Increasing the availability of clean water in Espiritu Santo (Vanuatu) via the means of water purification

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EXECUTIVE SUMMARY

Espiritu Santo is a northern island belonging to the remote country of Vanuatu. Currently, the residents of Espiritu Santo are faced with great adversity in simple everyday tasks; the most concerning of which is attaining clean water throughout the year. Consequently, Engineers Without Borders have challenged university students to devise a unique, applicable and simplistic solution to address this issue. Through consideration of several design factors, extended research was conducted to yield a selection of potential solutions: activated charcoal water filtration, water sedimentation, membrane technology, LifeStraw and water distillation. These initial design concepts were then assessed against a criteria matrix which took into consideration the technical requirements and abilities and the necessities of the community. A decision-making process was undertaken which involved developing weightings for each criterion by scoring the related criteria with regards to importance, the scoring of each initial design option with respect to the criteria and the subsequent application of the weighting. The initial design selection which scored the highest was the water distillation unit; this was a result of its high purified water yield, extensive durability, easily maintainable and repairable system and retrofit ability. However, values such as environmental sustainability and the need for minimal machinery for manufacture proved to be lacking.

Through further researching such factors in an effort to improve the viability of the final product, several developmental products were considered. Some of which relied on more readily available materials which proved to be advantageous, yet lacked in factors such as effectivity and safety. Furthermore, a trial experiment was studied in order to better understand the yield capabilities and relationships which determined the effectivity of a water distillation system.

Consequently, these factors were carefully considered and integrated into a final design which has been suggested as the most viable solution for the lack of pure water in Espiritu Santo. The final water distillation unit yielded several positive aspects such as the overall water quality, pure water yield, maintainability, frugality, locally available and durability. However, aspects such as safety, cost and environmental impacts have proven to be disadvantages and may be mitigated.

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1. INTRODUCTION

1.1. ISSUE STATEMENT

Espiritu Santo is the largest Vanuatuan island which is amongst the northernmost islands of the continent. Seasonally, the island experiences wet and dry periods. These dry periods can last for three to four months (Engineers Without Borders Australia and Live & Learn Environmental Education 2017), in which the residents use stored rainwater from tanks which tend to deplete before the season has finished. Water is usually sourced from natural deposits such as streams and water holes, but safe water cleansing procedures are not frequently practiced (Engineers Without Borders Australia and Live & Learn Environmental Education 2017) or the used methods are inadequate, making such water hazardous to drink. Two primary issues which prohibit the consumption of clean drinking water are apparent in Espiritu Santo. Firstly, not enough clean water can be stored during the wet season by some villages, for water tanks, which can be purchased in Luganville are quite expensive and out of the financial reach of many households (Engineers Without Borders Australia and Live & Learn Environmental Education 2017). Subsequently other than rainwater, water used for drinking is not always cleansed to a high enough standard for safe consumption.

1.2. SCOPE

The availability of clean water is a necessity for human survival (UNICEF & World Health Organisation 2013). The inhabitants of Vanuatu face great adversity in survival due to over half the population lacking access to a clean water supply (Landsmeer). As a result of which, the objective of the project is to devise a potential solution to increase the availability and provision of clean water to the communities of Espiritu Santo, Vanuatu.

The intention of the report is to provide an explanation of the issue regarding the deficiency of water availability and a discussion of possible solutions which will improve the quality of life of the residents of Espiritu Santo.

1.3. BACKGROUND INFORMATION

1.3.1. State of Living

Most individuals in Vanuatu are subsistence farmers whom earn revenue from cropping. Foods are often exchanged amongst community members so that a wide variety of food is available to everyone. Staple foods include yam, taro, banana, coconut, sugarcane, tropical nuts, seafood (primarily fish), and temperate crops such as cabbage, beans, corns, peppers, carrots and pumpkins. Those who tend to be relatively wealthier are able to afford canned food (rice and tuna) from local supermarkets (Amont and Indstrom 2006).

1.3.2. Natural Resources

Natural resources that are plentiful on the Vanuatu Island include copra, coconuts, cocoa, coffee, taro, yams, sweet pineapples, mangoes, island cabbage, flying fox, coconut crabs, natapoa nut, beef, fish & fruits and vegetables of various kinds. The villagers rely upon subsistence farming as their primary food source. Individuals tend to export beef to countries such as Japan, Australia, & other Pacific Island counties to earn revenue (Macro Connections 2017); from which, other facilities may be purchased such as cooking utensils, fire matches, and other food items that individuals are unable to attain such as rice.

1.3.3. Climate

Vanuatu experiences both dry and wet seasons due to its bi-seasonal climate. The dry season spans from May to October and the wet season from November to April (Vanuatu Meterology & Geo-Hazards Department 2017); the latter season is generally when Espiritu Santo reaches peak humidity of each year (TravelOnline 2017). The temperature throughout the rest of the year is generally uniform. The warmest time of year is during the month of February, and the coolest during July. As an indication, Luganville, located to the south-west of Espiritu Santo, has an average annual temperature of 25.3°C (Climate-Data.Org 2017) *(refer to appendix 1 for further information in graphical form)*.

1.3.4. Economy

The economy of the majority of Vanuatu is primarily founded upon fishing, tourism and agriculture. However due to its isolation and lack of water transport, the islanders have significant economic disadvantages and therefore require development projects to assist their basis of interaction with other countries (The Commonwealth 2017).

1.3.5. Water Quality

The residence of Espiritu Santo currently lack accessibility to clean drinking water as two of their three primary water sources are contaminated with salts (Engineers Without Borders Australia and Live & Learn Environmental Education 2017). Other fresh water sources are contaminated with anaerobic bacteria or pathogens, nitrates and fluorine; all of which are in large abundances (Australian Bureau of Statistics 2016).Furthermore, water sources which are clean for drinking such as groundwater is difficult to access and therefore is unable to be used (Engineers Without Borders Australia and Live & Learn Environmental Education 2017).

1.4. Design Criteria & Considerations

In order to accurately assess the effectivity and applicability of each possible solution with regards to the requirements of the community, a range of design criteria which considers the factors necessary to develop a complete and relative product have been formulated *(see appendix 2 for the design factors)*. The most significant of which include:

1. User Centred Design
   i. The functions of the design must be easily understood & controlled by the community
   ii. The physical practicality of the design must
      a. Allow for large amounts of water to be stored
      b. Be able to fit into each home / some per village
   iii. The economic demands of building and maintaining the product must be relatively cheap
   iv. People aged from children to the elderly should be able to make use of the product easily
   v. The product must be durable
      a. Everyday use
      b. Harsh / Abnormal weathering
2. Materials
   i. The properties of the materials used, respecting their role in the structure should be:
      a. Strong enough to contain allocated capacity of water
      b. Water tight (restricting the captured water to a finite space)
      c. Have the ability to filter water
      d. Malleable (allow the shape to change upon demand)
      e. Stable / form stable structure
      f. Recyclable
   ii. All materials should be readily available for harvesting and or use
3. Sustainability
   i. The environmental aspects of the product should include:
      a. The reduction and or the reuse of waste
      b. Harmless products (if any)
      c. Avoidance of rapid degradation
   ii. The social aspects should encompass:
      a. A communally simple build (understandable by all users)
      b. A culturally respectful build
   iii. The financial aspects should reflect:
      a. A replaceable build
      b. A profitable build
   iv. The community should be well informed regarding the structure and processes of the product in order for them to maintain the product
4. Technologies: Procedures & Conventions
   i. The manufacturing process should:
      a. Require minimal machinery

b. Locally sourced & conducted
c. Time effective

ii. The maintenance should be:
a. Local to allow for regularity
b. Should be able to be completed by the regular users

2. Initial Design Concepts

2.1. Activated Charcoal Water Filter

The activated charcoal filter is a single chambered water filtration system. The primary components of the system include sand, gravel, activated charcoal, and cloth layers; all of which hare essential in order to further purify unclean water. The cloth layers additionally serve a purpose in the overall maintenance of the design. They can be removed when certain materials need to be replenished or replaced altogether, such as if the activated carbon sites have been diminished. The assembly of the whole system then occurs within a recycled water bottle, which has the required volume to accommodate the raw materials. The function of such materials is key to the function of the water filter.

As the untreated water is introduced into the system, the "gravel layer" is firstly subjected to large sediments such as dirt, rocks, twigs, plastics or metals which is to be filtered. A cloth strip aids in the filtration process, however is primarily used to separate the gravel layer from the following "sand layer". The sand layer is then used to filter out finer sediments which the previous "gravel layer" neglected. Over time, organisms and other contaminants will accumulate in the top layer of the sand segment forming a biological zone to filter out bacteria, viruses and parasites (Apollonas 2017). Consequently, this will assist in eliminating such hazards from the water. Another cloth layer Is then used to separate the sand layer from the following charcoal layer. Activated charcoal layer is the most important layer through which the water must pass, as it allows for removal of the majority of hazardous contaminants via chemical absorption. A final cloth piece is then used to separate the activated carbon layer from the cap of the bottle; the latter of which must be pierced in order for the clean water to escape.

The system relies on gravitational force, which is responsible for fluid motion through the system. Consequently, if there were no downward force acting on water, the water is not able to flow through the system to be filtrated. This system thus eliminates the need for an electronic pump, which works by initiating movement in presence of pressure.

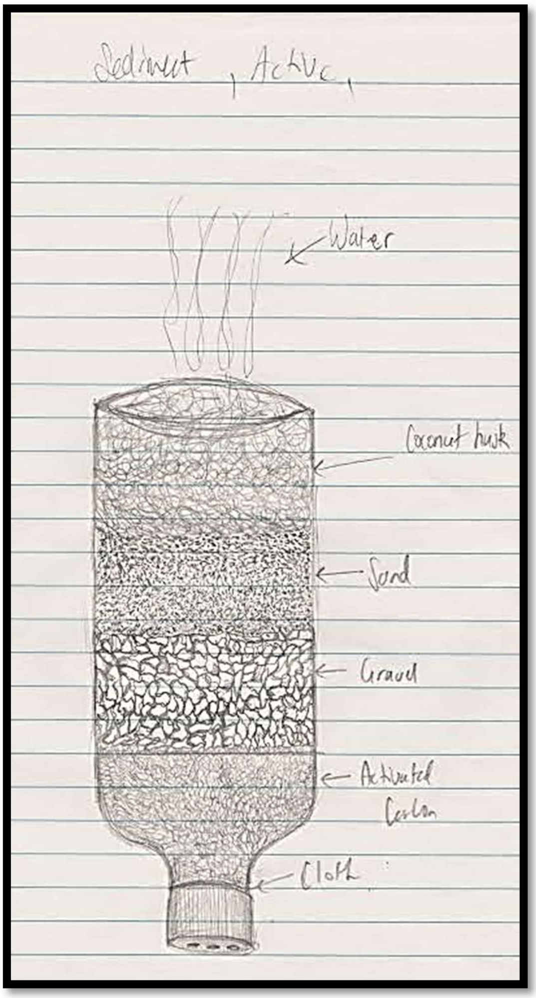
The overall design is quite easy to construct and relies heavily on locally available products, with only a few exceptions. Sand can be easily obtained from the beaches of Vanuatu. Gravel can be obtained from rivers, streams, and ocean beds. Plastic water bottles can be recycled for the purpose of this design, instead of being discarded or landfilled as per usual. Dirty water is attainable from local water holes, streams, or other relatively safe water bodies. Cloth would need or be purchased, or would require recycling of old clothes ensuring that the cloth is washed prior to use. Alternatively, using coconut husks in a lattice like structure would also suffice which is made applicable by flattening the coconut husk to form a solid, yet porous surface. All materials must be rinsed before use to ensure that the output of water does not collect pre-present impurities from the filtering layers.

A conflict may occur however in regards to the availability and the safe use of some materials. For example, the activated charcoal which is not a naturally occurring resource, and thus may be difficult to obtain. It may be produced using non-activated charcoal or naturally occurring charcoal through chemical treatment or by steam heating procedures; both of which can be quite dangerous to locals in case procedures are not appropriately followed. Charcoal could potentially be sourced from burning wood or coconut husks within an enclosed environment, which may be completed within a pit or a barrel in which the fire is deprived of oxygen to lessen the volume of the flame. The steaming procedure requires industrial grade furnaces in order to attain high temperatures of approx. 950º C in order for the charcoal to be activated in absence of oxygen (Charcoal House 2017). The steam reacts with the carbon atoms in order to produce carbon monoxide and hydrogen gas. As carbon monoxide is released, it therefore reduces the amount of carbon present in the charcoal structure

(Charcoal House 2017). During this process, charcoal's surface area vastly increases and is then referred to it as having had been "activated". Due to this increased surface area, filtration of substances such as water can occur. Unfortunately, this procedure requires large amounts of thermal energy and therefore industrial grade equipment that can be quite expensive to purchase and maintain in the future.

Alternatively, highly caustic chemicals such as sulphuric acid, hydrochloric acid, nitric acid, potassium or sodium hydroxide could be used for chemical activation of charcoal through corrosion of the carbon atoms. Moreover, the corrosion of carbon atoms also increases the overall surface area of the charcoal. The use of such harsh chemicals can be quite dangerous, due to which, the notion of chemical activation of carbon maybe disregarded. Not only are the chemicals caustic, they must be purchased through the market if they are available, thereby decreasing the practicality of the over design in terms of finance. The use of less caustic chemicals such as calcium chloride may be considered. Due to the fact that calcium chloride is not naturally occurring, its production requires handling of hydrochloric acid which is highly corrosive and impossible to handle without adequate protection such as gloves, clean beakers, and or other lab apparatus that are not easy to obtain on Vanuatu. Chemical activation of charcoal also requires multiple washing stages, which remove the acid from the activated charcoal; this procedure can be quite harmful to the local environment in which the rinsing occurs.

Figure 2.1: Activated Carbon Filter Sketch



2.2. Water Sediment Filter

The sediment filter uses a design that is similar to that of the activated charcoal filtration system (as in figure 2.1) with the exclusion of the activated charcoal layer. The overall process is similar however the activated charcoal layer is simply replaced with sand and or gravel to form a system in which sand and gravel are alternated along the length of a regular water bottle. This process would remove some bacteria and pathogens through filtration, however would not completely eliminate them from the allegedly pure water to be later obtained from the cap of the bottle. The purity of such water lacks due to the absence of a filter which removes organic matter such as the aforementioned activated carbon. Consequently, the purpose of the sand and gravel is to remove dirt, salts and other minerals which are present in the unclean water.

Having had obtained the partially cleaned water from the bottle, the water may then be placed in a pot and boiled in order to remove organic impurities. As the water boils, harmful bacteria and other pathogens are killed and the water is then free from all contaminants, thus making it safe for consumption. The advantage of filtering the water prior to boiling is that overall turbidity of the water is reduced, and minerals are removed that would otherwise be present in high concentrations. Using this method regularly will ensure that the accumulation of salts and minerals is reduced and that the overall health of the citizens would improve.

The sediment filter is constructed entirely out abundant local materials, making it a sustainable solution. The plastic water bottle that forms the hull or shell of the device, can be recycled from land fill sites. Sand and gravel can be found in large quantities towards the shores of the island, negating any costs involved with having to purchase such materials. Villages use pots and pans to cook, meaning they can also be used to boil the water that is cycled through the sediment filter. The main advantage to this device is its outstanding sustainability due to the ease at which components can be scavenged to construct the system.

2.3. Reverse Osmosis

Membrane filters were also studied as a potential solution to eliminate physical contaminants from unclean water through the use of reverse osmosis technology. For the system to function, four main components are required which cannot be hand-made or locally sourced. Firstly, a pump and an airtight compartment which will be used to carry unclean water must be attained. The system is then fixed with a membrane across the airtight container which divides the system into two parts. The unclean water is poured into the first segment above the membrane and air pressure is provided by the pump which is connected to the airtight container via an airtight hole into the top segment. In presence of high pressure, water molecules are forced through the membrane, while pathogens, bacteria and other contaminants fail to pass through due to their relatively larger size. Clean water can then be simply collected from the second compartment (the one below the membrane). It is highly important that the pressure within the first segment remains constant when extracting clean water from the second compartment, as the water will seep back into the first segment due to osmosis in order to reach equilibrium once again. A potential solution to this problem is a simply cut hole at the base of second segment, so that the clean water is filtered and collected instantly without it having the time to diffuse back across the membrane. The materials and energy required to create such a system makes it an impractical solution in this context. The yield of clean water is also relatively low when regarding the amount of pressure and therefore energy expended to produce such clean water. Without industrial grade equipment, the air tight compartment would also be hard to attain, as the device would not be able to withstand such high internal pressures.

Due to the high-quality material demands, financial implications will occur as the whole system relies on expenditure for purchases of expensive equipment. This indicates that the reverse osmosis system would not be an optimal solution to the problems experienced by the citizens of Vanuatu. Self-made reverse osmosis systems are simply too difficult to construct and sacrifice overall efficiency of the system and therefore would not be a viable solution; especially when other solutions such as the sediment filter are able to work efficiently within low costs and are able to provide a greater yield.

2.4. LifeStraw

An alternative design idea to the reverse osmosis system is LifeStraw. LifeStraw, founded by Vestergaard Frandsen, is a company that manufactures water filtration systems that utilize osmosis, as well as chemical filtering to purify dirty water. Lifestraw's function is very similar, if not identical, to the reverse osmosis system mentioned previously. Two of many LifeStraw products were analysed as potential solutions for improving water quality for the rural community of Vanuatu – the "LifeStraw Community" and the "LifeStraw", both of which have the same function but vary from one another in their yield capacity.

The smaller sized "LifeStraw" can filter "up to 1kL of contamined water into safe drinking water and costs approximately $19.95 USD/unit. The lifestraw works using a multistage membrane filtering system; "hollow fibres, which contained pores less than 0.2 microns across" trap bacteria and parasites, whilst allowing only clean water to pass through. A suction force is required for the device to operate, that is manually provided by the action of using the device as straw over a body of water (LifeStraw 2017).

The "LifeStraw Community" can filter up to "100kL (2)" of water and costs approximately $399.95USD/unit. The system uses gravity as opposed to suction forces to filter dirty water (LifeStraw 2017).

To determine the most cost-effective solution of the two products, price per litre of filtered water was calculated and compared, as follows:

LifeStraw: $\frac{1000L}{\$19.95} = 50.13\ L/\$$, and LifeStraw Community: $\frac{100{,}000L}{\$399.95} = 250.03L/\$$

(LifeStraw 2017)

These calculations revealed the LifeStraw is only capable of filtering 50.13 L of water, as opposed to 250.03 L of water with LifeStraw Community per US dollar spent.

Therefore in conclusion, it was obvious that the LifeStraw Community would be utilised due to its greater output (up to five times) for the same price. A safety feature within the device ensures that once the product utility expires, that no more water would be allowed to transfer through, thus eliminating consumption of dirty water upon the device's expiry.

Both systems are highly efficient in reducing turbidity of the water, but are unable to eliminate salts and other heavy metals from the water; therefore, the water being processed must be free of such contaminants prior to processing. Moreover, if the product were in need of repair/service, a trained technician would be required. Consequently in conjunction with the cost factor, the LifeStraw solution in general proves to be both expensive and problematic.

2.5. Water Distillation

The primary concern with each of the previously mentioned solutions is that they are unable to filter salt from water (Engineers Without Borders Australia and Live & Learn Environmental Education 2017). Due to Vanuatu's humid climate, evaporation occurs at a much greater rate than in climates with lower humidity. Hence, a possible device that could create water vapour and allow for distillation to occur in the given climatic conditions is evident. Such a design would comprise of two chambers: one in which unclean water is to be boiled, and second in which water vapour would be collected, cooled and thus converted back into liquid form. Heat energy from the sun could also be a source of heat when boiling the water in the metal drum. The system would provide clean water to the people of Vanuatu by eliminating a relatively wide variety of contaminants, including: pathogens, bacteria, heavy metals, and most importantly, salts. The system is easy to build, maintain and repair however may potentially be quite expensive in terms of energy expenditure, due to reliance on fire that would serve as a primary heat source for the U.V heated drum.

2.6. Design Matrices & Final Design Selection

2.4.1. Design Matrix Criteria

2.4.1.1. Sustainability

It is essential that environmental, social, cultural and financial are taken into consideration when assessing the sustainability of each design option. The design option chosen must be environmentally friendly in an effort to reduce its impact on the surrounding setting, preserving what will be for future generations. Vanuatu relies strongly on its picturesque landscapes to haul in tourists, contributing to their economy. Furthermore, it must have little to no effect on its surroundings in an act of environmental conservation. The design must also culturally and socially acceptable in order to assimilate into a society without offending or antagonising the beliefs and/or values of its residents. Finally, Obvious financial limitations are present in such circumstances, so the design option must have a fine balance between cost and product performance.

2.4.1.2. User Centred Design

Practicality through ease of use is essential to ensuring that the design encompasses the limiting factors that may occur depending on the ability of the user. Consequently, the design must be easily maintainable by local residents which is vital to ensuring the longevity of the product installed, allowing it to be repaired easily without the need of trained technicians. Furthermore, the safety of the design is also paramount; endangering the lives and/or wellbeing of the people of Vanuatu would pose as a deconstructive product and therefore would be redundant. Finally, the criterion requires a design which is simple to operate which will ensure the product can run to its maximum potential without the need of trained specialists. This will also combat financial implications that may arise with the reliance on a paid worker.

2.4.1.3. Materials

The materials which are selected for each potential design, and those which are chosen for use in the final design must follow guidelines in order to be suitable for the project. Due to the fact that Espiritu Santo is quite remote and third-world, accessibility to industrial materials such as steel and concrete are expensive and or difficult to attain and subsequently use. As a result, local materials which must follow the requirements as detailed in the matrix below must be considered during the final concept design, if such has not already been considered.

2.4.1.4. Procedures & Conventions

The procedures and conventions criteria outlines the requirements which primarily concern the manufacture, regular use and the maintenance of the final product. The nature of other design criteria in particular, user centred design and materials have predetermined the details for this design criteria. Consequently, factors such as simplicity, minimal use of machinery and time effectivity have been integrated into this criterion of the matrix.

2.4.2. Decision Process (Matrices)

The decision matrix which has been created to assess the viability of each design concept was based of the aforementioned design criteria. Consequently, each group member gave each of the criteria a weighting, of which a percentage weight was then calculated. This process can be seen in table 2.1:

Table 2.1: Design Objective Rating by Group Members

Design Objective	Group Member				
	Saurav	Aayush	David	Tim	Dylan
Environmentally friendly	4	2	2	4	3
Culturally & Socially acceptable	3	6	3	4	2
Financially profitable & easily replaced	7.5	7	5	6	3
Easily understood & controlled	8.5	8	6	7	7
Easily maintained / repaired	8.5	9	8	7	8
Easily employed into each community	6.5	6	8	6	8
Safe to function	6.5	10	10	8	10
Materials availability	7.5	6	4	4	3
Durability of system	7.5	8	8	9	10
Final Water Quality	9	12	17	15	14
Yield	6.5	7	10	12	10
Manufacture requires minimal machinery	5	3	2	4	3
Manufacture conducted & sourced locally	4	4	3	3	4
Manufacture is time effective	6	3	3	3	4
Maintenance is able to be completed by regular users (simplicity)	6	6	8	6	8
Ability to be modified to reach higher yields or greater efficiency	4	3	3	2	3
Total	100	100	100	100	100

Subsequently, the criteria were summed and the criterion which held the highest sum value was used to calculate the weight distribution. Thereby, dividing all other values by the highest sum value. The result is illustrated in the table below:

Table 2.2: Weighting of Design Objectives

Design Objective	Sum of Criteria	Weight (00.00%)
Environmentally friendly	15	22.39
Culturally & Socially acceptable	18	26.87
Financially profitable & easily replaced	28.5	42.54
Easily understood & controlled	36.5	54.48
Easily maintained / repaired	40.5	60.45
Easily employed into each community	34.5	51.49
Safe to function	44.5	66.42
Materials availability	24.5	36.57
Durability of system	42.5	63.43
Final Water Quality	67	100.00
Yield	45.5	67.91
Manufacture requires minimal machinery	17	25.37
Manufacture conducted & sourced locally	18	26.87
Manufacture is time effective	19	28.36
Maintenance is able to be completed by regular users (simplicity)	34	50.75
Ability to be modified to reach higher yields or greater efficiency	15	22.39
Total	100	100

Evidenced by the weighting process, the final water quality which is produced each of the product designs has been considered as paramount for a successful design. Using these weightings, each design concept will be graded with respect to each of the design criteria. Each of the group members will assign a score out of 10 to each of the design options with respect to the criteria; this result will subsequently be averaged and weighted to determine the final design. This data is represented in the following table.

Table 2.3: Initial Design Options Scoring

Design Objective	Weighting (%)	Initial Design Options				
		Activated Charcoal Water Filter	Water Sediment Filter	Reverse Osmosis	LifeStraw	Water Distillation
Environmentally friendly	22.39	8	10	8	9	6
Culturally & Socially acceptable	26.87	9	8	6	8	8
Financially profitable & easily replaced	42.54	8	9	2	6	7
Easily understood & controlled	54.48	9	9	3	10	6
Easily maintained / repaired	60.45	6	8	1	3	6
Easily employed into each community	51.49	7	8	1	6	6
Safe to function	66.42	9	9	10	10	8
Materials availability	36.57	3	10	2	2	5
Durability of system	63.43	4	6	8	7	8
Final Water Quality	100.00	3	4	6	5	10
Yield	67.91	4	4	4	6	9
Manufacture requires minimal machinery	25.37	8	10	2	1	6
Manufacture conducted & sourced locally	26.87	7	10	2	1	8
Manufacture is time effective	28.36	5	8	2	1	7
Maintenance is able to be completed by regular users (simplicity)	50.75	5	10	3	5	8
Ability to be modified to reach higher yields or greater efficiency	22.39	3	5	6	1	8

The weightings (as percentages) will then be multiplied by each score in their respective criterion. This result will be summed (by column) to reveal the highest scoring initial design option.

Table 2.4: Initial Design Option Scoring (with weightings applied)

Design Objective	Weighting (%)	Initial Design Options: Activated Charcoal Water Filter	Water Sediment Filter	Reverse Osmosis	LifeStraw	Water Distillation
Environmentally friendly	22.39	1.79	2.24	1.79	2.01	1.34
Culturally & Socially acceptable	26.87	2.42	2.15	1.61	2.15	2.15
Financially profitable & easily replaced	42.54	3.40	3.83	0.85	2.55	2.98
Easily understood & controlled	54.48	4.90	4.90	1.63	5.45	3.27
Easily maintained / repaired	60.45	3.63	4.84	0.60	1.81	3.63
Easily employed into each community	51.49	3.60	4.12	0.51	3.09	3.09
Safe to function	66.42	5.98	5.98	6.64	6.64	5.31
Materials availability	36.57	1.10	3.66	0.73	0.73	1.83
Durability of system	63.43	2.54	3.81	5.07	4.44	5.07
Final Water Quality	100.00	3.00	4.00	6.00	5.00	10.00
Yield	67.91	2.72	2.72	2.72	4.07	6.11
Manufacture requires minimal machinery	25.37	2.03	2.54	0.51	0.25	1.52
Manufacture conducted & sourced locally	26.87	1.88	2.69	0.54	0.27	2.15
Manufacture is time effective	28.36	1.42	2.27	0.57	0.28	1.99
Maintenance is able to be completed by regular users (simplicity)	50.75	2.54	5.07	1.52	2.54	4.06
Ability to be modified to reach higher yields or greater efficiency	22.39	0.67	1.12	1.34	0.22	1.79
TOTAL		43.61	55.92	32.65	41.52	56.29

2.4.3. Design Selection

As demonstrated through the design matrix decision process, the water distillation unit has proven to be the most viable of the initial design options. This is primarily due to the fact that this initial design option takes into consideration the high saline concentrations of the locally available water resources unlike the other options, and therefore scored highly in the final water quality criterion. This initial design option also attributes its selection to its high water yield, durability, easily maintained and repaired system and its ability to be modified in order to reach higher yields and or greater efficiency. However, factors such as environmental sustainability and a minimal machinery manufacture have been disadvantageous and therefore should be amended in further design considerations *(refer to table 2.4, green highlighting indicating high scoring factors and yellow highlighting indicating low scoring factors)*.

3. Final Design Development

3.1 Development 1

The initial design functions by using a weighted tarp to collect and divert water droplets to the centre bucket for collection. A stone is placed in the centre of the tarp shown below, creating an anchor point for the droplets to converge towards, falling into the bucket. Using a fire running on coconut husks or fire wood and U.V heat, dirty water in the oil drum chamber is heated to form steam, separating the water molecules from other contaminants present in the liquid. The result is distilled water, which is safe for consumption. Salt is also removed from the distilled water as a result of the evaporation process, addressing the concerns of high salinity levels of natural water sources.

The tarp is secured via ropes which wrap around the upper circumference of the oil drum. Hooks attached to rope is used to hang the bucket in the centre of the drum for water collection. It is important that the water levels inside the drum are lower than the bucket, in order to avoid contamination of the distilled water.

Figure 3.1: Development 1

Advantages to system:

- Low cost due to the lack of copper piping, compression joint, solder and other plumbing materials.
- Easy to build due to the non-reliance on equipment to construct.
- Easily portable due to the singular chamber design.
- Water produced is free of all contaminants, including particles such as salt and heavy minerals

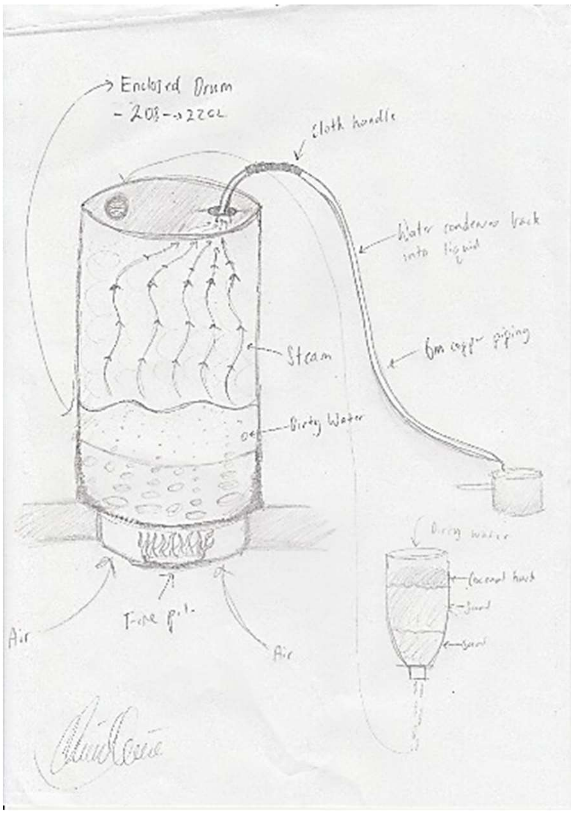
Disadvantages to system:

- Tarp is not heat resistant and would therefore not be able to withstand the heat of the steam.
- Removing of bucket requires contact with the hot oil drum, presenting safety concerns.
- Small amounts of steam would escape through gaps around the upper circumference of the drum and tarp contact points.
- Steam is not cooled effectively, meaning yield would be low due to lower rates of condensation formation.

3.2 Development 2

The second idea improves upon the lack of cooling solution depicted in the previous design. The oil drum is now sealed off to create a pressurised internal environment. Steam created within the chamber will want to escape the drum out of an opening. A copper pipe is used to capture this steam, allowing it to cool and condense into water droplets via a heatsink inspired design (air cooled). Gravity then draws the water droplets to the base of collection bucket, capturing the distilled water. The copper piping is secured to the top of the drum using clay, and a cloth handle has been incorporated to allow handling of the piping in case of emergency.

Figure 3.2: Development 2



Advantages to system:

- Higher yield than previous design due to separate air-cooled copper piping solution.
- Water is sediment filtered before entering tank to be boiled. This reduces the build-up of dirt and other unwanted sediments in the tank.
- Cloth handle allows for emergency removal of the clay secured copper piping.
- Easy to collect distilled water at the end of the distilling cycle.
- Water produced is free of all contaminants, including particles such as salt and heavy minerals.

Disadvantages to system:

- Dangerous due to the lack of a pressure release valve, the pressurised system could explode causing detrimental damage.
- Cooling solution is air cooled meaning there would be a vast decrease in cooling efficiency on hot days.
- Clay connection point is weak and hard to make air tight, decreasing the strength and also efficiency of the device.
- Clay connection point must be reconstructed after every cleaning cycle.

4. TRIAL EXPERIMENT

To estimate the total distilled water yield at an hourly rate, an experiment was conducted which utilised the same principles as the water distiller design; this experiment was downscaled by using a kettle with a diameter of 25 cm rather than an oil drum. To calculate the total surface area of the kettle, the following equation was used:

$$A_S = \pi \times r^2$$

In which case the variables A_S represents the surface area of the kettle and r represents the cylindrical radius of the kettle base.

A major factor affecting evaporation rate is the surface area of the body of water which is being heated. The larger the surface area, the faster evaporation will occur. By dividing the surface area of the oil drum by the surface area of the kettle, a ratio between their surface areas will be determined which will be used to calculate the relative water yield. The calculations are as follows:

Radius of the kettle = 12.5 cm, $\therefore, \pi \times 0.125^2 = 0.049m^2$ (surface area of the kettle base)

Radius of the oil drum = 28.6 cm. $\therefore, \pi\times 0.286^2 = 0.257m^2$ (surface area of oil drum base)

$$\rightarrow divide\ the\ smaller\ by\ the\ larger\ surface\ area,$$

$$\therefore, \frac{0.257}{0.049} = 5.24$$

This indicates that the oil drum has a surface area that is 5.24 times greater than that of the kettle used.

The yield of the kettle used was 1 litre every 1.5 hours which equates to an hourly yield of 0.667 litres. By multiplying 0.667 by the obtained ratio of 5.24, the amount of water produced per hour is obtained. Therefore, the water distiller will be able to produce an hourly yield of approximately 3.5 litres per hour, in regards to the yield of the kettle system shown. The water distiller also has a larger cooling solution, with 6m of copper piping as opposed to the 2m used in the experiment; this will further increase water yield hence serves as a discrepancy in the above calculation of which was not accounted (desertsun02 2016). The temperature of the flame used in the case of the oil drum will also greatly affect the rate of evaporation of the water. Consequently, it can be inferred that yield is largely dependent on maintaining the rate of evaporation of the water and the effectivity of the cooling agent.

To determine the usefulness of the amount of water which is produced with respect to the inhabitants of an entire community, further calculations will be completed. Firstly, the recommended daily water intake is 1.9 L (Mayo Clinic Staff 2014). If the estimated yield of the water distiller is 3.5 litres per hour, the daily yield of the device would be $3.5 \times 24 = 84$ litres. By dividing this digit by the recommended water intake, $\frac{84}{1.9} = 44.2$, indicating the distiller should be able to provide enough distilled water for around 44 people per day for drinking purposes alone. Depending on the size of the village this device is implemented in, more distillers can be constructed to provide a greater yield to satisfy the village's needs. For example, a village with a total population of two hundred people should construct three water distillers following these guidelines. Although these calculations only provide an approximate estimation of the devices water yield, it has proven to be useful in demonstrating the potential yield and effectivity of the final water distiller product.

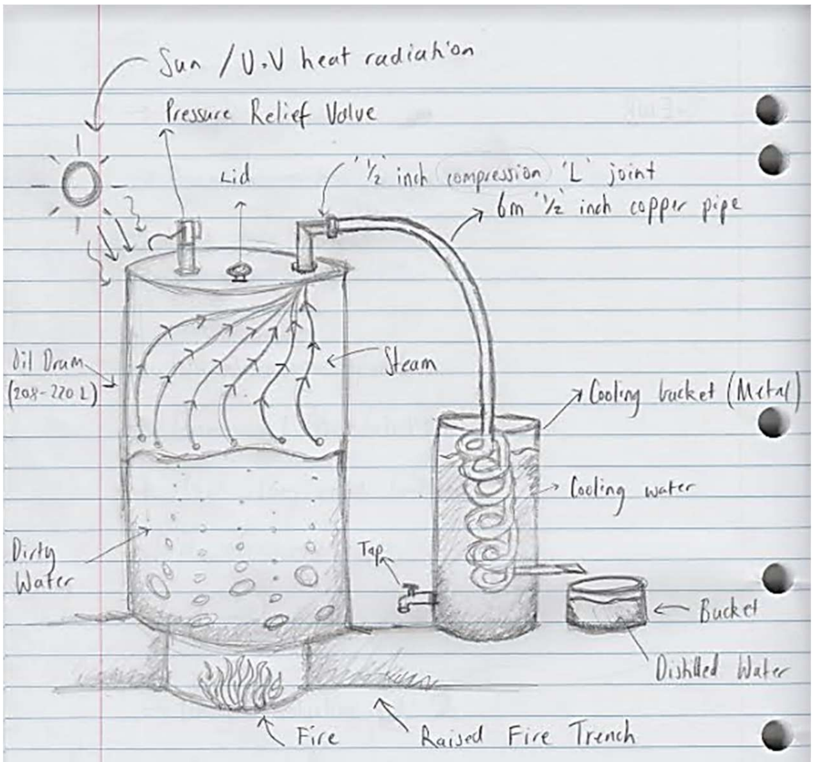
5. Final Design Presentation

4.1 Technical Design

4.1.1. Introduction

The final design solution involves an upgrade to durability, efficiency and safety of the Water Distiller. To prevent an explosion from occurring due to the failure of the oil drum to harness the internal pressure created, a pressure relief valve has been incorporated to prevent such circumstances. The copper piping is now connected to the drum via brass compression L joint, allowing the pipe to easily be removed for drum maintenance. Connection joints have been reinforced using plumbing solder as opposed to clay, to ensure that the joints are strong, airtight and durable. The copper piping cooling solution now functions on a combination of both air and water cooling. 2m of piping is exposed to air before the tubing is coiled into a bucket full of cold water. This will ensure that no excess steam is lost due to ineffective cooling. The bucket is soldered at the copper pipe connection joint to also ensure durability. At the opposite end of the bucket, a tap has been installed to allow for water within the bucket to be drained and replaced with fresh cold water, keeping in mind this water does not have to be filtered, it merely acts as a heat transfer across the copper piping.

Figure 5.1: Final Design (Sketch)



Advantages to system:

- Increased yield over previous design solutions due to elaborate cooling solution.
- Safe to function due to the incorporation of the pressure relief valve.
- Easy to maintain due to the compression joint functionality and included tap.
- Durable; made entirely out of metal.
- Easy and safe to collect distilled water at the end of cycle.
- Weather resistant due to raised fire trench (consult manufacturing procedure for further information.)

Disadvantages to system:

- Expensive compared to the other systems due to extra plumbing materials required
- Slightly more complicated to build as opposed to previous design solution
- Availability of materials may be of concern

4.1.2. Materials

- 6m of ½ inch copper piping
- 55-gallon oil drum
- Pressure relief valve (172.4 kPa)
- ½ inch brass compression L joint
- 20 L Metal bucket
- Tap
- 1 kg of salt
- Cloth / rag
- Plumbing solder

Equipment required to build water distiller

- Soldering iron / blowtorch / hot metal iron: for soldering joints
- Drill / knife: for puncturing holes
- Shovel / digging equipment: dig fire trench/ pit
- Optional equipment: file

4.1.3. Manufacturing Plan

Four main steps are required to build the water distiller. The steps have been categorised into the production of the three required segments; the drum, copper piping with cooling solution and the fire pit. The final step shown is the connection process of these 3 elements.

The fire pits dimensions are as shown in figures 5.1 and 5.2. The fire is raised to keep it from flooding during rain. To achieve this, mud was used to raise the level of the mid channel of the fire, reaching a height above ground level of 15 cm. The walls of the two channels were constructed using rocks as internal supports and compact mud to form the smoothed outside walls. The rock assists the channel walls in keeping shape under the force of the drum. These walls must be 25 cm high. A fire was then constructed in the middle of the channel, using coconut husks or firewood as fuel.

Figure 5.2: Fire Pit (Front View)

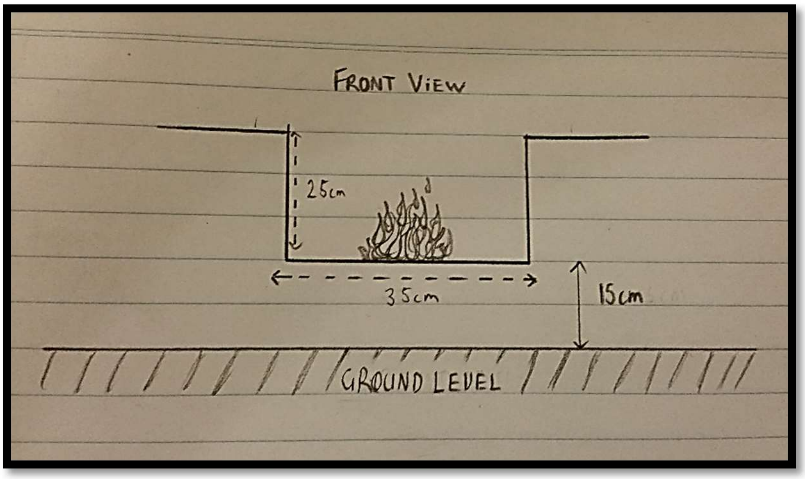
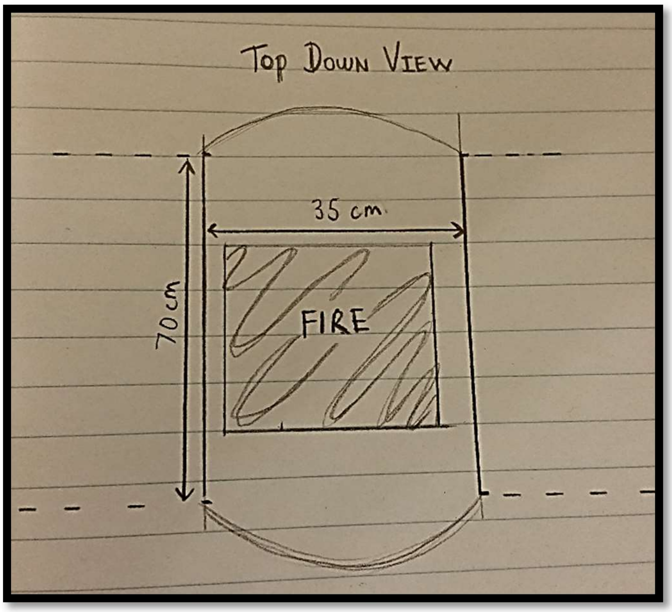


Figure 5.3: Fire Pit (Top View)

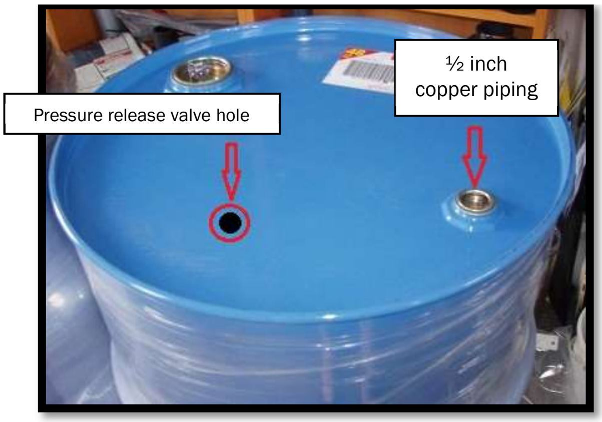


Standard oil drums are supplied with a lid and a breathing hole at the top of the drum. The breathing hole was used to mount the ½ inch or 1.27 cm compression L joint. With the non-compression joint facing downwards, the joint was inserted into the breathing hole of the oil drum, using a file to increase the size of the hole if needed. Once in place, a solder and a soldering iron was used to connect the drum and compression joint. This connection is demonstrated in figure 5.3.

Figure 5.4: Soldering

It was ensured that the screw on lid is in pristine condition, for steam must not escape from this point. An ½ inch or 1.27 diameter hole incision was made on the lid of the drum as shown in figure 5.4. The pressure relief valve was then placed into the hole and soldered which ensures an air tight and strong connection.

Figure 5.5: Oil Barrel Insertions

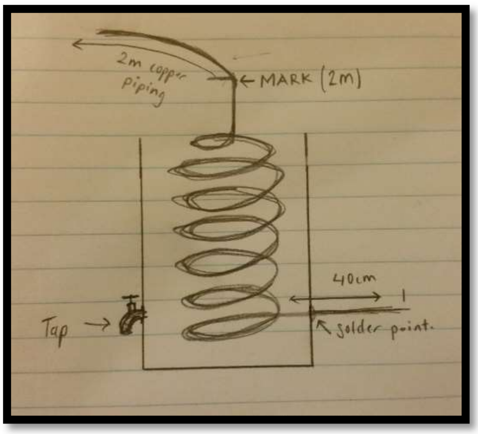


Starting from one end of the 6m ½ inch copper piping, a marking of 1.5 m in length was made. This is the point where the bending of the copper piping will begin. The copper piping was then filled with salt. The pipe was then gently tapped to ensure the salt filled all areas. The copper piping was then bent to coil around a coconut tree log after the marked point as seen in figure 5.5. The coiling diameter did not exceed 25 cm in order to fit into the metal bucket of the cooling solution. When approximately 40 cm of copper piping remained, the coiling was discontinued.

Figure 5.6: Coiling

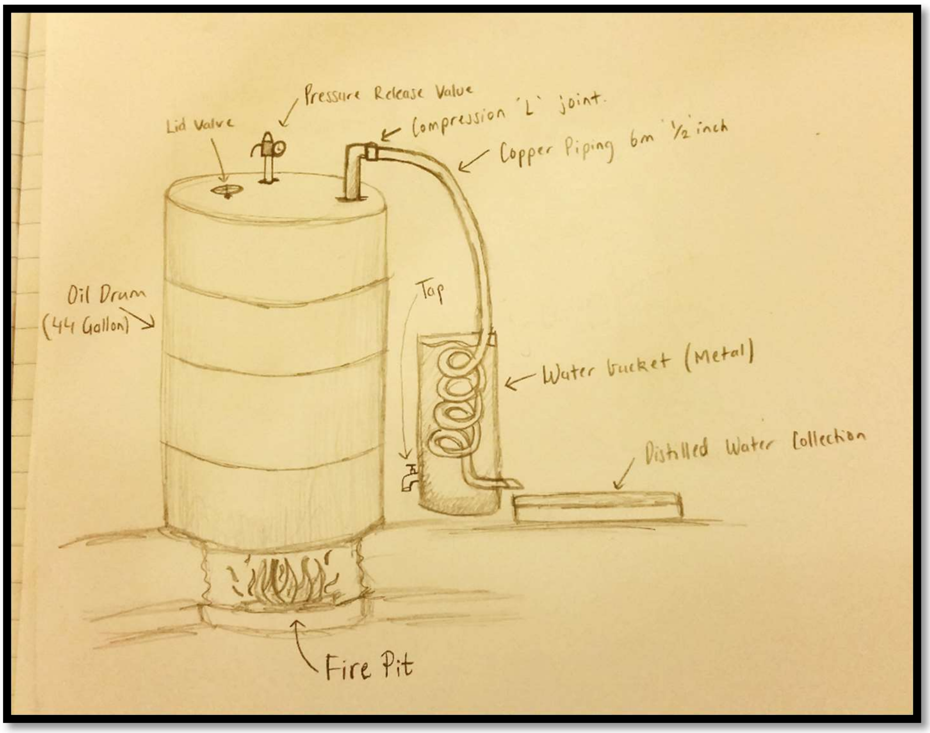
Three ½ inch or 1.27 cm in diameter holes were cut into either side of the metal bucket and at the top through the lid. Starting with the coiled end, the copper piping was then weaved through one hole. The remaining 40 cm pipe was soldered to the bucket hole ensuring water tightness. The ½ inch tap was then placed into the remaining incision which was subsequently soldered in place. Refer to figure 5.6 for a graphical representation.

Figure 5.7: Metal Bucket Placements

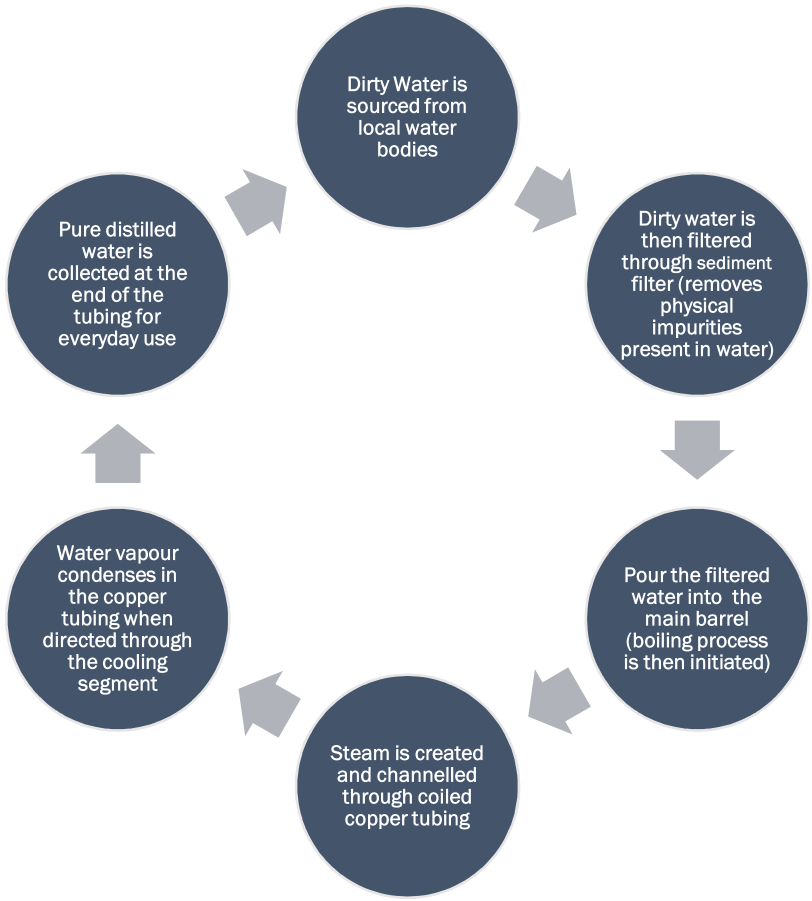


The oil drum was then firmly seated over the fire pit. The remaining 1.5 m of copper piping was then bent to reach the ½ inch compression joint previously attached to the top of the drum. Once in place, the nut of the compression joint was twisted until it firmly gripped the copper piping. The metal bucket was then filled with water (dirty or clean) to be used as a cooling agent. A thin rag / cloth was then placed over the lid opening of the oil drum. Unclean water was then poured through the same lid opening. Refer to figure 5.7 for a graphical representation.

Figure 5.8: Water Distillation Unit (Hand Drawn)



A block diagram which represents the manufacturing process has also been constructed:



Block 1: Dirty Water is sourced from local water bodies
Dirty water is collected from one of three main local sources and or to be later purified for safe use.

Block 2: Dirty water is then filtered through the sediment filter bottle

This process ensures that physical contaminants present in the dirty water are eliminated, and that the contents to be later evaporated in the main barrel consist of liquids only.

Block 3: Pour the filtered water into the main barrel (boiling process is then initiated)
The filtered water is poured into the main barrel and the boiling process is initiated by lighting a fire underneath the vessel. Upon reaching appropriate temperatures, the water turns into steam through the evaporation process.

Block 4: Steam is created and channelled through coiled copper tubing
Steam naturally rises, and is channelled through the coiled copper tubing (located at the top of the barrel) out of the container towards the cooling segment.

Block 5: Water vapour condenses in the copper tubing when directed through the cooling segment
Water vapour condenses inside the coiled copper tubing as it passes through the cooling segment due to the significant temperature difference.

Block 6: Pure distilled water is collected at the end of the tubing for everyday use
The condensed water (highly pure and fit for consumption) is then obtained from the end of the copper tubing by the local community and/or individuals.

4.1.4. Illustrations

Figure 5.9: Water Distillation Unit

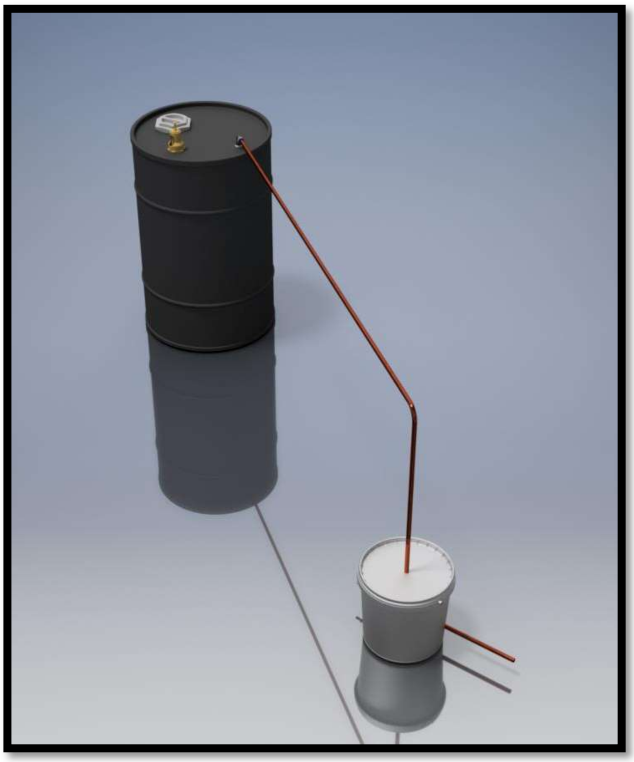
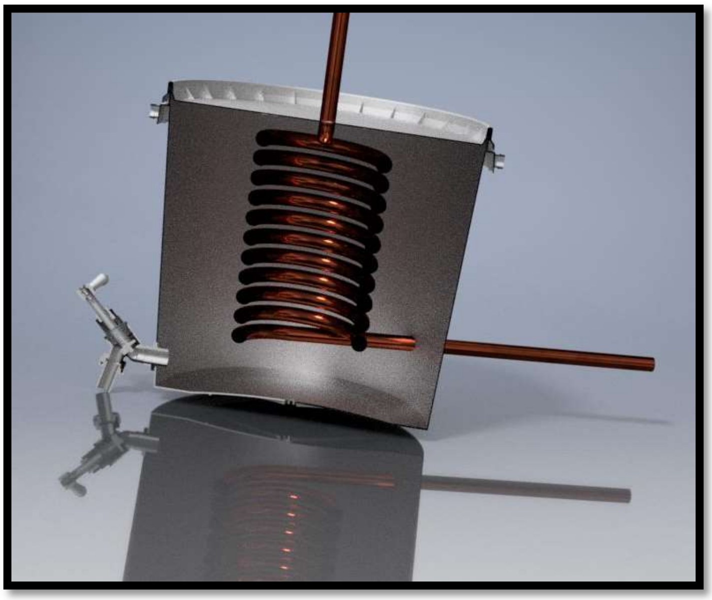


Figure 5.10: Oil Barrel & Components

Figure 5.11: Inspection of Pressure Release Valve, Water Input & L Fitting

Figure 5.12: Metal Bucket, Tap & Water Extraction (Copper Coil)

Figure 5.13: Sectional of Metal Bucket



Note: all dimensioned drawings have been placed in the appendix. Please refer to appendix 4.

4.2 Risk Assessment & Mitigation

The final water distillation unit involves a few operational health and safety issues that need to be addressed. This measure is undertaken to ensure that the safety of the user, and his/her environment can be maintained. Burn hazards are the most common risks involved with this design, due to which caution must be maintained before, during and after the operation processes have been initiated.

Due to the presence of an open fire (required for the heating of the main vessel), individuals behaving inappropriately in close proximity of the fire may incur skin burns. This is very unlikely to happen, but medical attention may be required when consequences like such are experienced. It is therefore strongly recommended that all members of the community maintain their distance, and also ensure that no flammable materials are left unattended near the fires.

As high temperatures are to be maintained for the water to boil within the main vessel, the tank itself and the copper piping are likely to become extremely hot (>60°C). This is primarily due to the thermal energy absorbed by the main tank from the open fire underneath, as well as the sunlight out in the open. Similarly, the copper piping is most likely to become hot from the channelling of steam away from the main vessel during normal device operation. In either of the cases, mishandling of the two design components are likely to burn individuals that are not cautious. Handling safety can be increased by wearing protective equipment, such as high heat resistance gloves, or by ensuring that temperatures of both components refrain from reaching such high temperatures; this may be done through the frequent monitoring of the temperature of such components. The system should subsequently be halted if such an extremity is foreseeable.

As mentioned previously, steam is an unavoidable component of the final water distillation unit. Water vapour, under high pressure, is regularly being channelled away from the main vessel through the copper tubing. Due to the presence of high pressures, safety must be maintained in case the main drum was to explode due to pressure accumulation and the failure of the pressure release valve. The likelihood of this occurrence is quite low, although such a consequence can be catastrophic. The risk can be minimised by performing regular checks on the installed pressure valves when the device is not in operation; it is not the drum explosion itself that is of high concern, but the high temperature of the steam to be released in case of an explosion. Being subjected directly to the hot high-pressure vapour can cause burns. To minimise the exposure, it is recommended that the operators of the device allocate appropriate cool down times to the system prior to handling. It is also recommended that the valve is facing away from the users when pressure is to be manually released.

Taking the recommendations into account, and appropriately following the procedures outlined in this report will ensure the safe functioning of the overall design. A numerical rating of the risk assessment in tabulated form is demonstrated as follows:

Table 5.1: Criteria of Risk

Level	Likelihood	Example Description
1	Rare	May occur in exceptional circumstances
2	Unlikely	Could occur at some time
3	Possible	Might occur at some time
4	Likely	Will probably occur in most circumstances
5	Almost Certain	Is expected to occur in most circumstances

Table 5.2: Criteria of Consequence

Level	Severity	Example Description
1	Insignificant	No injuries or financial loss, no inconvenience
2	Minor	First Aid treatment, minor inconvenience
3	Moderate	Medical Treatment required, some inconvenience
4	Major	Extensive injuries, Major inconvenience
5	Catastrophic	Death, Huge financial loss

Table 5.3: Numerical Assignments to Criteria of Consequence

Likelihood	Consequence				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Possible (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Rare (1)	1	2	3	4	5

Low Risk: 1 – 3 Moderate Risk: 4 – 5 High Risk: 2 – 10 Extreme Risk: 15 – 25

Table 5.4: Individual Risk Rating & Identification

Risk Involved	Likelihood	Severity	Risk Level	Risk Identification
Exposure to open fire	2	2	4	Moderate
High Temperature equipment	3	3	9	High
High pressure/temperature gas	2	3-5	6 - 10	High

Evidently, the risks which have been identified range from moderate to high. However, mitigations have been proposed and further design analysis may be completed to further amend the safety of the water distillation unit.

4.3 COST ANALYSIS

To advance the implementation plan of the water distiller, the total cost of the materials required to build the system must be estimated. The table below lists all components required to construct the device, as well as converted prices from AUD to VAV.

The conversion rate is shown in the table below.

Table 5.5: Cost of Materials & Components (AUD & VAV)

Component	Cost (AUD)	Cost (VAV)
Oil drum 55 Gallon empty	$15	1,208.04
6m ½ inch copper piping	$33.49	2,697.16
Pressure relief valve 25 PSI	$26.85	2,162.40
15mm inch brass compression L joint	$5	402.68
20 L used metal bucket	$5	402.68
Tap	$1	82.30
1 kg of salt	$1	82.30
Plumbing solder	$5.90	475.16
Cloth/ rag	$.50	40.26
Total	$93.74	7,552.98

Using these calculations, the total cost of materials for building the Water Distiller is an estimated 7,552.98 VAV.

For perspective, the average annual income in Vanuatu is less than $3,000 AUD. Converting that into VAV equates to 241,612.89 VAV annually. Given that the system has been calculated to be able to provide enough clean drinking water for around 44 people, the price of the components will be divided by 44 to calculate cost per person. If 44 community members each shared the cost of the materials required, the estimated cost would be equal to $\frac{7552.98}{44} = 171.66$ VAV per person. Evidently, it can be seen that a single water distillation unit is relatively affordable for the average Vanuatu resident. This conclusion however is subjected to several other factors in rural communities such as the volume of employed residents and wage earnings and therefore change accordingly.

4.4 IMPLEMENTATION

The implementation of the final design option and subsequent longevity across the Espiritu Santo island of Vanuatu is a critical factor to consider in guaranteeing the utmost success and use of the product. Subsequently, several guidelines for implementation have been devised and recommended.

The focus of any implementation plan into a rural community places aspects such as education, communication and community involvement at the paramount of concerns. Conveniently, a previously constructed program which focuses on improving the overall water quality and health of water resources has been implemented and is currently operating; Water Safety Plans (WSP) which is the operation of the World Health Organisation is a risk assessment and management approach to ensure clean drinking water for all of Vanuatu. This program was introduced to pacific island countries in 2005 and upon the gathering of 18 of such countries, a "Framework for Action on Drinking Water Quality" was forged; this was later expanded upon and funded (Nath, Mudaliar et al. 2006).

There are currently several steps to develop and subsequently implement a water safety plan of the assortment which was aforementioned. The first of which involve forming a group which will provide the driving force and direction for the plan; some organisations which were previously involved were the Department of Geology, Mines and Water Resources, Ministry of Health, Public Works Department, Meteorological Department and the relevant Provincial council (government), Live and Learn, UUNELCO and several NGOs. Some of these organisations in conjunction with the efforts of Engineers Without Borders may rally behind a similar WSP (Nath, Mudaliar et al. 2006).

Subsequent is the system description and analysis; in this section, a description of the water distillation unit and its relevant elements such as processes and purposes may be proposed. Shortly proceeding such is the tools, developments and pilot activities which must be outlined. Furthermore, the appropriate volumes of designs and materials for distribution to each community in need should be organised. Furthermore, education regarding the safe use, maintenance, mechanism understanding and sustainability of the product should be considered for the communities as a piloting activity. This will allow the community to understand the use and function of the water distillation unit (Nath, Mudaliar et al. 2006). Evidently, the driving organisations may distribute volunteers to run relevant education and interaction for each community.

Once the resources have been organised and distributed, the driving WSP organisations will monitor the progress of each village throughout the process of integrating the water distillation unit into their community; from the construction of the unit until further usage, with maintenance checking at least every 3 months. This will ensure the community understands the device and its usage and also maintain its sustainability for future usage.

Please refer to appendix 4 for work breakdown structure and GANTT diagram.

6. Conclusion & Recommendations

The final proposition of the water distillation unit yielded several valuable elements which will prove as effective in water purification. The most notable of which is the purified water quality, efficiency and therefore pure water yield, relatively safe functioning nature, maintainability and durability.

Firstly, the quality of purified water due to the distillation unit is notable as it purifies water to a safe drinking standard. As evidenced in the introduction, the unclean fresh water sources of Espiritu Santo contain pathogens, nitrates and fluorine; the remaining sources which are of the salt water variety evidently contain large concentrations of salts. These qualities of the local water sources deem them unsafe to drink. Therefore, the main function of the water distiller is to remove such impurities. The distiller utilises a pre-treatment phase of a sediment filter to remove large particles such as dirt and rocks directly from the water source, subsequently removing salts and other harmful bacteria through the process of evaporation and condensation. The result of the process is water which is purified to a standard which is safe to drink as according to the proposed research. Therefore, this ascertains the quality of the water distillation unit.

Similarly, the efficiency of the water distiller is a notable feature. Through the use of an intense and elaborate enclosed evaporation and cooling system and an expanded surface area of evaporation, the unit is able to remove impurities post pre-treatment at effective rates as demonstrated through the trial experiment comparison. Consequently, this reaffirms the quality of the design.

Furthermore, maintainability and durability of the final design is a significant achievement. The use of high quality and durable materials such as steel in the oil drum and high-heat resistant copper in the piping and coiling will allow for the water distillation unit to be repeatedly used.

Although there were several achievements worthy of recognition, there were also attributes of the final design which could be amended to improve its overall quality; some of which include the safety and cost of the design and overall impacts.

A key environmental impact of the final design is the use of the fire in order to evaporate the unclean water in the oil barrel. Not only does this pose as a safety threat to the users but also may cause local environmental deterioration through the use of firewood (such as deforestation). This however may be mitigated through the use of waste materials such as coconut husks and paper.

Such a design has allowed for the retrofitting of further improvements in the future. As a result, amendments for the issues discussed above may be made promptly and with ease.

7. TEAM REFLECTION

The Engineers Without Borders: Live & Learn Vanuatu Challenge has provided as an excellent first-year university project to which students were confronted with real world problems; upon which they needed to assess the issue and conceive a viable solution for the third world community at focus. Group 2 of tutorial 7 was tasked with creating such a solution to the lack of clean drinking water apparent in the communities of Espiritu Santo. Although our group performed valiantly, efficiently and cooperated well within the group, there were complications which hindered the quality of our final product. Consequently, we reflected and devised precautions which we would take in future similar circumstances.

In the overall scheme of the project, our group performed well in several aspects. Firstly, all team members cooperated in order to complete the prioritised work necessary to reach deadlines throughout the project; this includes the information seen in presentations and sections of the body of the final report. This indicated that all members treated their assigned tasks with the utmost of priority. Although this was the case, some work was completed to a substandard and therefore required editing and or extensive proofing by other members.

In order to ensure the relevance and holisticness of the response, we held frequent group meetings to exchange ideas and feedback to each other. This was highly relevant in sections such as the initial design phase and the assessment of the focus environment as seen in the introduction of this document.

This was only possible however through the dynamics of the team; each team member offered their strengths such as experience in the design process, computer aided drafting skills and report writing. Consequently, the group leader was able to delegate tasks to members according to such strengths. In doing so, not only was time saved but the process of creating the solution and accompanying deliverables was also made more effective.

There were several adjustments which were needed throughout the project to accompany for changing group dynamics such as the absence of certain group members and hence workloads. This was evident when a group member was absented during a section of the project task timeline; as a result, other members needed to increase their workloads to compensate for this minor change in dynamic. This helped to improve the skills which such group members were lacking and had minimal effect to the overall timeline of the project. A change such as this if strategically dealt with could be avoided in the future.

Although the final result of the project was according to standard, there were other aspects which could be strategically dealt with in the future to ensure a better experience and overall report quality; the most affecting of which was the lack of team co-ordination and participation by select team members. This was primarily due to either a lack of engagement or a mismatch in skill to task assignment. Therefore, this could be amended in the future by more critically assessing the skills of each team member and subsequently assigning skill relevant tasks for such members to complete. In order to ensure this and any other issue is highlighted, a more frequent communication channel across at least three different platforms should be established by all group members; this will also ensure that all group members have ease when needing to participate in group discussions or share ideas. Finally, a better engagement and dedication in the project timeline process was lacking in our teamwork. Through introducing the aforementioned strategies and internally set deadlines throughout the project, the group would be more inclined to complete the work required to standard and would have time left to revise such work.

Throughout the project, our team was challenged with applying ourselves to a real-world issue and addressing this issue with a viable solution. We co-operated to complete prioritised work to reach deadlines, exchanging feedback and sharing ideas. The overall team dynamic progressed smoothly with minor changes which were quickly mitigated. We encountered complications such as team member engagement and lack team co-ordination at some points during the project; at which point we learned and strategized for the future. In doing so, we decided that more frequent communication, better engagement to the project timeline and a more critical assessment of group member skills for better fitted tasks was necessary for a more successful project.

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APPENDICES

APPENDIX 1

Figure 9.0.1: Historical Climate Data of Luganville, Espiritu Santo

CLIMATE TABLE // HISTORICAL WEATHER DATA LUGANVILLE

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	26.4	26.5	26.4	25.8	25.1	24.6	23.9	24	24.3	25	25.7	26
Min. Temperature (°C)	23.1	23.1	23.2	22.7	22.1	21.7	21	20.9	21.4	21.8	22.4	22.7
Max. Temperature (°C)	29.7	29.9	29.6	29	28.2	27.5	26.9	27.1	27.3	28.3	29	29.4
Avg. Temperature (°F)	79.5	79.7	79.5	78.4	77.2	76.3	75.0	75.2	75.7	77.0	78.3	78.8
Min. Temperature (°F)	73.6	73.6	73.8	72.9	71.8	71.1	69.8	69.6	70.5	71.2	72.3	72.9
Max. Temperature (°F)	85.5	85.8	85.3	84.2	82.8	81.5	80.4	80.8	81.1	82.9	84.2	84.9
Precipitation / Rainfall (mm)	298	295	316	266	196	159	99	90	100	161	177	234

The difference in precipitation between the driest month and the wettest month is 226 mm. The variation in annual temperature is around 2.6 °C.

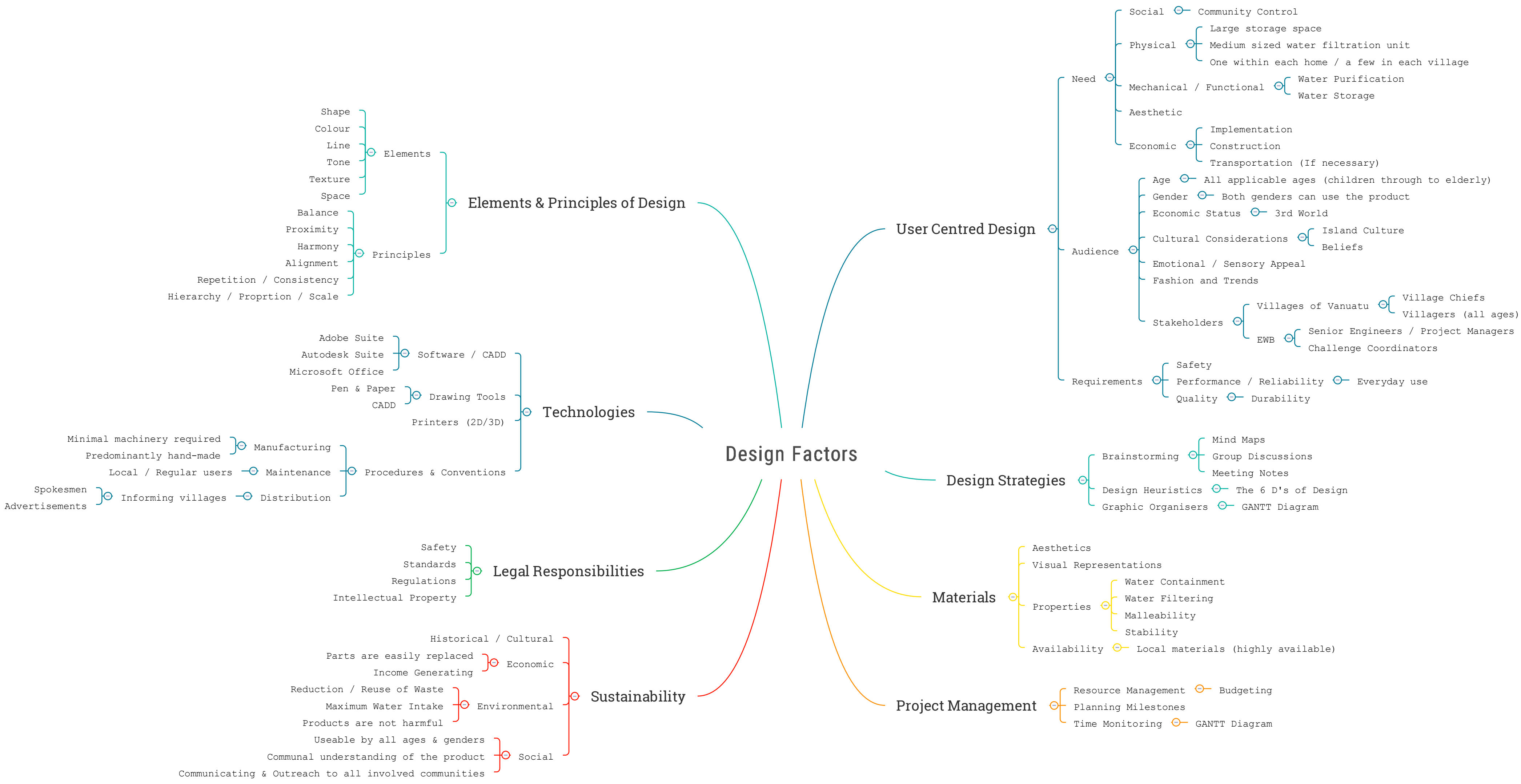
(Climate-Data.Org 2017)

The following appendices have been inserted in the following order:

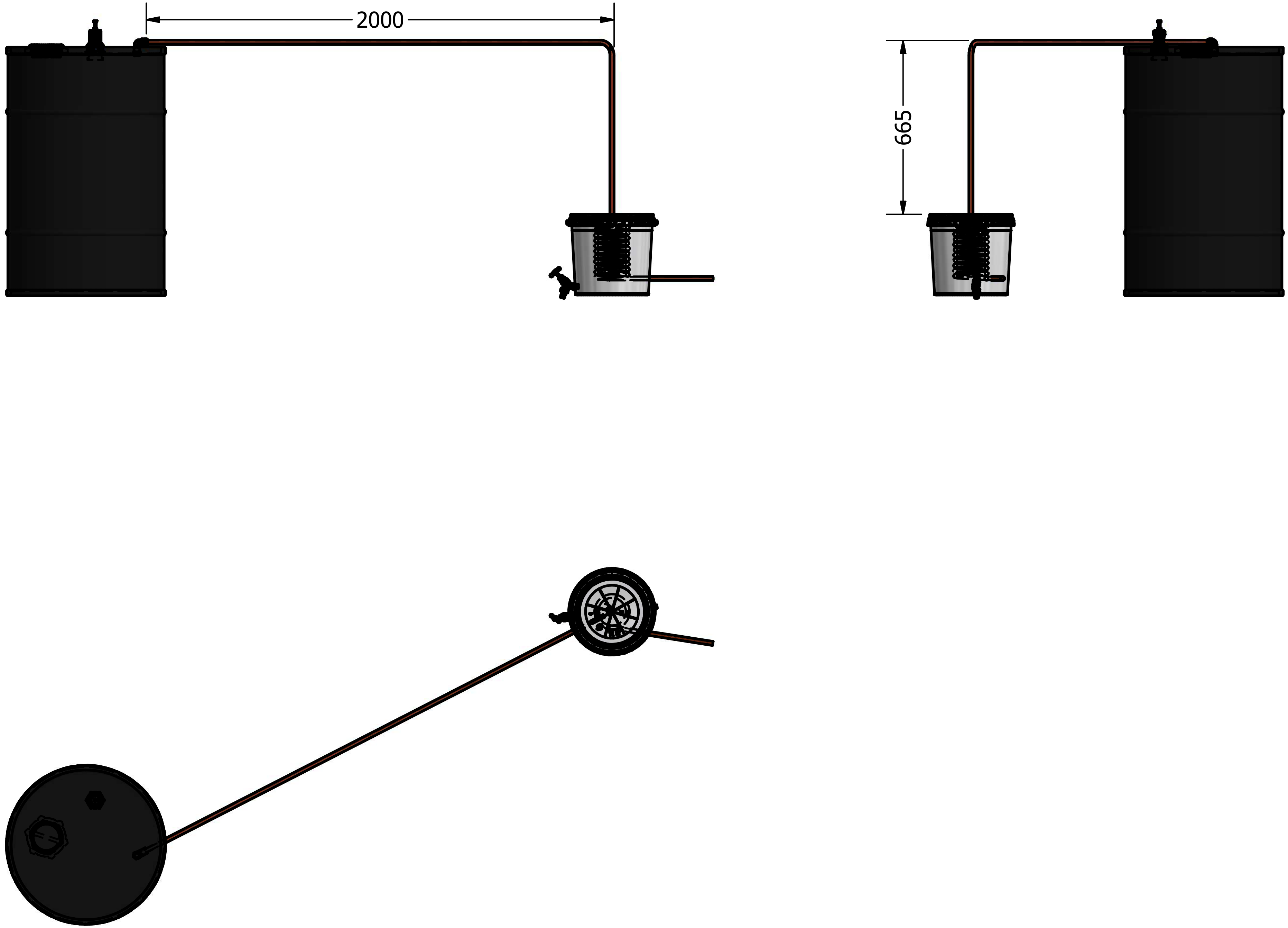
APPENDIX 2
Design Factors Tree

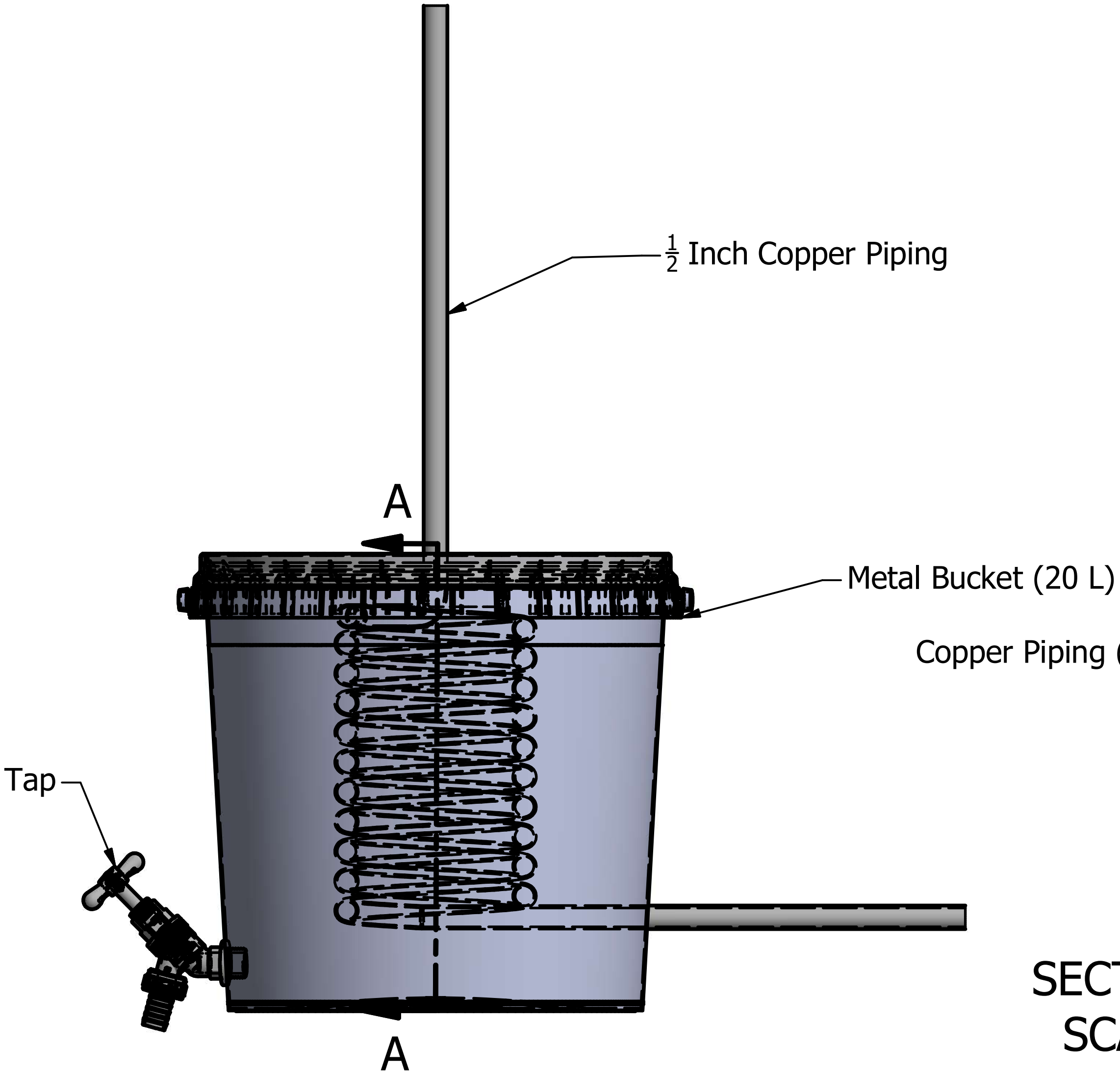
APPENDIX 3
Technical Drawings

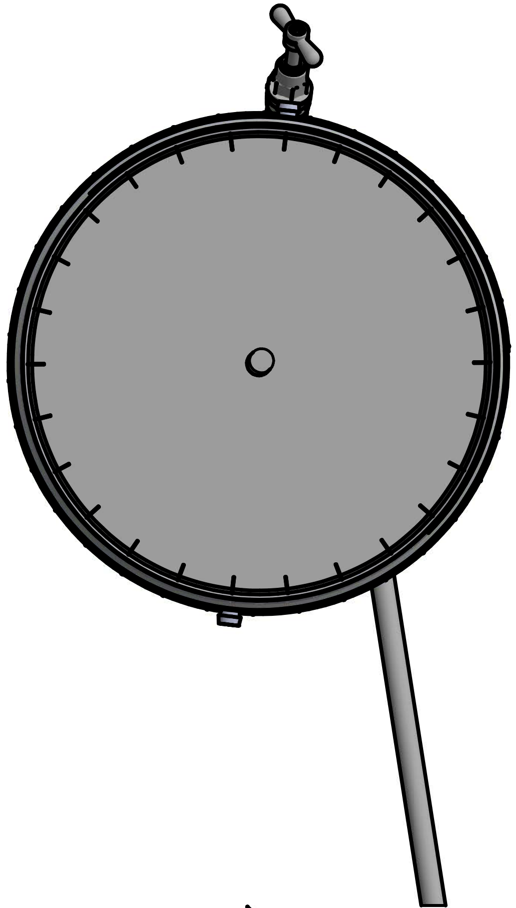
APPENDIX 4
GANTT and Work Breakdown Structure for implementation plan

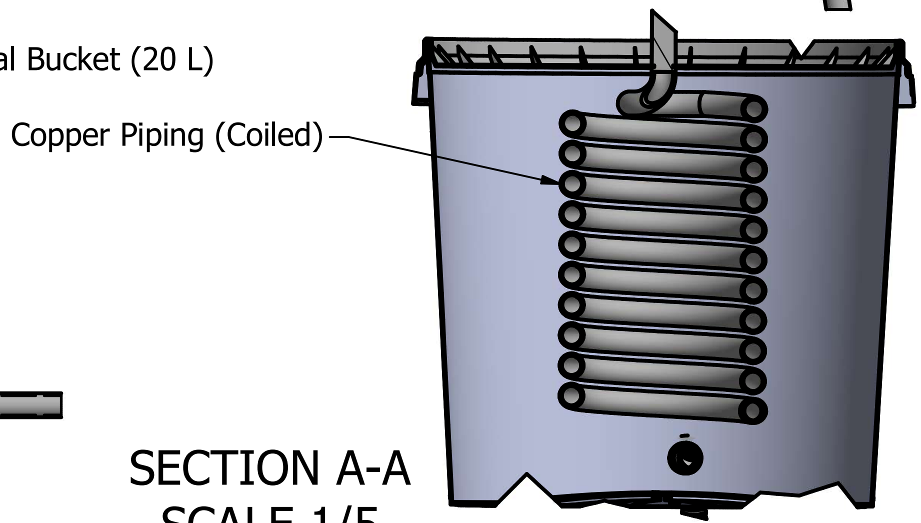


Design Factors
User Centred Design
Need
Social
Community Control
Physical
Large storage space
Medium sized water filtration unit
One within each home / a few in each village
Mechanical / Functional
Water Purification
Water Storage
Aesthetic
Economic
Implementation
Construction
Transportation (If necessary)
Audience
Age
All applicable ages (children through to elderly)
Gender
Both genders can use the product
Economic Status
3rd World
Cultural Considerations
Island Culture
Beliefs
Emotional / Sensory Appeal
Fashion and Trends
Stakeholders
Villages of Vanuatu
Village Chiefs
Villagers (all ages)
EWB
Senior Engineers / Project Managers
Challenge Coordinators
Requirements
Safety
Performance / Reliability
Everyday use
Quality
Durability
Design Strategies
Brainstorming
Mind Maps
Group Discussions
Meeting Notes
Design Heuristics
The 6 D's of Design
Graphic Organisers
GANTT Diagram
Materials
Aesthetics
Visual Representations
Properties
Water Containment
Water Filtering
Malleability
Stability
Availability
Local materials (highly available)
Project Management
Resource Management
Budgeting
Planning Milestones
Time Monitoring
GANTT Diagram
Elements & Principles of Design
Elements
Shape
Colour
Line
Tone
Texture
Space
Principles
Balance
Proximity
Harmony
Alignment
Repetition / Consistency
Hierarchy / Proprtion / Scale
Technologies
Software / CADD
Adobe Suite
Autodesk Suite
Microsoft Office
Drawing Tools
Pen & Paper
CADD
Printers (2D/3D)
Procedures & Conventions
Manufacturing
Minimal machinery required
Predominantly hand-made
Maintenance
Local / Regular users
Distribution
Informing villages
Spokesmen
Advertisements
Legal Responsibilities
Safety
Standards
Regulations
Intellectual Property
Sustainability
Historical / Cultural
Economic
Parts are easily replaced
Income Generating
Environmental
Reduction / Reuse of Waste
Maximum Water Intake
Products are not harmful
Social
Useable by all ages & genders
Communal understanding of the product
Communicating & Outreach to all involved communities

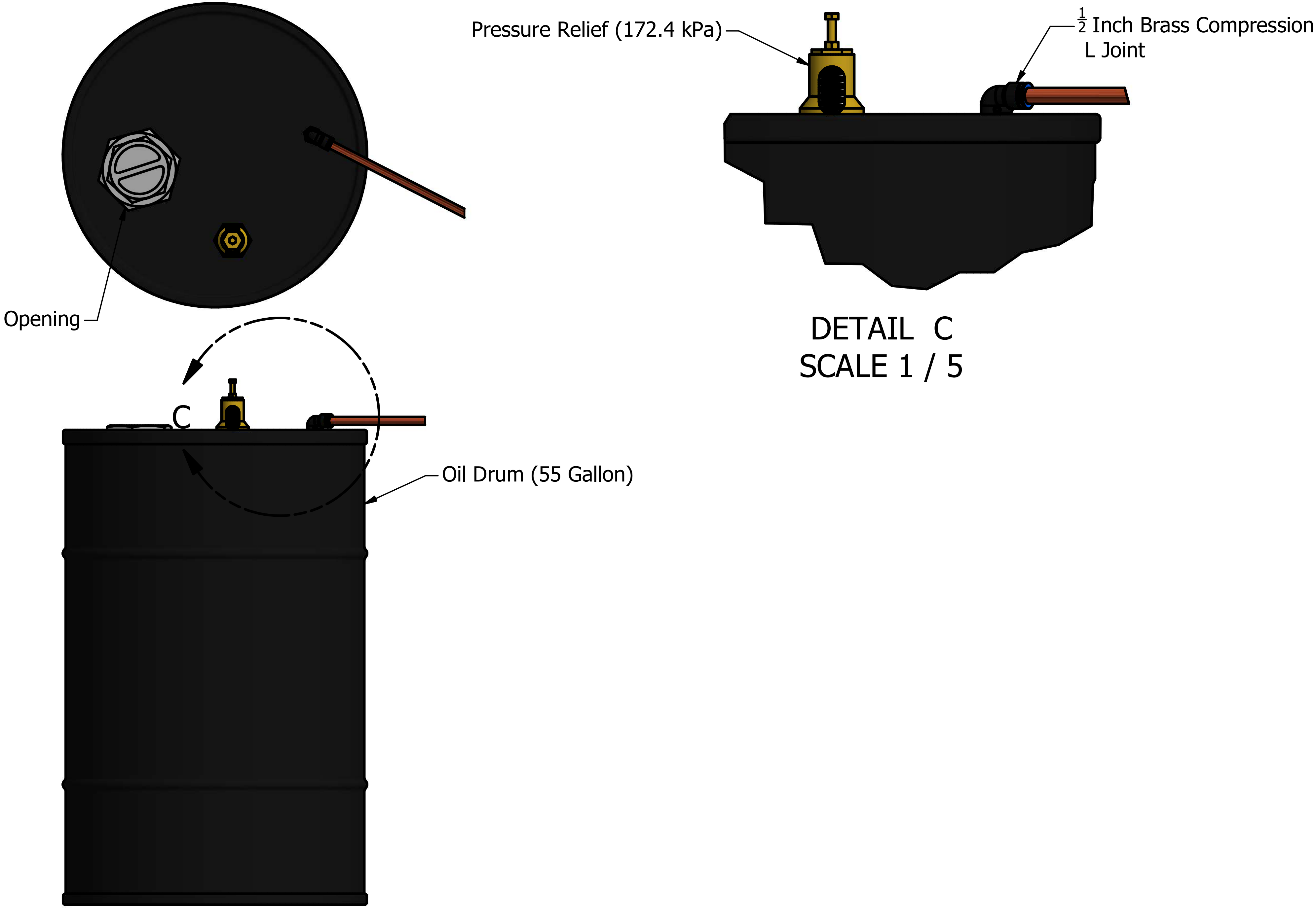

2000
665







SECTION A-A
SCALE 1/5

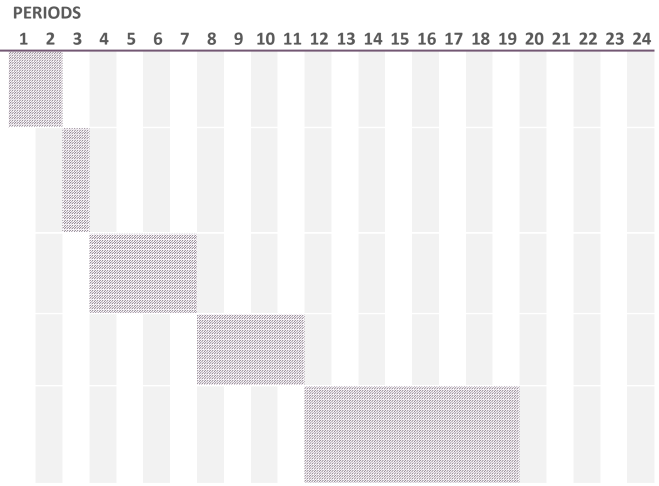

Pressure Relief (172.4 kPa)
$\frac{1}{2}$ Inch Brass Compression L Joint
Opening
C
Oil Drum (55 Gallon)
DETAIL C
SCALE 1 / 5

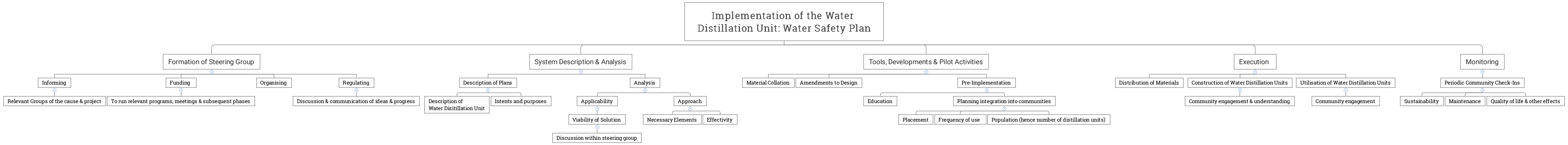
Implementation of the Water Distillation Unit: Water Safety Plan

1 Period = 1 Month

Period Highlight: Plan Duration

ACTIVITY	PLAN START	PLAN DURATION
Formation of Steering Group	1	2
System Description & Analysis	3	1
Tools, Development & Pilot Activities	4	4
Execution	8	4
Monitoring	12	8




Implementation of the Water
Distillation Unit: Water Safety Plan
Formation of Steering Group
Informing
Relevant Groups of the cause & project
Funding
To run relevant programs, meetings & subsequent phases
Organising
Regulating
Discussion & communication of ideas & progress
System Description & Analysis
Description of Plans
Description of
Water Disitillation Unit
Intents and purposes
Analysis
Applicability
Viability of Solution
Discussion within steering group
Approach
Necessary Elements
Effectivity
Tools, Developments & Pilot Activities
Material Collation
Amendments to Design
Pre-Implementation
Education
Planning integration into communities
Placement
Frequency of use
Population (hence number of distillation units)
Execution
Distribution of Materials
Construction of Water Distillation Units
Community engagement & understanding
Utilisation of Water Distillation Units
Community engagement
Monitoring
Periodic Community Check-Ins
Sustainability
Maintenance
Quality of life & other effects