Lydia Kavanagh
ENGG1100 project team leader
The University of Queensland
St Lucia
QLD 4072

Dear Lydia

With due respect we, PO6 Black, submit herewith a proposal in support of *Engineers Without Borders Challenge*; focusing on creating a solution to fresh water scarcity in East Santo, Vanuatu.

We have designed and constructed a modular water treatment system to purify hot spring water in East Santo, Vanuatu to be readily available for human consumption and use.

We have also incorporated a community engagement plan into our proposal that involves face-to-face teaching, an information booklet with diagrams, a designated community member testing the water and 6-month check-up visits to the community by a member of our company.

We hope that you will find this proposal worth reading. Please feel free to contact us for any clarification or enquiries that you would like us to further explain.

Thank you for your time, your consideration of this proposal is greatly appreciated.

Yours sincerely,

PO6 Black

2017

Final Report

P06 BLACK

Executive Summary

An outline of the guidelines, solutions and recommendations for a water treatment system that will be implemented in Vanuatu is provided in the following proposal. Background information about the East Santo community and the innovative water system design was acquired from a variety of sources such as journals, reports and online resources.

The information given outlines the requirements needed for this design:

- The system must produce enough water for a community of 50 people;
- It must take into consideration the rural location;
- The system must be cost efficient;
- It must take into consideration the context of the situation such as the social, technical and economic issues in the area; and
- The lower education levels of the community.

Possible designs that were suitable for the community were assessed using the following criteria:

- The input and output of the design;
- The sustainability of the design;
- The cost of installation and maintaining; and
- The impacts on the community and environment.

Using a decision-making matrix, it was found that a filtration and distillation system would be the most appropriate design according to the decided criteria. The final design was a rapid sand filter that was then linked to a solar still basin which was based on the following background research.

1.1 The water will first pass through a slow sand filter where the primary purpose will be to decrease the turbidity of the water by filtering out >95.4% of suspended solids

1.2 A distillation unit will then filter out the dissolved solids that need to be removed from the water with an estimated 99% efficiency

It is estimated that the filter will produce 12.5L of clean water per day, sufficient for a household of 5 people if it operates for at least 8 hours per day.

A waste management system has been devised that involves the storage of waste in plastic drums during the dry season. Then, during the wet season, the waste water will be released into the flooding waterways where the high salinity will have a negligible effect considering the vast amount of water flooding through the system. From calculations, the system is expected to produce 10.33L of waste from the community per day.

It is also recommended that to improve the community's engagement and understanding of the project, the community should give feedback on the design which will also improve the systems proposed design. There will be visits to the community every 6 months for this purpose. Furthermore, the committee of population planning and community development should be contacted as to improve understanding of the system and the implementation of the design.

The cost of the prototype is ($60.92 AUD) which is for a 5-person household. This equates to $609.20 for the community of 50 people.

The estimated lifetime of the prototype would be approximately 5 years. There is no ongoing electricity or running costs as it utilizes solar energy (as it is only required during the dry season) which makes it much more economically sustainable than systems powered by generators or gas burners. Maintenance is minimal, as the system just needs to be flushed every fortnight and the community would be taught how to do this so that this didn't occur any extra costs. With this lifetime and no running costs, the cost would work out to be $12.18 per household per year which is a reasonable cost considering the average monthly savings of households is approximately $120.80 AUD according to the Vanuatu National Statistics Office.

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1. Introduction

1.1 Background

A recent report by the United Nations Children's Fund (UNICEF) and the World Health Organization (WHO) showed that 663 million people worldwide still lack improved drinking water sources (UNICEF, WHO, 2015). There is evidently a great need to bridge the gap in many countries. This gap includes the availability of drinking water for urban and rural dwellers and the different socio economic groups as it has a large impact on quality of life. Vanuatu is a country that comprises of more than 80 islands with a current population of approximately 250,000 people (Advameg 2017). With 80% of the population living in rural areas with the rest in tourist areas, it is difficult for many people to have clean water throughout the year because of the seasonal changes (Vanuatu National Statistics Office, 2010).

The main water sources currently utilized in East Santo are rainwater which is stored in tanks and water collected from wells and rivers. There are also hot springs at various location across East Santo that could provide water without requiring travel time, however the water has a high salt content and subsequently hasn't been fully utilized previously. An effective way to solve the low availability of potable water would be to exploit these nearby hot spring sources and provide a purification system for the community.

1.2 Objectives & Aims

The objective of the project is to create a water treatment system for the East Santo Communities in Vanuatu that can purify hot spring water to potable water standards according to WHO requirements. This is so the community members can exploit the nearby hot spring water sources. This will decrease travel times to collect water from the river each day and increase quality of life for the community. The goal of the designed water purification system is to be appropriate for Vanuatu. The following is a list of requirements that must be met:

- Must be socially, culturally and economically appropriate;
- Can produce water for a community of 50 people (2.5L/person/ day);
- Meet WHO's water quality standards;
- Can dispose of or reuse the waste products of the system; and
- Have no significant negative impact on the environment.

1.3 Contents

The following report is set out in sections regarding various topics:

- The first is section 1 regarding the various topics and introducing the overview and aims of the project, the problem definition and the scope.
- Section 2 follows and contains the literature search of existing systems and an analysis of the appropriateness of the design for Vanuatu.
- Section 3 is the decision-making matrix that details how the system was chosen.
- Section 4 contains the feasibility calculations including mass balances and cost calculations
- Section 5 is the design details and concepts, drawings and justifications.
- Section 6 contains the technical understanding and sustainability considerations.
- Section 7 has the community engagement plan, final conclusions and recommendations for the system for the next steps that should be taken to improve the design.

1.4 Problem Definition

This project aims to purify hot spring water during the dry season in Vanuatu. The dry season that lasts for eight months in East Santo requires communities to minimize water usage as to not waste supplies (Davendra Nath 2006). The designed system will treat hot spring water so that it is compliant to the water regulations set by WHO (refer to Appendix 15.7) and so that drinking water is readily available during the dry season. This system will need to be environmentally and culturally suitable as well as cost efficient.

1.4.1 Design Problem

East Santo (the East side of the island of Espiritu Santo in Vanuatu) has low availability of drinking water and the water sources are very dependent on the season. The water sources in East Santo include rainwater (stored in tanks), wells, springs and rivers. During the three-four month dry season water is tightly managed and used sparingly. Members of the communities use seawater to bath and wash clothes to allow for rainwater supplies to be used only for drinking and cooking. (EWB,2016)
A 2010 reports outlines that in Vanuatu, 37% of rural and urban households had to travel to get water; and of the 18,920 households where members had to travel to get their drinking water, 81% were in rural areas. (Vanuatu National Statistics Office, 2010) Water from the hot springs around East Santo could be utilised to provide accessible sources of drinking water, however there is a high salt content and other heightened levels of dissolved and suspended solids in the water that would need to be purified using a modular treatment device for it to be drinkable. A prototype will be created that purifies hot spring water to suitable parameters.

1.4.2 Outputs

The water must be treated to produce drinking water to WHO standards. Waste management protocols must be instigated as there is no formal or coordinated waste management system in place in East Santo. (Engineers without borders, 2017) Water needs to be tested to ensure it is safe and this needs to be well communicated to the community so they know it is safe to drink. The system will have to produce 0.5L/h for a 5-person household and 2.5L per person per day (12.5L total per day).

1.4.3 Functions

The functions of the modular treatment system will be:

- To treat hot spring water to produce drinking water to World Health Organisation standards
- Any waste products will need to be disposed of or reused and the system will have to be able to be operated and maintained by the community
- The water quality also needs to be easily tested
- The prototype needs to be portable and must maximise water recovery
- Use an alternative to grid power it power is required (solar power is available for purchase)

1.4.4 Constraints

- The water treatment system will need to treat sufficient water to supply the community of 50 people using a module approach (single 5 person household units that each provide 2.5 L/ per person/ per day) and treating roughly 0.5L/ hour
- The cost of the prototype must be as low as possible
- The size of the prototype must be compact to minimise material use
- Grid power can’t be used as this isn’t viable

1.4.5 Social issues

- A cultural factor considered when assessing the appropriateness of household water purification systems is that these systems will cause much less impact on the community in terms of noise pollution and an eyesore when compared to a large water treatment plant.
- A factor to consider is how the project will be implemented in a cohesive way with the community.

- Communities in Espiritu Santo generally have a community leader (Chief) who takes charge of guiding the community and encouraging development. (Engineers Without Borders, 2017)
- The Chief should therefore be consulted and included in the implementation phase as they could be an important leader in encouraging the community to use the technology effectively.
- The system needs to be maintained by the community which means that education levels of community members should be considered. On average, most females and males 15 years and over from rural Vanuatu have only completed Primary school and have not progressed to secondary school (Vanuatu National Statistics Office, 2010). Therefore, methods that are highly technical such as reverse osmosis that would require careful maintenance would not be the most feasible option

1.4.6 Environmental Issues/ Pre-Existing Water Sources

The availability of water in East Santo is highly dependent on the season. April/May to October is the "dry" season, when temperatures range from 18 to 28 degrees Celsius (Espiritu Santo Tourism Association, 2017). In the dry season water is managed carefully and used only sparingly, with rainwater generally only used for drinking and cooking. There are four main sources of water: rainwater ranks, wells, springs and rivers (Engineers Without Borders Australia, 2016). The wet season in Vanuatu is from January to March, and is also known as the cyclone season. A report by the Intergovernmental panel for climate change shows projections for the pacific including strong patters of climate variability, sea level rise and natural disasters and suggests low-lying remote communities are at highest risk. In Vanuatu, this risk is heightened by already low rural resilience owing to lack of infrastructure, social services, markets and income, lack of climate projections and information, etc. (Pacific Islands Applied Geoscience Commission, 2007) Vanuatu receives about 2-3 cyclones every season which also should be considered as it would not be logical to install a water treatment system that could be easily destroyed by an extreme weather event such as a cyclone.

This is another reason why modular devices are suitable (Climate of Vanuatu, 2007) Local materials will be used but only those that cause minimal environmental damage (e.g. sand and potentially coconut husks which are waste from the production of Copra). This is instead of using materials that would cause a significant negative environmental impact such as harvesting trees for fuel for heated distillation.

1.4.7 Economic issues

The 2010 Vanuatu Household Income and Expenditure survey outlines key characters of the population of Vanuatu, including that it is largely rural with 78% of people living in rural areas. It also estimates the average monthly income of rural households (such as those in East Santo) in Vanuatu at 79,500 VUV and monthly expenditure of rural households at 69,300 VUV which means that on average only 10,200 VUV is saved per month which is equivalent to $120.80 AUD (Vanuatu National Statistics Office, 2010). Consequently, the household treatment system shouldn't cost the residents much to maintain because their funds are very limited and if it was costly to purchase and/ or maintain they most likely wouldn't be interested in using it. Slow sand filters are relatively affordable as an average slow sand filter's construction cost ranges from US $15-$60, depending on materials chosen. Community motivation, distribution, education, and follow-up can add significantly to program costs. For Samaritan's Purse, the average overall cost is about $100 USD per filter, partly due to these extra costs.

However, in the long term it is cost effect as assuming it lasts 10 years and families filter 40 litres per day, the cost per litre of treated water is 0.068 US cents (Centre for Disease Control and Protection, 2014).

2. Project Scope

The scope of the project has been outlined in Table 2.1 as to ascertain what is in the scope of this project and identify what is not being addressed in this report.

Table 2.1 What has been defined as in scope vs out of scope

In Scope	Out of Scope
Easy maintenance and operation: instructions will be taught to community members with the aid of local translators and booklets	Providing translators is out of our scope- the community should provide
Generation of potable water	Collection of the water from springs
Usage of low-cost resources (under budget)	Buying the plastic drums to store the waste
Each household system should be suitable for 5 people	The maintenance over a long-time period – max 5-year time is long enough to consider
Process of reusing/disposing of produced waste	Removing viral and bacterial contaminants
Allow the water to be tested easily by the community	Building a testing kit is out of scope- it is more feasible to buy on effective one and have the community share it around
System for the storage of both spring and treated water: plastic drums will be used	Exact costs of sourcing materials/ transportation of materials are out of scope as predominantly local materials will be used

2.1 Assumptions

As seen in Table 2.1, assumptions of the design and the context of the situation have been identified and the associated effects have been understood. This is so a full understanding of the system and project can occur.

Table 2.2: A summarization of the assumptions and effects of the design scope

Assumptions	Justification	Associated Effects
That there are no biological or viral contaminants	The hot spring water reaches a high enough temperature that it kills the pathogens present	The system will not need to be able to remove viral contaminants
That the parameters of the hot spring water are consistently close to the values set	That depending on where the water is from these values will change so an average gives us a good estimate	Additional testing should be done as water from different springs could have extra contaminants
That there are no unexpected chemicals in the water	No chemical plants or industrial areas are around	No need to test for unexpected chemicals regularly
That materials are constantly available	Simple materials chosen- should be always accessible, also it is possible to import materials at any time but price may be high	Able to use the same chemicals and materials when and if they are replaced
That prices for materials won't change over time	For such simple materials, they most likely won't change significantly	Will not take into consideration inflation
That each person will consume 2.5 L/ day – not more or less	This is an average value	Don't need to adjust for people consuming different amounts
The system will only be used during the dry season	During the wet season there is plenty of rainwater to drink – they wouldn't need a purification device during the wet season	It is assumed that there is plentiful solar coverage during the days of the dry season (at least 8 hours per day) and therefore a solar still has been chosen

3. Literature Search & Prior Art

3.1 Overview

To obtain the WHO standards shown in Appendix 15.7, a combination of different water treatments is required. These will remove the contaminants such as total dissolved solids (TDS), sodium, and turbidity, resulting in drinking water for the community in East Santo. It was also discovered that taste is an issue and the community will be disinclined to drink it if the water tastes or smalls different from what they are used to (Engineers Without Borders, 2017). The spring water is high in salts and this highly contributes to why the Ni-Vanuatu aren't using it for drinking. Therefore, the design must remove a large quantity of salts to meet the community's requirements.

3.2 Water Sources

In East Santo, there are three main water sources available, rainwater, surface water and groundwater resources. Rivers and springs depend on the seasons and can often be found close to villages (Nath Davendra, 2006). This surface water is most likely contaminated by human or animal interactions. Rainwater is collected in tanks by individual households in the community. Furthermore, wells are built in rural places to assist in periods of low rainfall (Department of Economic and Social Affairs, 2009). If these wells are built away from contaminant sources, the water is mostly of good quality. The average pH of water in Vanuatu is 5.9, making it slightly acidic (A. Homm, 2008). This is below WHO standards as it can cause irritation and corrosion of the human body (Harvey, 2011). Taste is most important as even if the water is safe to drink, if it tastes unpleasant the community won't drink it, therefore heavy metals and salts need to be removed as these are the biggest affecters of taste (Nath Davendra, 2006).

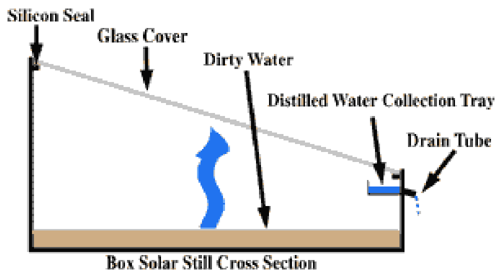
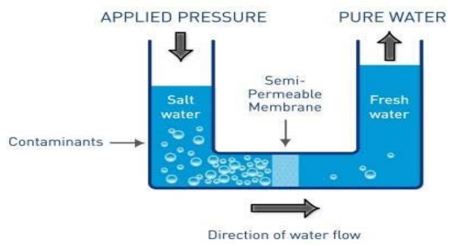
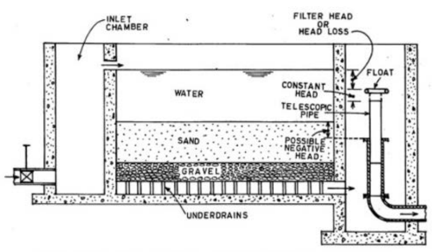
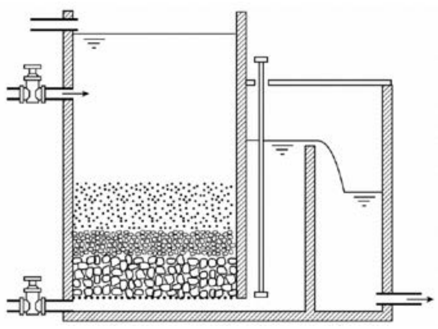
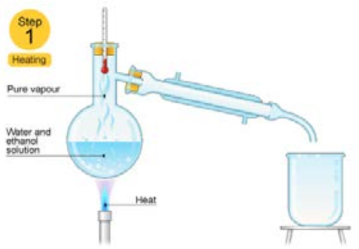
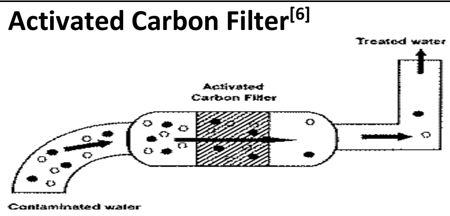
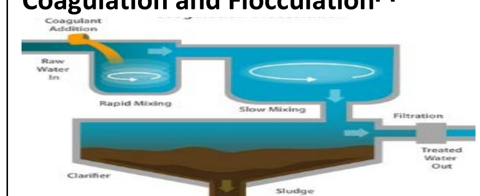
3.3 Water Testing

For water testing it is proposed that the village purchase litmus paper for pH testing, it is a cheap (around $2 for a pack of 30) reliable way to test the acidity of the treated water. For turbidity, sight will be used where an image is placed under a glass/clear container. If the image is easily visible, then the water is safe the drink. The main problem with the water was salts in the form of total dissolved solids, ideally the village should be able to purchase a conductivity, pH and TDS meter for water testing, they can be found between $20-300 AUD depending on quality (WaterQuality, 2009). Only one of these would be required as it could be shared by the community and due to the inexpensive cost of the cheaper types of TDS/EC/pH meters, villagers could purchase a personal meter if desired.

3.4 Existing Solutions

The main approach of treating water in Vanuatu is chlorination using sodium hydrochloride (NaHCl) that is kept in steel tanks which is slowly added to the water to treat for biological factors; this is a form of disinfection. This is mostly for rain and well water and to keep algae and other biological contaminants from growing in the storage tanks (Nath D., 2006). To extend from this technology there are several viable systems that could be used in this purification design. The context of the situation was taken into consideration with the cultural, economic and environmental effects being considerations into the most appropriate design. As seen in Table 3.1, many different options are discussed and compared in depth. The targeted-- purification method must include treatments that can remove the following pollutants: turbidity (suspended solids), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), chloride (Cl^-), and carbonates (HCO_3^-).

Table 3.1: Summary of Research on Existing Water Treatment Methods

Technology and Diagrams	Strengths	Potential Problems	Notes
Solar Distillation[1]  *Figure 3.1: Solar Distillation*	- Uses natural resources - Passive system with no moving parts that will wear out over time, making it a sustainable design - Cost effective as the system only requires natural sunlight - Removes TDS with boiling points over 100°C - Produces a pH of 7 - UV radiation kills any biological factors - No chemical waste or harmful by-products produced	- Produces pure H_2O which is unhealthy for human consumption as there are no minerals - Supply of sunlight energy may not always be available (cloudy or overcast) - Glass may be hard to come by in Vanuatu - The metal for the base may be slightly more expensive - Basin of the distiller needs to be flushed frequently to clean out excess salts left behind	This method can take a long time to produce a small amount of water hence it is not the most practical for Demo Day- if an external heat source was used it may be more applicable for demo day. Appropriate for Vanuatu
Reverse Osmosis[2]  *Figure 3.2: Reverse Osmosis*	- Removes biological factors, TDS and TSS - Less waste than distillation - RO is the dominant technology for large scale desalination	- Produces acidic water - Inefficient, 3 gallons needed to produce 1 gallon of clean water - High pressure needed - Materials are difficult to source in Vanuatu, also expensive - Lots of maintenance required - Highly technical process- doesn't fit lower education level of Ni-vans	Too expensive and not efficient enough for consideration at Vanuatu as it needs a constant supply of electricity- this is not an option, solar power could be considered but overall this is not an ideal technology. Not applicable to situation
Slow Sand Filtration[3]  Fig 6.19 Section of slow sand filter *(Source: Modi, 1998)* *Figure 3.3: SSF*	- Simple design made from easily sourced materials - Removes nearly all biological factors, turbidity and TSS - No energy required - Basic maintenance required - Small amount of water lost in filtration - Long durability - Highly reliable - No chemicals are needed, reducing the risk to the community and the environment	- Can become clogged if not cleaned regularly - Regular cleaning destroys the bio-layer - Water quality decreases if flow rate is too high - Constant water flow is required as to not dry out the bio layer - Slow sand filters take up large land space and requires large infrastructure - Long periods to produce water	Community may be hesitant to drink from a green slimy filter (algae bio layer) Over a longer time period the PVC shell will degrade. Not very practical
Rapid Sand Filtration[4]  *Figure 3.4: RSF*	- Same advantages as slow sand filters - Smaller land requirements as opposed to slow sand filtration - No limitations in relation to initial turbidity levels - Simple, quick backwashing cleaning process - Fast and efficient for filtration of larger particles	- Can become clogged if not cleaned regularly - Although backwashing is not time consuming it needs to be done frequently	RSF is basically a slow sand filter without the bio-layer and with less components. This causes filtration to be much quicker and only passes through layer of sand. As there are no biological factors in the water, this will be better suited to the project than a SSF. It is still very effective in the removal of turbidity It is also much smaller than a SSF Good practicality
Heated Distillation[5]  *Figure 3.5: Heated Distillation*	- Removes all TDS components which boil over 100°C - High temperatures kill any possible biological factors (bacteria, viruses and protozoan cysts) - Gives a neutral pH - No conductivity - No harmful waste produced	- Requires a constant heat source, which may be unavailable for village - Energy costs may become exceedingly high as the water needs to be heated with power - Produces pure H_2O which is unhealthy for human consumption	Faster than solar distillation, - as water is boiled and not naturally evaporated. More effective than solar over shorter periods of time. One of the most effectively technologies for producing purified water. Practical for Demo Day
Activated Carbon Filter[6]  *Figure 3.6: Activated Carbon Filter*	- Carbon filters are relatively inexpensive in countries with facilities to create them (would have to be imported to Vanuatu) - Removes ionic compounds such as salts	- Treated water may appear black due to the charcoal, not appeasing to drink although safe - Most likely needs to be imported - Components need regular replacement - High temperatures needed to make activated carbon	Removes salts and other ions from the water Black/dark water is not desirable to drink and has increased turbidity Cheaper than reverse osmosis to maintain, but distillation will remove ionic compounds more efficiently Not appropriate to project
Coagulation and Flocculation[7]  *Figure 3.7:Coagulation and Flocculation*	- Removes anions from water as well as bacteria - Both inorganic substances and bacteria can be removed from the waste source - Speeds up sand filtration process as it acts as a pre-treatment	- Chemical coagulants must be utilised during the process, which can be harmful to the community and environment in big doses - Requires electricity - Many mechanical components - Toxic waste and solids must be carefully treated	High costs in relation to the purchase of chemical coagulants and energy costs for electricity for flocculation process These contaminants can be removed using distillation instead, it also takes out more TDS. Not suitable for project

Footnotes

[1] – (Mehta, 2011) (Maehlum, 2013) [2] – (All About Water, 2004) (Australian Government, 2014) (History of Water Filters, 2014) (Kershner, 2008) (PureTec Industrial Water, 2013) [3] – (All About Water, 2004) (Bredero, 2003) (Australian Government, 2014) [4] – (Water Treatment, 2010) (BioSandFilter.org, 2004) (United Nations Environment Programme, 2011) (Bruni, 2012) [5] – (History of Water Filters, 2014) (Dvorak, 2013) (BBC, 2014) (The Editors of Encyclopaedia Britannica, 2009) (Yoder, 2017) [6] – (Lemley, 1995) (Lenntech, 2015) (Environmental Protection Agency, 2005) [7] – (WaterQuality, 2009) (Mazille, 2012)

3.5 Critical Evaluation

As shown in Table 3.1, each system has its pros and cons and none of them remove all contaminants required. Therefore, a combination of technologies must be chosen that are both applicable to the project and remove the necessary contaminants. Rapid sand filtration was chosen over other filtration methods as it is the quickest system that provides generally clean water at a fixed low cost. The only downside was the filtering components need regular cleaning to ensure that water quality remains clean over extended periods of time. The design for this proposal will need to be cleaned fortnightly. The rapid sand filter also does not remove any biological factors but as the system is designed for hot spring water it has been assumed that any biological components have been killed by the hot temperatures in the spring. This filter removes most suspended solids, both organic and inorganic, lowering turbidity levels to less than 1 NTU (Water Treatment, 2010).

The rapid sand filter will be followed with a combination solar and heated distillation system. This is a solar still made with a heat conductive base to aid evaporation during overcast periods. The distillation process is highly effective in removing dissolved solids that have higher boiling points than water (100°C) which are all the ions and salts that the system is targeting in the contaminated water. The only issue is to ensure that the system is sealed completely as to not lose water vapour to the outside environment. It is a simple design that can be easily understood by the community and maintained. The additional heat source is proposed to be the burning of coconut husks which are a readily available resource on the island as a waste product of the production of Copra and are already used for a heat source during cooking. When combined, rapid sand filtration and distillation should result in pure H_2O. Unfortunately, this is unsafe to drink as it strips vital minerals and vitamins from the body (Harvey, 2011) (Kozisek, 2003). Therefore, a splitter and mixer will be used to rectify this issue, adding a small amount of mineralised water to the purified water. It is believed that this design is maintainable by the community as it only requires a fortnightly clean of the sand and gravel and rinsing of the brine from the still.

4. Decision making matrix

4.1 Decision Making Matrix

After evaluation of each individual treatment process, this knowledge was then used to construct the decision-making matrix, which ultimately allowed us to select the most appropriate design concept for the community. As seen in Table 4.1, three options were critiqued using the criteria and compared. (Refer to Appendix 15.1 for further working out of the weighted matrix)

The options that were available for the system were as follows:

1. Rapid sand filtration and solar still basin
2. Slow sand filtration and distillation (powered by gas)
3. Sand filter and coagulation and flocculation

Table 4.1: Weighted Matrix (the process for the weighted matrix can be found in Appendix 15.1)

Criteria	Weight	Benchmark		Option 1		Option 2		Option 3	
		Score	SxW	Score	SxW	Score	SxW	Score	SxW
A - Effectiveness	0.35	3	1.05	4	1.4	5	1.75	3	1.05
B - Maintainable	0.25	3	0.75	3	0.75	3	0.75	4	1.0
C - Environmental Impact	0.05	3	0.15	5	0.25	1	0.05	2	0.1
D - Cost	0.20	3	0.6	2	0.4	1	0.2	3	0.6
E - Durable	0.15	3	0.45	4	0.6	4	0.6	2	0.45
SUM	1.00		**3**		**3.4**		**3.35**		**3.2**

4.2 Sensitivity

It was decided that from Table 4.1, the rapid sand filter and solar still basin was the best choice for the context of Vanuatu. With option 1 and 2 only having a 1.5% difference within the weighted matrix, both had pros and cons. Option 1 was the best choice with the highest score of 3.4 compared to option 2’s 3.35. The two options scored the same results in maintainability and durability but scored higher in cost with a 2 compared to option 2’s 1. However, option 1 scored less in effectiveness with a 4 compared to a 5. The greatest difference was the environmental impacts with option 1 scoring a 5 and option 2 and 1. Even though it has a low weighting of 5%, this was ultimate factor that made the system a better choice. Option 3 was the last choice with a sum of 3.2 and this was because it did not excel in any of the decided categories with only a 3 in effectiveness and a 2 in durability. This meant that it was not an appropriate choice for Vanuatu.

4.3 Conclusions

The weighted matrix demonstrated that Option 1 was the design concept that would be most applicable to Vanuatu with the highest weighted matrix value at 3.4. Therefore, the final design concept will entail the use of a rapid sand filter, followed by a solar distillation chamber.

Although the matrix concluded that this option was the most appropriate, this design did not take into account the complete removal of minerals in the water after solar distillation. Distilled water does not comply with WHO drinking standards, and thus an additional process was essential to implement to ensure that the filtered water contained its essential minerals.

To resolve this issue, the team has devised a mechanism involving a splitter and a mixer. This mechanism will work by the following process:

- The raw water is first treated through the rapid sand filter to remove turbidity
- The treated water will then enter a splitter where a fraction of the water will be stored in a mixer and the rest of the water will enter the solar distiller for solar distillation
- The water treated by the solar still distiller will be stripped from its minerals. This distilled water will then enter the mixer to be combined with the fraction of water that was not treated by the distiller. This way the distilled water will now contain its essential minerals and abide by the WHO drinking standards

5. Feasibility calculations

5.1 Hot spring water

It was found that if you took away the average composition of water in the East Santo district from the World Health Organizations' values for the maximum water standards, it showed the quantity of excess contaminants that were in the water. This can be seen in Appendix 15.7 which shows the total contaminants removed. Water needed for a community would be approximately a minimum of 125L/day to a maximum of 150L/d as this supplies the average 2.5L/p/d for a community of 50 people. However, it also includes a contingency of 20% as the average person will drink 1.5-3L/d (Davendra 2006). Table 4.1 shows the mass flow diagram which is the quantity of components in each stream. These streams are shown in the preliminary process flow diagram in Figure 5.1. This shows the spring water being treated in the filter and distillation system chosen.

5.1.1 Mass Flow Diagram

There are several assumptions that were made during the calculations of mass removed from the system:

- That 1kg = 1L
- That the system is steady state
- No reaction occurring
- Conditions remain constant
- Moisture content is 0

Table 5.1: Mass flow diagram

Stream	Unit	1	2	3	4	5	6	7	8	9
Hot Spring Water	kg/d	12.5	12.5	0.676	11.824	0.331	11.493	0.356	11.137	11.468
					Composition					
Water	kg/d	11.426	11.426	0	11.426	0.32	11.106	0	11.106	11.426
EC	ms/m	0.159	0.159	0.00295	0.156	0.004	0.151	0.147	0.005	0.0089
Turbidity	kg/d	0.019	0.019	0.0186	0.00019	5.25E-06	0.00018	0.0001	8.2E-05	8.72E-05
TDS	kg/d	1.055	1.055	0.657	0.398	0.011	0.387	0.356	0.031	0.042
Na^+	kg/d	0.35	0.35	0.218	0.132	0.004	0.128	0.118	0.0103	0.01396
K^+	kg/d	0.007	0.007	0.0045	0.0027	7.66E-05	0.003	0.0024	0.0002	0.0003
Ca^{2+}	kg/d	0.009	0.009	0.0053	0.0032	8.98E-05	0.003	0.0029	0.0002	0.0003
Mg^{2+}	kg/d	0.003	0.003	0.002	0.0012	3.43E-05	0.0012	0.001	9.53E-05	0.00013
Cl^-	kg/d	0.411	0.411	0.256	0.155	0.004	0.151	0.139	0.012	0.0164
SO_4^-	kg/d	0.000025	0.000025	1.56E-05	9.43E-06	2.64E-07	9.16E-06	8.43E-06	7.3E-07	9.97E-07
CO_3^-	kg/d	0.275	0.275	0.171	0.104	0.003	0.101	0.093	0.008	0.011

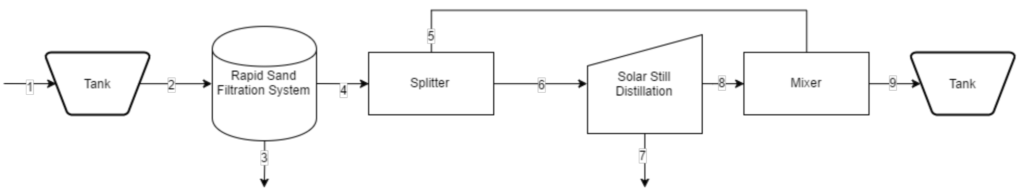


Figure 5.1: Process Flow Diagram

Overall, this system is feasible as it produces values that are less than WHO water standards. (see Appendix 15.7 for WHO standards) This design is good for the environment as the harm from waste produced is negligible, and is economically suitable/ cost effective as it costs $60.92 per system and the average monthly saving of a household is approx. $120.80 AUD.

5.2 Generated Waste

The system will produce waste from the sand filter and the solar distiller which is removed from stream 3 and stream 7 from Table 4.1. The generated waste from the rapid sand filter and the solar still was approximately, 0.03L/day and 0.014L/day respectively. Therefore, the total waste produced from 0.5L was 0.04L (see Appendix 7 for calculations). This was then scaled up for a family prototype (daily flow of 2.5/L/p/d for a 5-person household) and a community prototype (50 people). This can be seen in Table 5.2. Therefore, the community is expected to produce approximately 3770.6L per year. Waste will be stored in a sealed bin until the wet season where the waste will be released. As this waste is not toxic and is predominantly salt and dissolved solids, this waste will have a negligible effect on the environment.

Table 5.2: Waste Removal Scale Up Consideration

DURATION	**WASTE PRODUCED FROM FILTER**	
	Family Sized Prototype	Community Sized Prototype
One Day	1.03	10.33
One Week	7.23	72.31
One Year	377.06	3770.63

5.3 System calculations

5.3.1 Energy

As the rapid sand filter uses gravitational energy it does not require power to maintain the system. However, the distillation system uses solar power to heat the water. It was found that 1 sun hour is equal to 1Kwh/m^2. With Vanuatu getting approximately 8 solar hours of sun during the dry season, each system will require 1.5Kw per day (see Appendix 9) (SolAqua 2008). Therefore, the power needed to distillate the spring water is 1.5Kw/day or 12kWh/day.

5.3.2 Equipment

For a 50 people community, the system is required to produce at least 125L per day. This will be managed by having 10 of these systems in an exposed area as to be able to use solar energy. Each will have a filtration and distillation system that will produce 12.5L of purified water per day. To find the area needed for a RSF:

$$total\ filtered\ water \left(\frac{L}{h}\right) = \frac{water\ filtere(L)}{no\ of\ hours\ (h)}$$

$$rate\ of\ filtering\ (\frac{L}{h}/m^2) = \frac{litres\ (L)}{no\ of\ hour\ (h)}$$

$$area\ of\ filter\ (m^2) = \frac{total\ filtered\ water \left(\frac{L}{h}\right)}{rate\ of\ filtering\ \ (\frac{L}{h}/m^2)}$$

$$volume\ of\ tank\ (m^3) = area\ of\ filter\ (m^2) \times depth\ of\ sand\ (m)$$

Using this volume of the rapid filter tank should be approximately 1.5m^3 with a radius of 0.63m and 1m height. This is feasible as the materials of the rapid sand filter and cheap and accessible (coarse sand, gravel and fine sand) The distillation system will have a base of 1.5m^2, dimensions of 150 x 100cm, a glass tilt of 11 degrees and a depth of at least 10cm. The pipes will be a sizing of 48.3mm diameter as this is appropriate for the water flow rate and this is a standard pipe size.

5.3.3 Costs

As the bill of materials (Appendix 15.6) demonstrates – The cost of the prototype is $60.92 which is for a 5-person household. This equates to $609.20 for the community of 50 people (10 systems).

6. Design details and drawings

The prototype is mainly covered with PVC Plastic materials as it is the most cost-effective and efficient option. The QR Code (Figure 6.2) can be scanned to display the video of the exploded sketch of the design. Also refer to Appendices 15.4 and 15.5 for other sketches of the design.

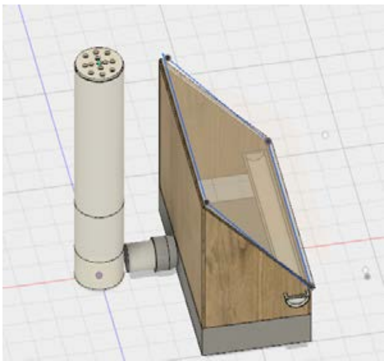


Figure 6.1: Isometric Diagram

1. The sand filtration is produced using mostly PVC pipe that is very cheap and can be imported to Vanuatu as it is waterproof and easily maintained. The filter contains 4 main layers which are gravel, coarse sand, fine sand and a diffusion plate. The diffuser plate is manufactured from PVC so is also durable and cheap.
2. The sand filter is then connected to a solar distiller by plastic pipe connected to copper pipe as they are sturdy, waterproof and strong materials and the copper is heatproof.
3. The solar distillation is made of a baking tray, wooden sides, glass roof and a narrow diameter copper pipe that will be cut into a half section (for drip collection). The baking tray is made of stainless steel as it is the best conductor of heat. The stainless steel is a sturdy and durable material compared to other metals as it is a malleable so it can be drilled and punctured easily. The wood is used for its sides as it is a cheap and easy to source material. Wood is physically a sturdy material that can withstand external interruption such as strong wind. Glass was used for the top of the structure as it is durable and requires little maintenance and is transparent to let in heat from sunshine. Cut sectioned copper pipe is used to collect boiled water from the baking tray and transport it to a container.

The prototype is made of two main components, which are filtration and solar distillation. In the prototype, as it is a smaller scale system and was required to work successfully even on an overcast demo day, a baking tray is used as the base to easily heat the water and an electric stove is used as a safe and contained heat source to increase the rate of boiling of the water. In Vanuatu, the system will still have a metal base and a backup power source of burning coconut husks for when the weather is not optimal, even though during the dry season (when the system is needed) the weather will be expected to be mostly sunny. This backup option is to allow the community to always have access to potable water even with unexpected weather conditions.

Figure 6.2: QR Code for AutoCAD Design Sketch

7. Technical Understanding

7.1 Rapid Sand Filter

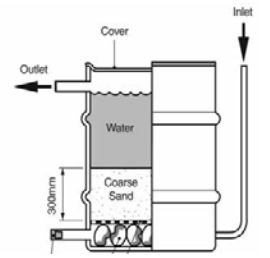


Figure 7.1: RSF

A rapid sand filter uses gravity to push untreated water through several layers of sand and gravel as to remove contaminants as seen in Figure 7.1. This system was decided on rather than a slow sand filter because of its higher flow rate and the use of gravity to process the water, reducing the energy required to power the system. The proposed design consists of a fine sand, course sand and gravel layer in descending order. These layers are designed to trap the different sized particles of contaminants. In the fine sand, adsorption will occur afterwards, in the sand to remove the unwanted ions. The adsorption will filter out the chloride, sulphate, calcium, magnesium and alteration of sodium ions by the fine sand (Stowell, 1927). Coarse sand will also alter the concentration of sodium, magnesium and calcium ions in the hot spring water. A small diameter was chosen over a pipe that was thicker and shorter as this meant untreated water would pass through a thicker layer of fine and course sand. Because of retention, the treatment takes longer but the water is cleaner as more particles are trapped in the layers.

The advantages of using this system is that it requires little area and is insensitive to changes in untreated water quality. The disadvantage to the system is that it requires regular maintenance and cleaning. For a filter to operate efficiently, backwashing the system is necessary as to remove the trapped particles. As the community, will employ minimal staff, the back washing of the system will occur periodically which might reduce the quality of water. As their energy is used by gravity, no chargeable energy consumption will be used for the process.

7.2 Distillation Chamber

A solar still basin was also decided as a subsystem for the proposed design. This is attached to the rapid sand filter and uses solar energy from an angled glass pane to heat the water within the sealed chamber (see Figure 7.2). This concentrates energy to then evaporate and condense untreated water on the glass which then is collected. As the chamber reaches temperatures of 100°C, the water evaporates but other contaminants, such as salt and magnesium, have higher boiling temperatures so remain in the basin. Because of the high effectiveness of distillation at removing minerals, minerals are need to be replaced in the water after treatment. This system also acts as a disinfectant as it eliminates microbiological organisms from the heat. It is also effective at removing salt from water which was important for the East Santo community.

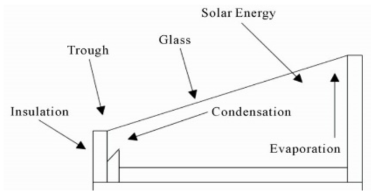


Figure 7.2: Solar Still

The disadvantage of using this system is that it is time consuming and requires large quantities of surface area, requiring large quantities of exposed land to produce the necessary amount of water. The community will also be dependent on the weather because cloud and minimal solar hours will reduce the quantity produced. This is because less solar heat might not allow the inside of the system to reach the required temperature of 100°C. As the system is required during the dry season, the weather will be mostly sunny. When the weather is not optimal, coconut husks will be used as an alternate energy source and will produce the equivalent to solar energy. The system will reduce in efficiency over time because of the need for the systems to be air tight. As the systems age, the silicon and liquid nails will deteriorate allowing steam to escape. This is the major problem with distillation chambers so the community will need to regularly check for holes and do regular maintenance.

7.3 Splitter and Mixer

A splitter will be used in the design after the water has been treated in the sand filter by splitting 2.8% of water around the distiller. This is because the distillation chamber removes most of the heavy metals from the system. Because of this, the quantity of metals such as magnesium is around 0.4mg/L. Although below the WHO water standards, water requires a certain level of contaminants in drinking water, if this is below the water will leech the contaminants from its surroundings. This means, when the community drinks the water, the system will remove some ions from the body as to produce appropriate equilibrium. This splitter, although increasing the turbidity level in the water, will allow the water to retain some minerals before the distiller removes them. A manual mixing will occur as to evenly spread the minerals through the treated water. As this manually performed by staff, there is no energy needed by the system which keeps the system costs affordable for the community.

8. Sustainability

8.1 Triple Bottom Line Assessment of Design

The triple bottom line refers to the framework consisting of social, economic and environmental performance. This evaluates materials and products and enhances the sustainability of the final product. To assess the sustainability of the chosen design a Rubric has been constructed using a 1-5 scale. This specifically critiques three criteria from the areas environment, social and economic. The results from this Triple Bottom Line Assessment are seen in Table 8.1. The criteria for the Triple Bottom Line can be found in Section 15.3 of the Appendices.

Table 8.1: Results from the Triple Bottom Line Assessment of Design

Criteria		Results (1-5)	Description
Environmental	Energy	1	• Plastic and glass components require energy to produce • Materials will need to be imported • Solar energy used to offset energy usage
	Resources	3	• PVC piping is non-renewable • Sand and gravel are reusable • Wood recyclable
	Impact	4	• Low impact waste produced with negligible impacts • Minimal waste from materials
Social	Employment	3	• Small number of jobs created to operate and maintain the system • Creates job awareness by the possibility of employment in the community
	Culture	4	• Designed with the community's culture taken into consideration • Supports the local culture • Does not disregard the values of the community
	Education	4	• Provides an opportunity to learn about technology • Teaches the community about basic sanitation and water quality • Creates awareness of the local community situation
Economic	Initial cost	3	• Inexpensive and abundant materials • Majority of materials can be resourced from Vanuatu
	Operational Cost	4	• Solar powered so no energy cost • Will require staff to bring untreated water to the system • Staff will need to regularly clean the system
	Profit	2	• Enables profit through the preservation of the ecosystem and community • New revenue from the ecotourism business

8.2 Quantifying Embodied Energy

When proposing a design, it is important to decide on materials that are sustainable and appropriate. During the design process, materials were analysed as to decide which would be the most sustainable design for the water purification system in Vanuatu.

8.2.1 Materials

As seen in Table 8.2, the materials that were selected were used as to find the total embodied energy of the water. These materials were selected using a comparison Table as seen in Appendix 15.2. These materials were compared by their embodied energy, the energy of transportation and its attributes.

Table 8.2: Embodied energy

Material	Embodied Energy (mJ/kg)	Attributes	Justification	Appropriateness	Energy (MJ)
Steel	38	Durable, strong, inexpensive	Must be produced and refined then imported	Timber	380
Plastic PVC	55.4	Durable, stable,	Needs to be refined and imported		165.8
Aluminium	219	Conductive, durable, malleable	Must be imported, has excess material, is refined		876
Sand	-	Recyclable	Can be manually moved in Vanuatu		-
Gravel	-	Recyclable	Can be manually moved in Vanuatu		-
Silicone	131	Water resistance,	Refined, has excess, must be imported		131
Timber	10.9	Durable, strong, cheap, recyclable	Found in Vanuatu and easy to refine		43.6
Glass	41.3	Strong, durable, fragile, transparent	Must be refined then imported as well as being fragile which increases cost	Plastic	93.9
Copper	62.8	Strong, flexible, conductible	Must be imported, has excess material, is refined		123.6
Total					1800

NOTE: Colour coding, green – appropriate, yellow – possible, red – inappropriate
Embodied energy (EduPack 2017)

Therefore, the total embodied energy of the water is approximately, 66Kj. This could be improved by using materials that are already available in Vanuatu. This would be difficult but possible.

8.3 Process flow

The life cycle analysis produced a visual representation of the energy required to produce, transport and dispose of the water purification system. As seen in Figure 8.1, the energy requirements and emissions have been identified throughout the life cycle of the system.

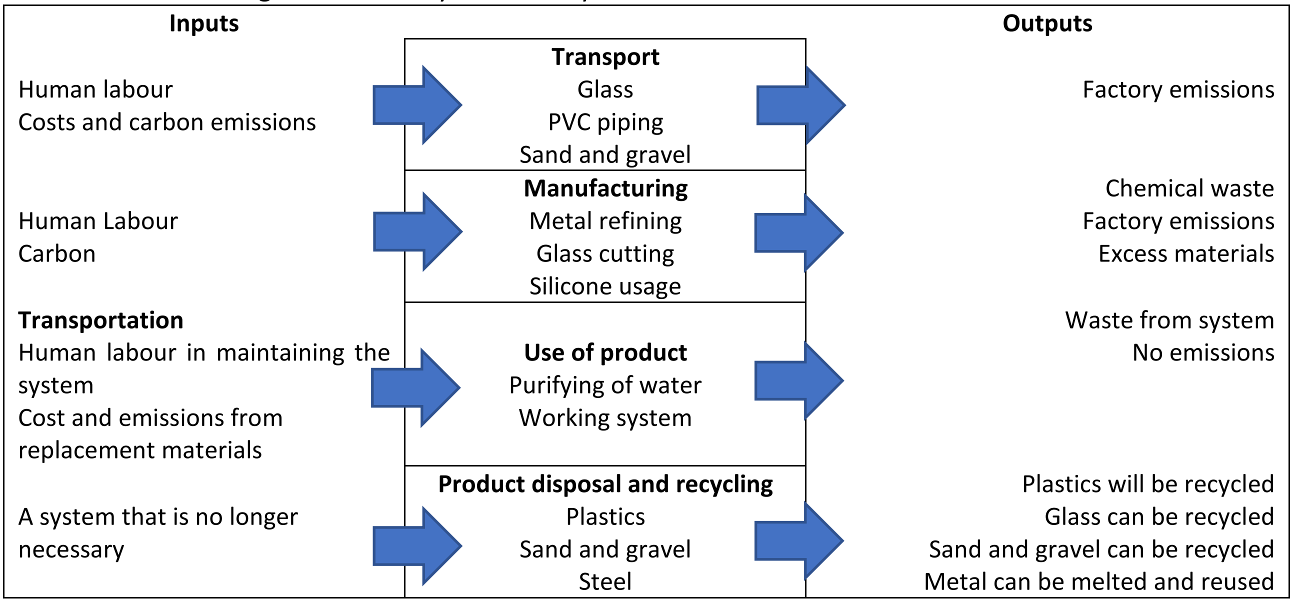


Figure 8.1: Process Flow Diagram

Evidently, a lot of energy is used transporting the materials to Vanuatu. It is important to minimize this as much as possible by using materials already available. The PVC piping is necessary to import but the sand, gravel and timber are abundantly available in Vanuatu. However, the amount could be reduced by using alternate materials such as timber for the distillation chamber. The manufacturing of the system can be refined by minimizing wastes produced such as filings and excess piping. When the system is disposed of, the sand and gravel can be washed and then put on the land. The plastic piping and glass can be recycled and used in other systems or for other uses.

8.3.1 Recycling

After the system, has been used and is being disposed of, several materials can be recycled. Table 8.3.1 shows the process that will be used to recycle a variety of materials.

Table 8.3: The Process of Recycling Materials

Material	Process
Plastics	Melted and remoulded
Glass	Cleaned and reused or put in a land pit
Sand and Gravel	Washed
Metal	Melted and refined

8.4 Community Sustainability

For the system to be maintained for the expected longevity, the community must be able to replace and understand the processes of the design. Therefore, a community consultation plan (including teaching sessions, a booklet with diagrams and check-ups on the community) will be initialized as to allow the community to understand the system (refer to section 11 for further information). This will allow the design to be sustainable in the community by being used effectively and efficiently.

9. Failure Modes and Effects Analysis

The FMEA represents the prototype in terms of components and identifies which of them can fail during testing or use. This prevents accidents that could occur otherwise. The risk of operating the prototype should have decreased after a FMEA, providing a safer environment for testing. Figure 9.1 shows the FMEA system breakdown and explains the system and its subcomponents. Table 9.2 is a summarisation of the analysis of possible failures in the system and recommendations for improvements to increase reliability. (Refer to Appendix 15.11 for expanded FMEA analysis)

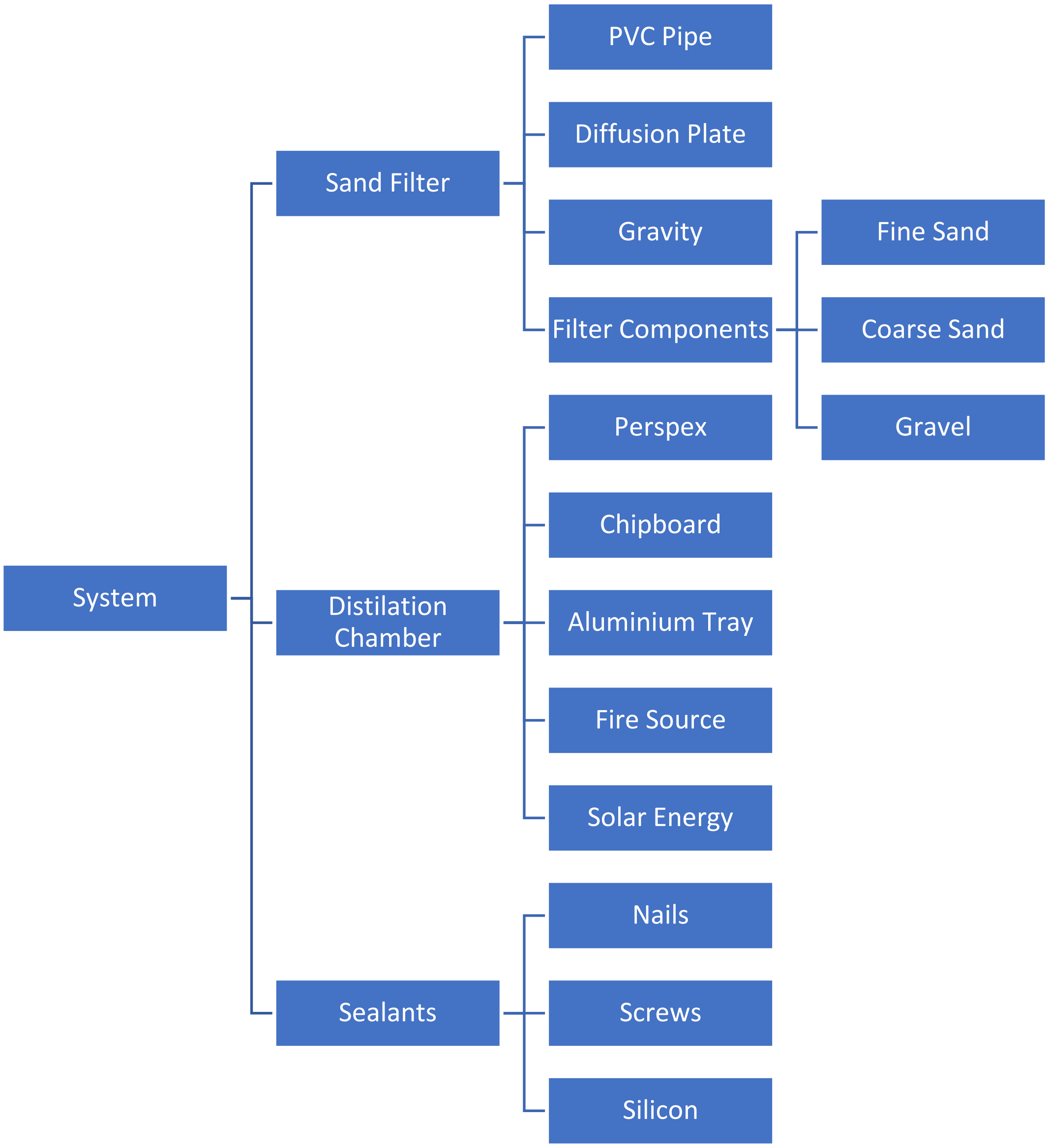


Figure 9.1: FMEA System Breakdown

Table 9.1: FMEA Calculations

Item	Failure Mode	Causes	Effects	Recommended Improvement
PVC Pipe	Melting	Heat from gas burner	Structure compromise	Replace with copper pipe
Diffusion Plate	Clogged	Too many large solids	Less water flow	Clean regularly
Gravity	Minimal water flow	Placed on slant	Low flow rate	Keep filter upright and tilted towards outlet if possible
Fine Sand	Clogged	Not cleaned	Impure water	Cleaning
Coarse Sand	Clogged	Not cleaned	Impure water	Cleaning
Gravel	Clogged	Not cleaned	Impure water	Cleaning
Perspex	Melting	Heat from gas burner	Loss of vapour	Replace with Glass
Chipboard	Burning	Fire	Structural Compromise	Use baking tray to transfer heat but keep fire away from structure
Aluminium Tray	Buckling	Kept at high temperature for long periods	Structural Failure	Keep temperature low enough just to boil
Solar Energy	No energy	Overcast Conditions	Low production rate	Add heat source for such instances
Nails/Screws	Loosen	Stress on System	Structural failure	Add liquid nails for extra support
Silicon	Melting	Excess heat	Leakage in system	Heat proof silicon

As seen from Table 9.1, the causes and effects of items failures have been critiqued and analysed using the FMEA calculations. To see in further detail, please refer to Appendix 15.11. From this, it was found the risk priority rating was a total of 128 and the recommended improvements reduced this to 64. By following the recommended improvements in Table 9.1, the risk of failure has decreased by half (50%). The resulting risk is only from wear and tear of the system where breakage may occur over longer periods of time and use.

The major concerns for failure is the silicon melting at high temperatures as this would cause leakages and reduce the effectivity of the distiller. It is highly recommended that the system use heat proof silicon and thoroughly fill suspected leak areas. The smallest concern in the diffusion plate being clogged as this can be easily be seen by the village and is remediated by cleaning the plate by thoroughly washing.

10. Details of the full-scale design and scale up considerations

The final design is a columned sand filter purification device and a water evaporation system. See Figure 10.1 for measurements for the prototype and then the up-scaled design. The volume of fine sand is 35.3 litres. The volume of course sand Is 10.3 litres and the volume of gravel is 5.7 litres. After water flows through the gravel, it goes through a PVC pipe which is 20 centimetres long and the diameter is 15mm, and then water enters the heat conducting base of the solar still which is formed by metal and surrounded by 4 plywood walls. The water tank is covered by glass. There is a 23cm long copper pipe near the low-side plywood to collect these clear drips which then goes into a sealed tank (see Figure 15.4.1 for further AutoCAD sketches of design). As this treatment recovery module will be used for a small community, there are three problems that should be considered for the scale up of the design:

1. East Santo village communities consist of small related family groups with ceremonial buildings located in the centre of the village. Although placing the modules at each house is convenient for each family to get water whenever they want, placing them together would be easier to maintain. Moreover, every family in East Santo village is close to the ceremonial buildings, it is also convenient to get water from there. It would be more expensive and take more energy to set and administrate at each house than placed together, but be more convenient for the families to access drinking water throughout the day from their own home.
2. This modular system can be adapted to suit differently sized communities. Because this modular system is not a complex system, its materials can be sourced easily and it is easy to establish and fix. People can build a series of this modular system or scale it up to suit the need of the large population. Similarly, they can just set up 1 or 2 appliances if the community is small.
3. For the management, these treatment systems belong to either the government or the community members, depending on who purchases it; this will affect who is responsible for these systems and who has the duty to build and take charge of these devices. Our company will do 6 month check-ups.

As the demo day prototype runs on a gas burner but the final design in Vanuatu will use primarily solar energy, the base dimensions of the solar still will be increased as this is necessary so that it will produce enough water per day. As section 5.3 demonstrated, a minimum base area of $1.5m^2$ is required. This means the base dimensions will change from 23x33cm to 100x150cm. The sand filter will remain unchanged.

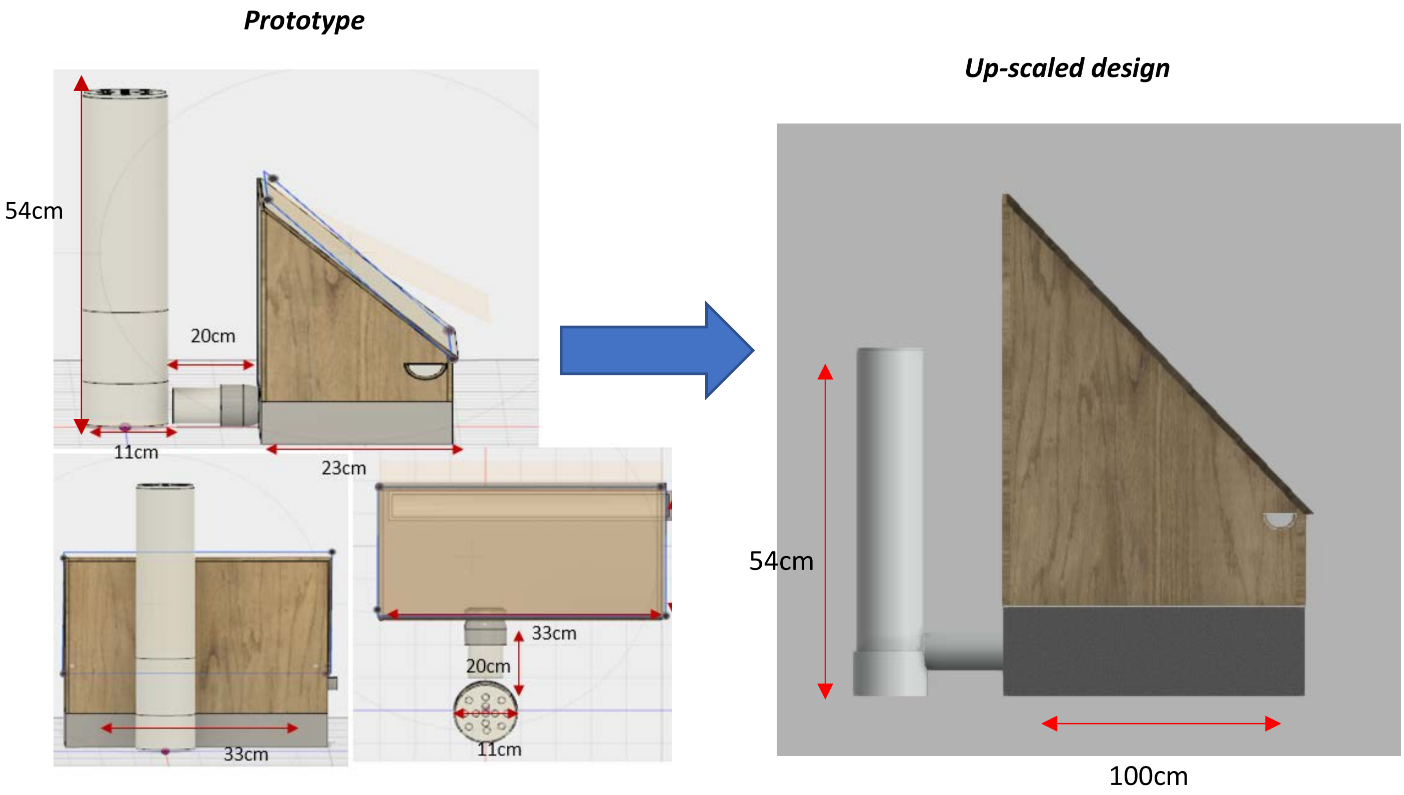


Figure 20.1: Prototype vs Up-scaled design

11. Community Consultation Plan

The water purification system can easily and efficiently be introduced into the community; a community consultation plan has been provided as to increase understanding of the process and design. With each of the household systems, families will be provided with a booklet with pictures and diagrams educating about how the system works, how to use it, how to test water quality and how to clean/ maintain it (an example shown in Appendix 15.10). This is so the less educated community members can still understand and visualize the process. This is done in a format that is very interactive and possible for even the younger members of the family to understand, this ensures that the whole family can engage with the water purification system. Furthermore, other development groups in the area such as global development group and Caritas Australia will be contacted as to help with the initializing the development of the community. These groups will be able to help with moving the project into the community and protecting the values of the people.

When the system is installed, the families will be educated face-to-face on how it works with the help of a local translator and possibly a community representative. This will allow the community to ask questions and initially learn how to use the system by being verbally taught the process. Furthermore, the families will be taught how to clean the system during instillation (needs to be done fortnightly) and store the waste in the plastic tubs. A designated member of each 50-person community would oversee testing – using the communal testing equipment to increase accuracy of testing and providing this person with an occupation. However, the knowledge on how the water is tested will be available to everyone as to increase understanding of water hygiene and so someone else would be able to test water quality if necessary. One other aspect of the community engagement plan is that every 6 months, the community will be visited to ask them about their feedback of the technology and to see if it is being used appropriately. This will allow the community to continue maintaining the system effectively and solve any issues or concerns.

12. Conclusions

The initial design problem was that the East Santo Communities of Vanuatu require a water purification system as they lack adequate drinking water during the dry season. After researching and using a weighted matrix, a water purification system has been designed for implementation in East Santo. Important features of this design were minimal impact on the environment, fitting in with the culture and values of the community, minimal cost and waste production, and a simple design that could be easily taught and maintained. The combined system of the sand filter and distiller costs $60.92, has no considerable maintenance or running costs and the water quality can be easily tested by the community. It is evidently a suitable design for the situation in Vanuatu.

13. Recommendations for further work

The following is a list of recommendations to improve the design and implementation:

- Further communications with the community, monitoring the use of the system, the community will be visited every 6 months to monitor the use of the system and if there are any issues with it.
- Implementing an interactive presentation or demonstration with the people of the East Santo community to show how the water system works. This will allow them to be more comfortable with the system, and may prolong the life cycle of the treatment system if the community is educated in terms of how to correctly maintain the treatment system.
- A potential further recommendation would be to do a cost-benefit analysis about the possibility of using metal for the main material for the solar still rather than wood. Although many household stills are commonly made from wood and it is considerably cheaper, metal would last for longer and testing on demo day showed bulging of the wood at high temperatures so metal should be considered.
- The collection container was a glass bottle attached with electrical tape in the initial prototype, for the implementation in Vanuatu a more permanent solution needs to be found of a container that can be detached after water collection and yet is still completely sealed with the system when collecting water.
- A better sealant needs to be found for the system- the glass sheet was attached to the wooden sides with heat resistant liquid nails designed for glass- however during demo day this began to melt so evidently wasn't heat resistant enough.

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15. Appendices

15.1 Working out for weighted matrix

The following Tables in Section 15.1, demonstrate the thought process used in creating a reference system for the weighted matrix in Section 4.1 of the report

Table 15.1.1: Criteria

	Criteria	Definition	Quantitative or qualitative
A	Effectiveness	It works and does the job well	Qualitative
B	Maintainable	It is easy to use and maintain	Qualitative
C	Environmental Impacts	Does not hurt or damage the environment or cause long lasting damage	Qualitative
D	Cost	The price of the system	Quantitative
E	Durable	It continues to work	Quantitative

Table 15.1.2: Qualitative and Quantitative Breakdown

<u>Benchmark: Nothing</u>

Criteria	Effectiveness	Maintainable	Environmental Impacts
1	Not Potable	Not used correctly	Environmental Destruction
2	Low Quality	Needs regular explanation	By-products are dumped
3	Average Water Quality	May need some explanation	Dispose by-products appropriately
4	Potable Water	Little teaching required	No by-product disposed
5	High Quality	No teaching required	Eco-Friendly

Criteria	Durability	Cost
1	Needs constant attention	>100
2	Needs constant attention	>50
3	No system	0
4	> 6 months	$50 profit
5	> 1 year	$100 profit

Table 15.1.3: Pairwise Comparison

Criteria	A	B	C	D	E	Sum	Weight (%)
A	-	½	1	1	1	3 ½	35
B	½	-	1	½	½	2 ½	25
C	0	0	-	0	½	½	5
D	0	½	1	-	½	2	20
E	0	½	½	½	-	1 ½	15
Total						**10**	**100**

15.2 Life cycle analysis

The following Table shows the values used to calculate the embodied energy of the system in Section 8.2.

Table 15.2.1 – Life Cycle Analysis

Material	Energy (mJ/kg)	Attributes	Justification	Appropriateness and possible option
Ceramic tile	12	Durable, strong	Must be refined can be found in Vanuatu	Brick
Brick	2.5		Can be produced in Vanuatu and uses little energy to refine	
Steel	38	Durable, strong, inexpensive	must be produced and refined then imported	Timber
Glass	12.7	Fragile, durable, transparent	Must be refined then imported as well as being fragile which increases cost	Plastic
Plastic PVC piping	90	Durable, stable,	Needs to be refined and imported	-
Plastic	90	Flexible, durable,	Needs to be refined and imported	
Sand	-	Recyclable	Can be manually moved in Vanuatu	
Gravel	-	Recyclable	Can be manually moved in Vanuatu	
Aluminium	170	Malleable,	Refined, mined and imported	Plastic, steel
Silicon	230	Water resistance,	Refined, has excess,	
Timber	8.5	Durable, strong, cheap, recyclable	Found in Vanuatu and easy to refine	

NOTE: Colour coding, green – appropriate, yellow – possible, red – inappropriate

15.3 Triple Bottom Assessment Criteria

Table 15.3.1:

	S			S			S	
Energy	1	Needs more than the community can produce	**Resources**	1	All non-renewable	**Impact**	1	Long term impacts
	2	Just manageable		2	Some recyclable materials but most non-renewable		2	Minimal long term impacts
	3	Manageable		3	Some recyclable		3	Short term impacts
	4	Minimal		4	Mostly recyclable		4	Very minimal
	5	None		5	All recyclable		5	None

Table 15.3.2:

	S			S			S	
Employment	1	None	**Culture**	1	Unusable	**Education**	1	reduced
	2	Some occasional jobs		2	Inappropriate		2	Does not improve
	3	1 person full time		3	Slightly inappropriate		3	Could possibly help
	4	1 person and some other occasional		4	Possibly appropriate		4	Improves education
	5	Optimal amount		5	Appropriate		5	Highly improves education

Table 15.3.3:

	S			S			S	
Initial Cost	1	<150	**Operational Cost (day)**	1	>$20	**Profit**	1	<0
	2	100-150		2	10-20		2	0-20
	3	50-100		3	5-10		3	20-40
	4	<50		4	0-5		4	40-60
	5	<25		5	0		5	60<

15.4 Sketches of the design

The orthogonal and isometric sketches are shown in the Figure 15.4.1

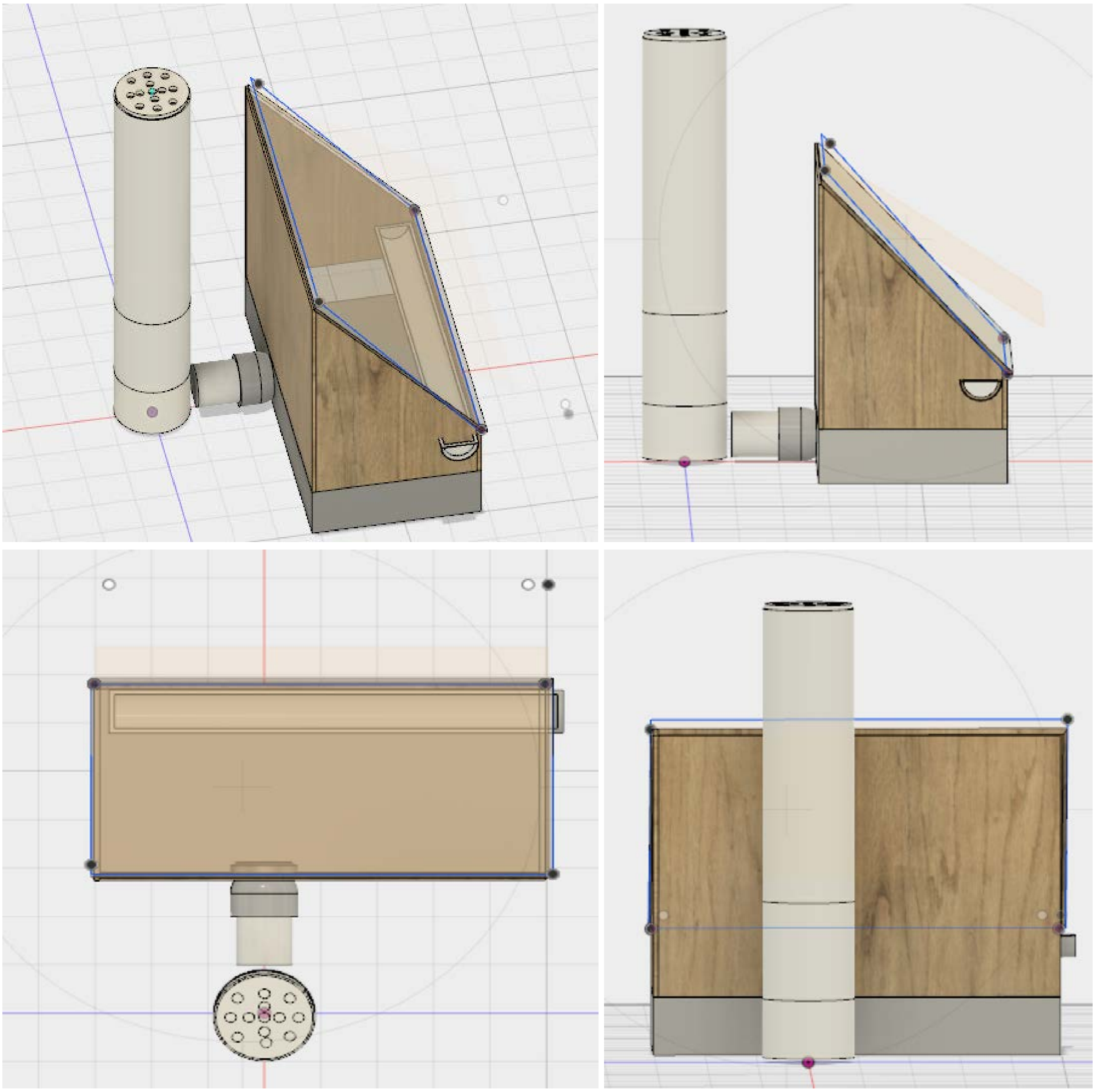


Figure 15.4.1: Designs of the water purification system

15.5 Orthogonal sketches of design

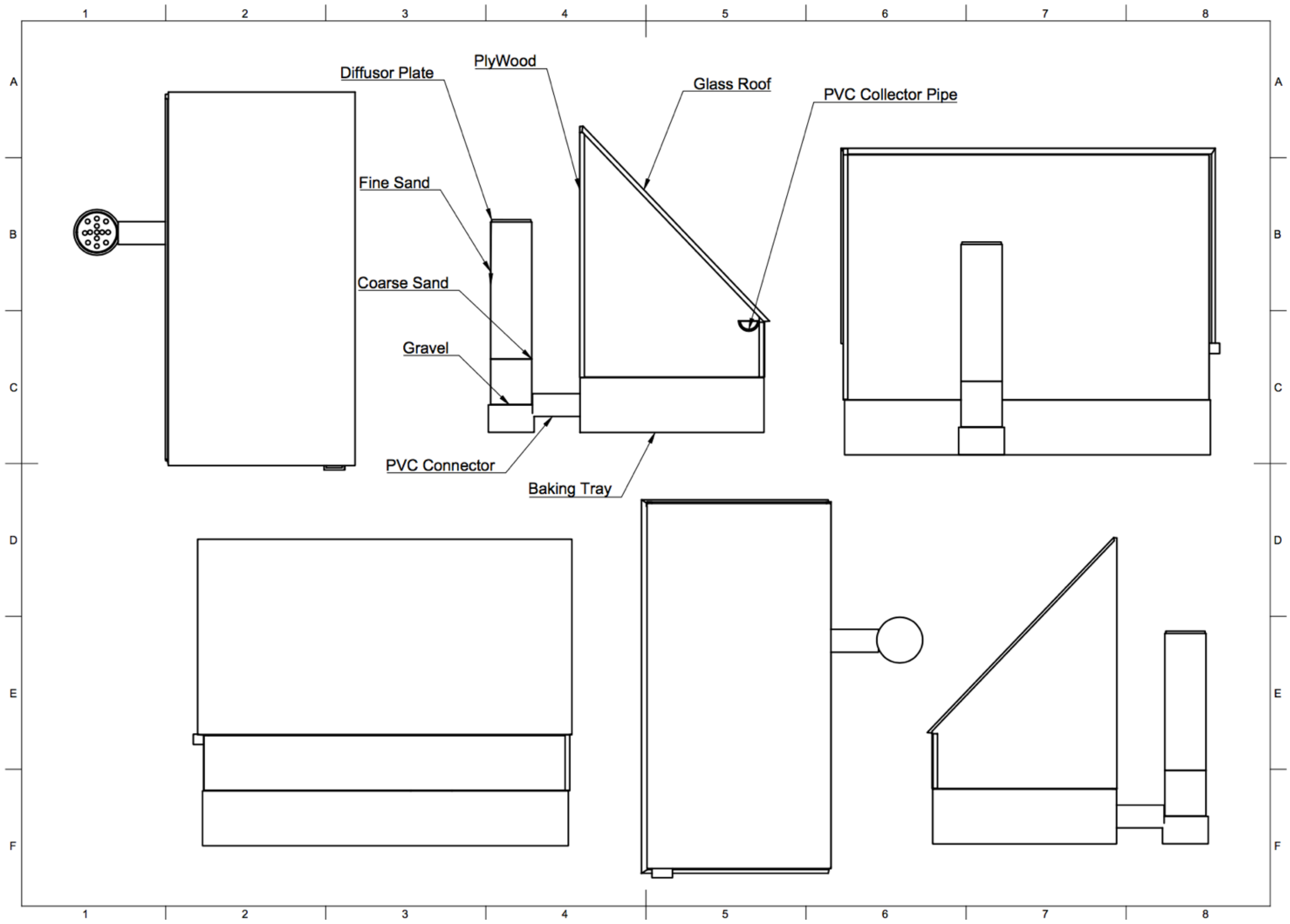


Figure 15.5.1: Orthogonal Design of the water purification system

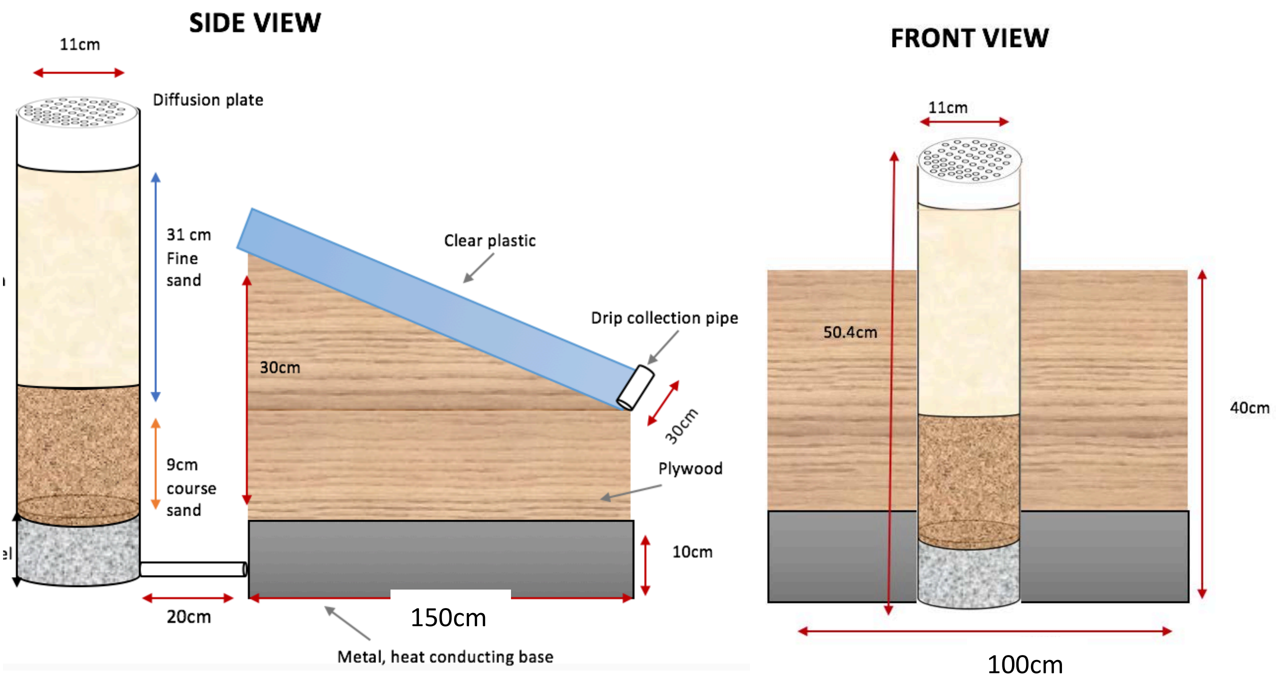


Figure 15.5.2: Side and Front views of the water purification system

15.6 Bill of Materials

Table 15.6.1: Bill of Materials

Part	Quantity Purchased	Quantity Used	Receipt Cost	Estimated Cost (for free materials)	Build cost
Copper Pipe	1m	½ m	$15.35		$7.68
Baking Tray	1	1	$7		$7
Gravel	1 bag	¼ bag	$1		$0.25
Coarse Sand	1 bag	¼ bag	$1		$0.25
Fine Sand	1 bag	½ bag	$1		$0.50
PVC Pipe	½ m	½ m	$3.96		$3.96
Plywood	1 board	½ board			$3.00
Small PVC Elbows		1			$4.50
Nails	1 pack (220)	36	$4.90		$0.80
Sealant	445 g	½ bottle	$15.98		$7.99
Liquid Nails	310 g	½ bottle	$13.15		$13.15
30 x 40cm Glass	1	1	free	*$10 estimated	$10
Screws	1 pack (100)	8			$0.41
Chux cloth	20 pack	$5cm^2$	$6		$0.03
Electrical tape	1 roll (30m)	1m	$3.83		$0.13
Plumbing glue	Free- already owned	10ml	Estimated-$15 (118ml)	$1.27 estimated	$1.27
Total					$60.92

***** The glass was sourced free- from scraps/ off cuts – estimated at $10 as at Bunnings there is 1200cm x 300cm glass sheet for $30.

15.7 WHO Guidelines and Water Chemistry of Vanuatu

Table 15.7.1: WHO Requirements for Drinking Water and Hot Spring Water Given

Parameter	Units	Hot Spring Water	WHO requirements
Temperature	°C	38	25
pH		5.9	6.5 – 8.5
Electric Conductivity (EC)	mS/m	1270	<150
Turbidity	mg/L	50	<1
Total Dissolved Solids (TDS)	mg/L	8443	500
Sodium (Na^+)	mg/L	2800	180
Potassium (K^+)	mg/L	58	20
Calcium (Ca^{2+})	mg/L	68	60
Magnesium (Mg^{2+})	mg/L	26	40
Chloride (Cl^-)	mg/L	3290	250
Sulphates (SO_4^{2-})	mg/L	0.2	250
Carbonates (HCO_3^-)	mg/L	2200	250

15.8 Calculations for waste from the full-scale system

Waste Removal from Sand Filter

Waste from the sand filter is removed from Stream 3; please refer to Table 5.1 for Stream 3 values:

$$0.000743\frac{kg}{day}+0.026294\frac{kg}{day}$$
$$=0.027037\frac{kg}{day}=0.027037\frac{L}{day}$$

Waste Removal from Solar Distiller

Waste from the solar distiller is removed from Stream 7; please refer to Table 5.1 for Stream 7 values:

$$4.02371\times10^{-6}\frac{kg}{day}+0.014281219\frac{kg}{day}$$
$$=0.014285\frac{kg}{day}=0.014285\frac{L}{day}$$

Scale Up Considerations

The total waste produced per 0.5L of water is calculated by adding the waste from both the sand filter and solar distiller:

$Total\ Waste\ (per\ 0.5L)=0.027037L+0.014285L$
$Total\ Waste\ (per\ 0.5L)=\ 0.041322L$

This value can then be used to calculate how much waste would be produced per 1.0L of water:

$Total\ Waste\ (per\ 1.0L)=\ 0.041322L\times 2$
$Total\ Waste\ (per\ 1.0L)=0.082644L$

15.9 Calculations for energy used by the solar still distillation system

Assuming 12 hours of sunlight hours with 4 hours being out of range of the glass, there are 8 hours of solar power available.

Since 1 hour = 1kWh/m^2

Therefore,

8 hours = 8kWh/m^2

Since the base area of the distillation system is 1.5m^2

= 8kWh/m^2 x 1.5m^2

=12kWh

Convert kWh to kW

kWh = kW x h

kW = kW/h

kW=12/8

kW=1.5

Therefore, the amount of energy needed for powering distillation is 1.5kW/d

15.10 Screenshots of pages of example informative booklet (part of community engagement plan)

Who we are

At Sky Solar Treatment Solutions, we aim to provide the residents of remote Vanuatu with quality drinking water, and we believe that our system of sand filtration and solar distillation is the most economical and effective way of doing this.

If there are any issues with our product, contact our company as soon as possible and we will work hard to solve any problems that are encountered!

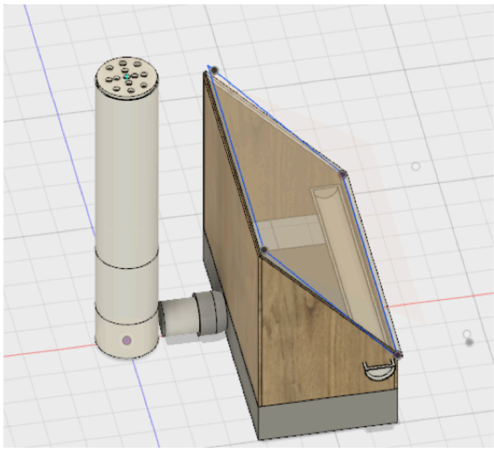
Contact Us

Contact: Kate Atkinson

Brisbane, Australia

Phone: 0481949332
Email: kateatkinson777@gmail.com
Web: www.skysolartreatmentsolutions.com.au

Information booklet: Sand Filter and Solar Distiller



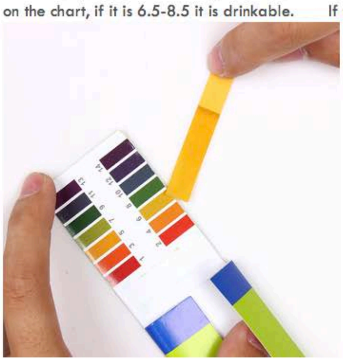
SSTS™

How to test the water quality

You will be provided with PH paper and a simple turbidity test and the community will share PH and Turbidity testing probes

How to use the PH Paper

Dip a piece of paper in the purified water. It will change color. Match it up to a color on the chart, if it is 6.5-8.5 it is drinkable.



How to use line test

Put water into the bottle until the lines aren't visible. If this is before the 'level' mark then the water is drinkable

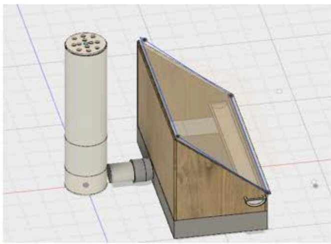
How to use the PH and TDS probe

Place the probes in the water sample. Record this and check if the pH and TDS are in the drinkable limits.

4

Our Products & Services

Our product: Water treatment system



Our water treatment system removes the impurities from hot spring water. It is cheap, effective and if used currently will last for at least 5 years.

Out services: 6 monthly check up visits

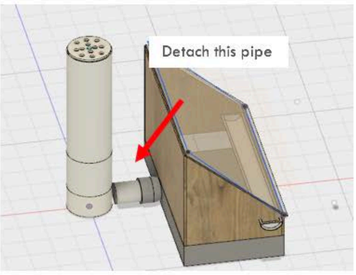
We will visit your community every 6 months to ensure that the systems are running well. If there are any problems, we will fix any issues with the system.

1

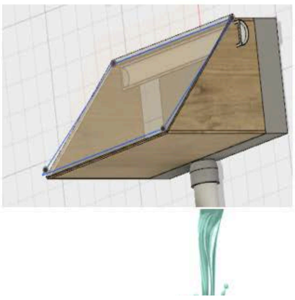
Table of Contents

How to clean the system

Step 1: Detach the sand filter from the distiller



Step 2: Tip the distiller to remove the dirty water via the outlet

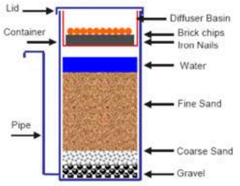


How it works

The system is a sand filter followed by a solar distiller

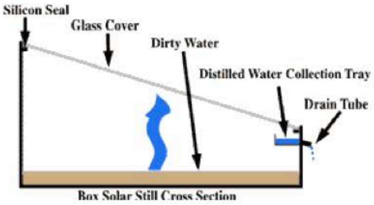
The sand filter:

The sand filter has layers of fine sand, coarse sand and gravel. They trap the particles of material in the water to produce cleaner water.



The solar distiller:

The still works by trapping sun rays to heat dirty water to make it evaporate, this leaves the unwanted particles at the base. The clean water then runs down the clear lid to be collected by the pipe.



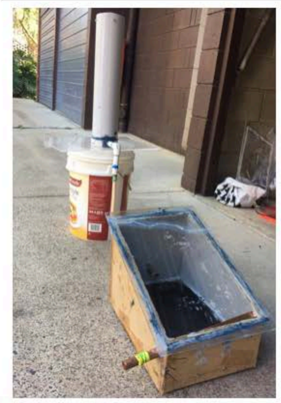
2

How to use the system

Step 1: Make sure that the sand filter is attached to the distiller and that there is a collection bottle on the outlet pipe

Make sure that the connecting pipe is attached to the filter and distiller.

Step 2: Place the system where it will be exposed to the sun for at least 8 hours per day



The more hours of sun in the day, the more drinking water will be produced, however 8 hours should be enough for your family.

15.11 The expanded FMEA analysis

Table 15.11.1: FMEA report

Item	**Failure Mode**	**Causes**	**Effects**	**Risk Priority Rating**				**Recommended Improvement**	**Risk Priority Rating**			
				S	P	D	RPN		S	F	D	RPN
PVC Pipe	Melting	Heat from gas burner	Structure compromise	3	2	1	6	Replace with copper pipe	3	1	1	3
Diffusion Plate	Clogged	Too many large solids	Less water flow	2	4	1	8	Clean regularly	2	2	1	4
Gravity	Minimal water flow	Placed on slant	Low flow rate	2	1	1	2	Keep filter upright and tilted towards outlet if possible	2	1	1	2
Fine Sand	Clogged	Not cleaned	Impure water	3	4	1	12	Cleaning	3	2	1	6
Coarse Sand	Clogged	Not cleaned	Impure water	3	4	1	12	Cleaning	3	2	1	6
Gravel	Clogged	Not cleaned	Impure water	3	4	1	12	Cleaning	3	2	1	6
Perspex	Melting	Heat from gas burner	Loss of vapour	4	3	1	12	Replace with Glass	1	1	1	1
Chipboard	Burning	Fire	Structural Compromise	4	3	1	12	Use baking tray to transfer heat but keep fire away from structure	4	1	1	4
Aluminium Tray	Buckling	Kept at high temperature for long periods	Structural Failure	4	1	1	4	Keep temperature low enough just to boil	4	1	1	4
Solar Energy	No energy	Overcast Conditions	Low production rate	2	4	2	12	Add heat source for such instances	2	2	2	8
Nails/Screws	Loosen	Stress on System	Structural failure	4	2	2	12	Add liquid nails for extra support	4	1	2	8
Silicon	Melting	Excess heat	Leakage in system	4	3	3	24	Heat proof silicon	4	1	3	12
Total							**128**					**64**

Table 15.11.2: FMEA Key

	4	**3**	**2**	**1**
Severity (S)	Catastrophic	Critical	Marginal	Negligible
Probability (P)	Expected	Occasional	Remote	Improbable
Detection (D)	Impossible	Possible	Likely	Certain
Frequency (F)	Everyday	Once a week	Once a month	Twice a year