which water surface is exposed to the air as it passes through the water dam.

Further, it can exert some control on water flow, which is beneficial in instances where flow rate is low and water may stagnate leading to poor water quality. The control and regulation which is ensured by the structure create healthier river ecosystems in terms of a more consistent flow. The last benefit is that the project is associated with the implementation of green manufacturing principles in the process of designing and implementing the project. There is focus on the use of environment- friendly resources as it ensures that they contribute lesser to the ecological impacts. This approach also supports the SDG goals and puts the foundation measure for future infrastructure development projects to embrace green practices. Concerning the operation of policies mentioned above, the focus on green policies guarantees that the project remains attuned to the environment for the sake of a sustainable and self-sufficient ecosystem.

There is however always the disservice of the destruction of natural ecosystems in the process of constructing the dam structure. They may cause a little interregnum to the wildlife animals and plants in the dam construction area, thus affecting the ecological system.

Moreover, as the dam has potential to increase water quality there are other impacts of the structure such as the impacts of the change in sediment transporting processes whereby the structure may cause accretion of sediment or cause erosion downstream. They may alter the physical form of the river and the structures in it, which may impact the river's morphology and the habitats of aquatic organisms. To mitigate this impact, a special type of cement called porous vegetation eco-concrete (PVEC) is used. This innovative material encourages the growth of aquatic plants on its surface, helping to restore and support the natural habitat that might be affected by construction activities.

Another disadvantage is high costs which may be required for the company to initiate the green manufacturing principles in its operations. Utilising sustainable materials and processes means using resources that can cost more than the traditional ones. Profiling may therefore present a financial burden especially, where it may be challenged in terms of sourcing for funds and explaining the cost incidences to the stakeholders. Further, some may involve repair and require technical input for management such as the case with the dams which may put pressure on resources by constantly needing maintenance because of the green technology associated with them.

Overall, the proposed low head river dam project is sustainable, environmentally friendly in a way that develops a way to purify water and adopt environmentally friendly manufacturing. Nevertheless, it is crucial also to think through such factors as ecological impact, financial costs, and prospecting maintenance of the project for its successful existence.

6.0 Conclusion

Overall, the utilisation of the low head dam (weir) is tackling the objective of Malaysia's commitment to achieve the United nation Sustainable Development Goals (SDGs) framework, to make the world a better place. Specifically on SDG 6 which is clean water and sanitation, ensure availability and sustainable management of water and sanitation for all. Hence, the usage of low head dams can maintain water levels during dry seasons, which improves water security. For the SDG 14, this goal is much focused on conserving and sustainably using the oceans, seas and marine resources for sustainable development. Due its capability to increase the dissolved oxygen level through aeration operation resulting in bubbles creation in the water, this is highly beneficial for the life below water since oxygen are the basic needs for living things to survive.

Furthermore, an engineering approach has been taken to design the low head dams and it is the Product Design Specification. It's a comprehensive document that outlines all the requirements and constraints of a product design project. There are five criteria that have been taken to design the low dam head which is performance, material, lifespan, maintenance and durability. Hence the low head dam has been designed carefully to fulfil each criterion.

Next, to produce the actual low head river dam it will require recycled aluminium, sand, gravel and cement. Thus, all these materials will involve cost except the recycled aluminium, as it applies the green concept. The total cost would be RM 4008.96. The shape of the actual low head dam is trapezoidal with the length of 8 metre, width of 0.5 metre, length of base of 0.7 metre. The total volume that combined all of the material 2.4 m^3 .

Furthermore, green manufacturing principles have been applied to the low head dam, first is the green design. As the design is environmentally friendly and will uplift the river ecosystem through innovative techniques. Hence in the design process the material has been selected carefully which can offer sustainability to the environment. As mentioned before, this can be categorised as the green material since all the material used such as cement, sand and gravel will not cause any damage to the environment chemically.

Finally, the utilisation of the low head river dam would give extraordinary advantages as follows: Significantly increase the oxygen level in the water. Increase in the flow rate of the water. Allow the introduction diverse aquatic plants to increase river ecosystem. All the benefits of the low head dam are associated with the green manufacturing implementation in which it also shows that it follows the SDG framework. Despite its drawbacks concerning impact on aquatic life, the low head-dam can be optimized to work as intended, however the maintenance and continuous testing of wate parameters to evaluate the weir performance and impact might prove costly.

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Appendix

First Reading

pH (6.78)

Salinity (0.06 ppt)

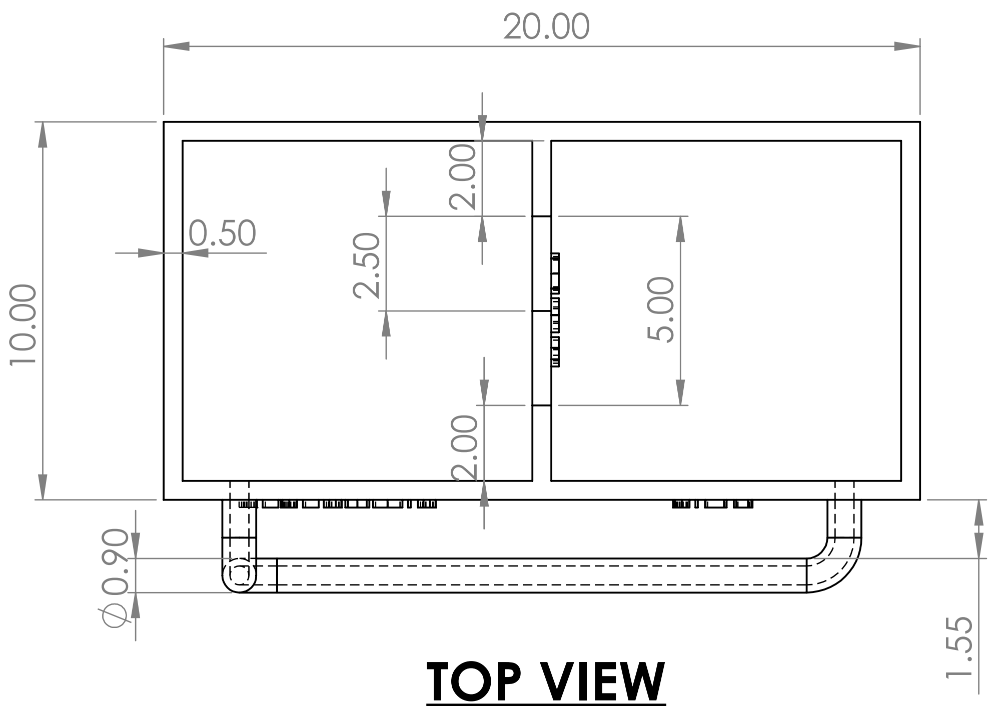
Conductivity (0.00937 ohm)

DO (4.73%)

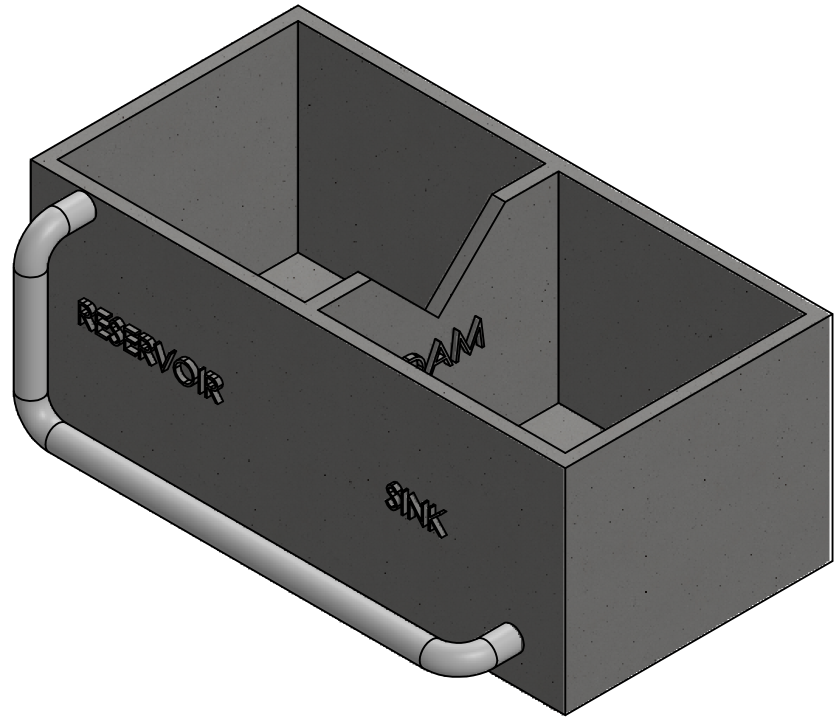
Temperature (May be water)
(27.9°C)

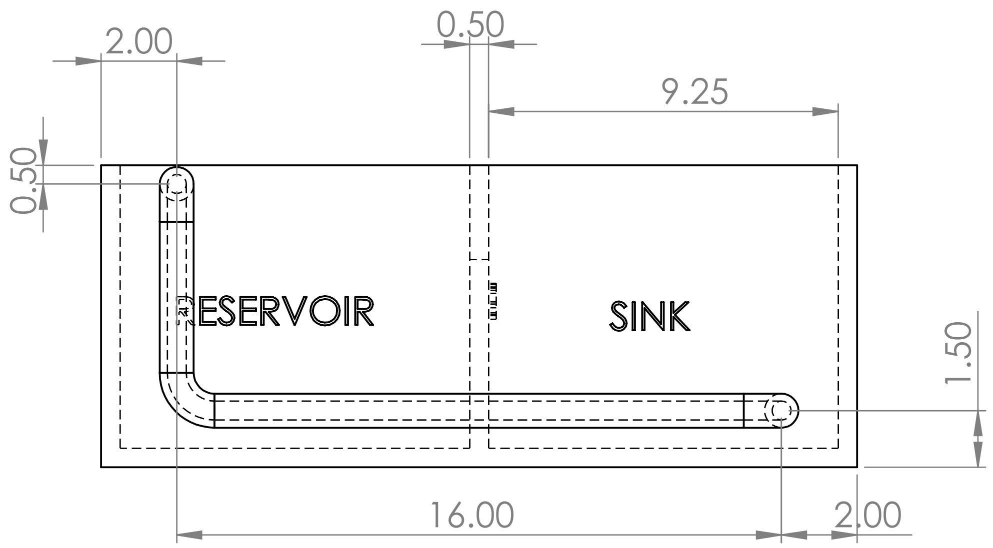
From my Infinix

* Water Parameter Readings

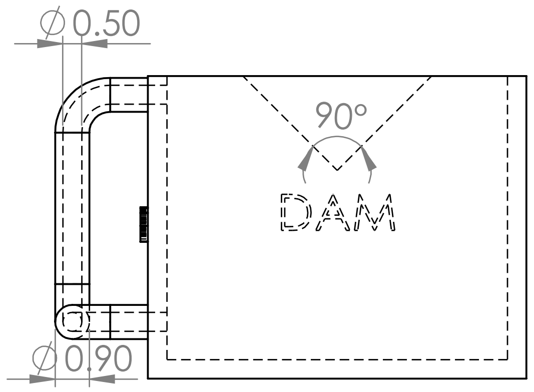


TOP VIEW





FRONT VIEW



SIDE VIEW

SCALE: 1:2
UNIT : cm

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING / REVISION / GREEN MANUFACTURING PROJECT
	NAME	SIGNATURE	DATE		TITLE:
DRAWN	Asyraaf	Af	4/7/24		PROTOTYPE DAM DRAWING
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	DWG NO. Assembly A3
				WEIGHT:	SCALE:1:2 SHEET 1 OF 1

Minutes of the Meeting

Willifred Industries

Date and Time	19/05/2024
Venue	E07 , UTM

MEETING ATTENDEES

- All group members

Priority

- Concept Discussion and water testing.

OPEN ISSUES

- Water Testing for Lake E07
- Identifying possible pre-emptive concept designs and green innovations.

NEW BUSINESS

- Group members initiated discussed and exchanged ideas regarding concepts.

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
• Various concepts were suggested ranging from Weirs to digitally controlled floats and mesh nets before an accurate problem with the river was identified.	• Conducted and Adjourned after class timing on Sunday (4 pm)

Minutes of the Meeting

Willifred Industries

Date and Time	24/05/2024
Venue	Online Discussion

MEETING ATTENDEES

- Arslan, Mazen, Ahmed, Asyraaf, Faizz, Tasfiqul, Haziq

Priority

- Discussion in waste routes of the river and investigation in polluting inlet streams.

OPEN ISSUES

- Water Testing for Lake E07
- Identifying possible issues with waste being thrown into the river resulting in murky water.

NEW BUSINESS

- Group members investigated the murky river water and tried to analyse the cause.

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
• Various labs were contacted to conduct water testing, however there was none available in the desired time frame.	• Conducted and Adjourned online

Minutes of the Meeting

Willifred Industries

Date and Time	09/06/2024
Venue	C23 UTM

MEETING ATTENDEES

- All group members

Priority

- Contacting Civil Faculty for water testing E07 Lake.

OPEN ISSUES

- Water Testing for Lake E07
- Distributed and structured report for Weir green proposal.

NEW BUSINESS

- Group members chose and divided the tasks on report writing and some focused on contacting water testing lab.

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
• Water testing was not possible as lab technicians were not available to assist in operating equipment- Deferred to next meeting.	• Conducted and Adjourned 4-6 pm

Minutes of the Meeting

Willifred Industries

Date and Time	29/05/2024
Venue	Online Discussion

MEETING ATTENDEES

- All group members

Priority

- Finalizing one concept stream and dedicating time to develop and generate further variations.

OPEN ISSUES

- Water Testing for Lake E07
- Identifying common problems with rivers through literature review due to lack of testing equipment.

NEW BUSINESS

- Group members discussed and finalized one single concept stream (Weirs) to focus and develop. Literature review on Weir design was started.

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
• Due to lack of modern weir research, old articles and journals were reviewed to determine the advantages and disadvantages of Weirs.	• Conducted and Adjourned online

Minutes of the Meeting

Willifred Industries

Date and Time	12/06/2024
Venue	C23 UTM

MEETING ATTENDEES

- Faiz, Tasfiqul

Priority

- Testing Water Quality of E07 Lake

OPEN ISSUES

- Water Testing for Lake E07

NEW BUSINESS

- Faiz and Tasfiqul collaborated with technicians to sample water and determine various parameters.

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
• Water testing was finally possible and DO%, Salinity, pH and Temperature were determined	• Conducted and Adjourned 2:30-5 pm

Minutes of the Meeting

Willifred Industries

Date and Time	23/06/2024
Venue	Online Discussion

MEETING ATTENDEES

- All group members

Priority

- Finalizing Report and Green Innovation discussion

OPEN ISSUES

- Green Design and Innovation

NEW BUSINESS

- Discussion on using renewable materials for dam construction as well as proposal to use planting concrete (PC)

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
• Haziq suggested using renewable CSGRD (Concrete, Sand, Gravel and Rock Dams)	• Conducted and Adjourned Online

Minutes of the Meeting

Willifred Industries

Date and Time	23/06/2024
Venue	Online Discussion

MEETING ATTENDEES

- All group members

Priority

- Finalizing Meeting Before Submission
- Revising and proof reading report.

OPEN ISSUES

- Green Design and Policies
- Conclusion

NEW BUSINESS

- Further Discussion on Aquatic plants using in PC (Planting Concrete) which allow for nitrogen fixing in the river.
- Conclusion and evaluation of green system.

UPDATES AND ANNOUNCEMENTS	ADJOURNMENT
- Ahmed suggested PC (Planting Concrete) and we further discussed its benefits and compared the literature. - Mazen evaluated and summarized the system. Arslan proofread and edited final report.	Conducted and Adjourned Online