Reflections on our Engineers Without Borders submission:

During our first semester of studying engineering, we were fortunate to participate in the Engineers Without Borders Challenge. This provided an opportunity to explore sustainable development and design within a 'real-life' context.

Our four-person project team developed a strong rapport, and by working together, we were able to consider multiple opinions and combine our ideas at all stages of the project to produce the final product. As we brainstormed, not only were we able to gather the best of our individual ideas, we came up with new ones that had previously not been considered. We drew on the knowledge of the variety of different engineering disciplines that were present in our team, e.g. chemical, material, civil and environmental engineering; this not only benefited the project, but it also deepened our personal understanding of the many facets of engineering.

The most difficult aspect of developing a suitable solution for Devikulam was meeting the requirements of the village, in particular, the lack of reliable power. We were forced to look past the obvious solutions to simpler more appropriate ones that we believed would still do the job. We felt that the use of chitosan in the filter would have greatly improved the filter's capabilities; however, due to religious beliefs this was not possible. Given the option, we would have liked to be able to test the filter without such restrictions. Nevertheless, the challenge of creating a water purification device suitable for the village was highly beneficial in shaping our understanding of what engineering entails as well as the sort of issues facing developing nations.

The most enjoyable part of the challenge was working on a project that we knew could help people in another part of the world. For our assignment, we built a prototype; seeing that our design had the potential to really work in Devikulam was not only a great motivation for us, but was also one of the most satisfying moments of the project.

We are all able to look back on this project with a sense of pride for what we have accomplished. What follows is the product of our work.

Devikulam Water Purification Project

University of Queensland

June 3 2011

Team Scarlet

University of Queensland

St Lucia Campus

To Engineers Without Borders:

Enclosed is our solution to the Devikulam community's water quality crisis involving the collection of water from the local bore, followed by a treatment method using a combination of filtration and adsorption processes.

The design elaborates on the importance of sustainability and community involvement throughout the entire development of the system, and also includes a proposal for an education program to be put in place. This would teach the villagers about the importance of clean water as well as the operation and maintenance of the water purification device. The social, cultural, economic, environmental and technical impacts of the system have been evaluated and detailed, with these factors contributing significantly to the final outcome. The system is a simple, effective, low-cost design that is able to be easily integrated into the Indian lifestyle and supply the community with clean water year-round.

Please contact us if there are any queries regarding the report.

Regards,

Team Scarlet

Mitchell Fletcher Kristiane Fox

Larissa Hughes Scott Luengen

Executive Summary

This year, Engineers Without Borders (EWB) is working in collaboration with the Devikulam community in the Kauveli Bioregion of Tamil Nadu, India, to develop a water purification device for the village. Recent sanitation tests on the drinking water supplies of this community have shown that the greatest areas of concern are salinity and bacterial contamination. The system was designed to take water directly from local reservoirs and then reduce or eliminate these contaminants, in a simple yet effective manner.

The specifications for the device were to:

- Supply an adequate clean water supply to a household of 10 people
- Meet the water quality standards of the WHO
- Be constructed within a $AU 100 budget
- Minimise initial capital investment and ongoing expenditure
- Engage the community from the initial design stages; in order to encourage their acceptance and use of the final product
- Educate local villagers on the importance of water quality; in order to help with its integration in the village
- Create a socially, culturally, economically and environmentally feasible solution

A wide range of water purification technologies were considered and compared, with research suggesting that the device should incorporate slow sand filtration, chemical disinfection, ionic chelation or carbon adsorption into the purification process.

It was concluded that the most suitable solution would utilise slow sand filtration as the predominant purification technique. Slow sand filtration significantly reduces turbidity and bacteria concentrations and moderately reduces salinity levels in the water. It is recommended that this design also incorporate carbon adsorption and chelating agents. The addition of a charcoal layer, made from burned rice hulls and wheat husks, would provide a suitable filtration media and dispose of these otherwise useless by-products. Chelating agents are implemented through the addition of select organic acids to the filter beds and would act by absorbing salt cations. When used in conjunction with carbon adsorption, the salt ions are completely removed from the solution. Antibacterial plant extracts could be used in conjunction with the bio-layer of the sand filter to completely remove bacteria from the water.

This method is an easy to use, low cost option for the community, with an expected capital cost of $AU 16.59 and minimal ongoing expenditure, due to the durable nature of the materials. Unlike other methods, this technique requires little additional infrastructure and can be made into a portable modular device, suitable for the community's needs. It also has minimal detrimental effects on the environment, as it is self-sustainable, recyclable and is essentially carbon neutral.

The combination of these techniques creates a sustainable solution to the problem of water quality within the Devikulam community.

Table of Contents

List of Figures and Tables

1 Introduction

1.1 Background Information

Nearly 75% of the world's population live in developing parts of the world, and over 1.2 billion people have inadequate access to clean water (Ahuja 2009). In India, there is an insufficient quantity of fresh water to meet the growing populations' needs, and local water supplies are commonly heavily polluted with chemicals and domestic waste. This is responsible for a large portion of disease in these areas, which causes between five to ten million deaths each year, mainly in children (Chaudhuri & Sattar 1990).

The village of Devikulam is located in the region of Tamil Nadu, India. Due to deteriorating water quality, the village requires the implementation of a water purification system. Three separate bores supply the village's water. One of the bores contains water that is unfit for human consumption, due to its excessive salt content. The other two supply the village through a communal tap. A nearby pond is used for watering cattle, bathing and washing machinery and clothes. The pond poses a problem when the monsoonal rains transfer contaminants to the bore. As a result, the water quality in Devikulam fluctuates. Currently, the water supply is safe. However, salt-water intrusion has the potential of rendering the water too saline for consumption. The most prevalent issues with the drinking water are salinity, turbidity and bacterial contamination, all of which will need to be remedied by the proposed purification system.

1.2 Aim of Report

This report aims to develop a suitable water purification device that can be easily integrated into the Indian lifestyle, be built, operated and maintained at a low cost, be sustainable and possibly makes use of readily available materials. In addition, the purified water must reach a quality that complies with the international standards for drinking water, declared by the World Health Organisation (WHO).

To be effective the system must be economically and logistically feasible as well as culturally accepted by the people of Devikulam. The lack of reliable electricity in the village means that the filter must be able to operate without electrical power.

1.3 Contents of Report

This report is organised as follows. Section one provides an introduction to the current water situation faced by the global population and locates the community of Devikulum, India, as an area in need of a water purification device. Section two further defines the water quality problem faced by the community and assesses the need for a suitable solution to the problem. Section three outlines the scope of the project and any assumptions that were made throughout the development stages. Section four explores the technical aspects of water purification and current techniques that are used. Section five compares various feasible purification techniques and determines the most suitable method for the situation. Section six presents the final solution and assesses the feasibility of this design. Section seven outlines the community plan that was developed for the village to lead to their long-term acceptance of the device. Section eight provides details of a 'proof of concept' shown through a prototype device. Section nine is a detailed cost analysis of the system including capital and ongoing charges. Section ten lists possible failure modes of the system and provides methods for both prevention and repair. Section eleven details a lifecycle assessment of the final solution with reference to material production, use and disposal. Section twelve discusses the sustainability of the design with consideration to social, environmental and economic factors. Section thirteen provides any conclusions and recommendations that were drawn throughout the design process.

2 Problem Definition

2.1 Task Identification

The Devikulam community is located in the Kauveli Bioregion of Tamil Nadu, India. It is a small coastal village that depends mainly on agriculture for household income, due to the abundance of natural resources and a climate that is suited to farming. The community has approximately 320 members living in a number of households, with an average number of five in each household (Engineers Without Borders 2011). Generally, the houses are positioned in small clusters where extended families live in close proximity with one another (Engineers Without Borders 2011). Currently, water is supplied from a bore and is stored in a 30 000 litre tank. Here, it is distributed through a network to a number of communal taps throughout the community, where villagers collect water in large vessels for daily use. This water is used for various purposes, such as drinking, cooking, cleaning and personal hygiene. However, due to the community's unreliable reticulated power supply, access to the tap is only available for one hour in the morning and one hour at night.

Other water resources around the village include the pond, which is unfit for drinking but is alternatively used for bathing, washing and watering cattle, washing machinery and clothes. These uses result in the pond water being contaminated with human and animal waste.

On the 3rd of April 2010, a water quality analysis was undertaken by the Innovations Project Team of EWB and indicated that the current water quality is suitable for human consumption (Engineers Without Borders Innovations Team 2010). The report also indicated that the greatest areas of concern for the water supply are salinity and bacterial contamination (see Table 2.1.1). Salinity in the water is due to the over-extraction of groundwater, causing salt-water intrusion into the bore supply. It is believed that this level of salinity will increase over time as more water is taken from the bores. The increased levels of pathogens in the water of Devikulam are suggested to be due to human and animal contamination.

Table 2.1.1 – Devikulam Water Quality Results Compared to International Standards

Parameters	Units	Results		Desirable Standard (WHO, 1993)
		Bore Sample 1	Bore Sample 2	
pH (at 25°C)	-	6.8	6.7	6.5-8.5
Salinity - EC (at 25°C)	µS/cm	650	650	R. <308 µS/cm ≈ <200mg/L
Total Dissolved Solids - TDS (at 103°C)	mg/L	572	578	2000
Turbidity	NTU	<0.1	<0.1	10
Total Bacterial Level	N/100mL	124	142	0

Note: R= recommended, EC conversion based on conversion factor, TDS (mg/L) = 0.65 x EC (Harter 2003) Data only indicative of the quality on the day of testing.

Adapted from: Engineers Without Borders 2010

2.2 Task Analysis

Functions

The function of the purification unit will be the supply of drinking and cooking water only. A survey was conducted by Engineers Without Borders (EWB) that included data on the amount of water usage for all of the families in the village (Table 2.2.1). Water used for flushing and bathing is excluded, as it does not need to meet the same quality standards.

Table 2.2.1 – Devikulam Water Usage

Uses	Per Person (L/day)	Per 10 People (L/day)	Total Community (L/day)
Drinking	0.70	7	227
Cooking	0.78	7.8	252
Total	1.48	14.8	479

Note: Figures are averages derived from EWB survey (Appendix 16.1).

Source: Engineers Without Borders, 2010

A single water filter will need to have an output capacity sufficient to supply drinking and cooking water for 10 people. This amounts to a daily output of approximately 15 litres.

Outputs

The device is required to fulfil several output criteria, as listed below;

- Create a permanent modular solution to the water quality problem
- Meet the water quality standards requested by the locals and the international drinking water standards set by the WHO (1993)
- Produce enough clean drinking water to meet the needs of the community

The solution will aim to achieve all of these criteria, with the most suitable design being capable of reaching many (if not all) of these goals with consideration to social, cultural, economic, environmental and technical factors.

Impacts
The impacts on local community must be considered in order to create a suitable purification device. The final product must be a self-sustainable solution that improves the current water situation without impacting on the village's way of life. By involving the community in the process from the initial design stages, combined with the use of local materials, labour and production; the costs and environmental impacts are reduced. The Devikulam community will also learn to appreciate the need for clean water. With this understanding, the community would feel more inclined to use and maintain the purification device, improving the overall health of the village.

2.3 Design Requirements

Ethical practices should be at the forefront of the design and selection process, with considerations being made in regards to the social, cultural, economic, environmental and technical specifications specific to Devikulam.

Social
Due to the housing location and population density of the Devikulam village, a modular device is believed to be the most suitable option. This way, the device can be free-standing and serve purified water for one cluster of houses which would contain approximately ten people. Alternatively, the devices could be connected together to create a clean water supply for the entire village. When designing a system, the lack of infrastructure, technical skills and education of the villagers must be taken into consideration so they are able to operate and maintain the device.

An education program complete with assembly, operation and maintenance manuals should accompany the system, to encourage the understanding and long term acceptance of the final solution.

Cultural
In general, the Indian community is relatively conservative with strong family support systems. The device should be designed to purify water for each of the small clusters of houses, as a more private system designed for use solely within a family would tailor to the conservative nature of the people.

Census India (2001) indicates that approximately 88% of Tamil Nadu is Hindu. The design process needs to reflect an understanding of this cultural diversity. This is particularly important to note when deciding on the type of treatment to use. Hindu beliefs dictate that some forms of animal products cannot be ingested. This means that any form of animal-derived membranes or chemicals may not be accepted by a majority of the community.

Economic
The economic standing of Devikulam residents is extremely low as their main source of income, agriculture, is variable and unreliable. On average, Indian's living in rural areas earn only $AU 42 a month (Kripalani 2002), which is minimal in comparison to an average Australian wage. Although many people die or become ill as a result of water-borne illnesses, a study performed in 2002 by the United Nations Children's Fund (UNICEF) show that 'residents are still hesitant to spend money on water filtration systems due to their

extreme poverty'. Therefore, affordability of the solution is a major factor. To ensure that the final solution is of minimal cost, cheaper materials with long working life spans should be selected. Locally available materials should be considered where possible, with minimal importing of specialist technology. Despite the initial investment of the device, the use of local materials and labour to build, operate and maintain the device would support local business and improve the local and national economies.

Economic considerations will also limit the type of technology that can be implemented. The system will need to operate in such a way that the filter media will not require costly replacement or rejuvenation. If any of the components require replacement, a cost analysis will need to be undertaken to determine the financial feasibility of having such continued upkeep costs.

Environmental
The environment must also be taken into consideration with the design, through the choice of locally available, sustainable materials, whilst also exploring options for the disposal or recycling of the materials and their by-products.

Technical
The purification system is required to be simple, practical and easy to use. People of all ages, backgrounds and educational levels should be able to operate the device safely and efficiently, with very little manual labour required. The final design must be able to operate without the use of reticulated power, as the electricity system in the Devikulam village is unreliable. It should be able to make use of current water collection and storage systems that are already in place, and designed to be a portable system so as to be more suitable for the village conditions.

3 Project Scope

3.1 Project Boundaries

The scope of this project will be limited to only look at the production of a function water purification system that is specific to Devikulam's water conditions (Table 3.1.1).

Table 3.1.1 – In and Out of Scope Aspects of Design

In Scope	Out of Scope
• Be a modular device that is capable of purifying water for a household of ten people in the Devikulam community • Meet the water quality standards of the locals and the international drinking water standards of the WHO – within the parameters of being bacteria free, below recommended concentrations of suspended solids (salt and other chemicals), have a neutral pH range and be aesthetically pleasing (1993) • Not use reticulated power as electricity is an unreliable resource in Devikulam	• Be an effective purification device suitable for use in all areas of the world that do not have high water quality, both rural and urban • Water purification within the parameters of: other chemical removal and other water quality parameters • Treatment of existing water reservoir– village pond and bore supply • The proposed purification system will not be integrated into the current infrastructure; instead, it will be freestanding • Create a solution to fix the reticulated power

In Scope	Out of Scope
• Treat the current water supplies after removal from reservoir • Be culturally and socially appropriate for use in the Devikulam community, and consider the capacity of the residents to operate and maintain the system – simple, low cost and use local materials and labour • Be economically viable to implement, under a budget of $AU 100 for the entire system, with consideration to capital and ongoing costs • Be a permanent, sustainable solution for both the community and environment	problem experienced by the community • Repair Devikulam's second bore • Additional infrastructure improvements such as: water delivery, collection methods, waste water treatment, plumbed-in toilets and household taps

3.2 Assumptions

In order to limit the scope of what needs to be addressed, certain assumptions will be made about the conditions in Devikulam. These include:

- Approximately 15 litres of water will need to be able to be purified per day (Appendix 16.1)
- The water supply is constant and reliable, with water available year-round
- The village has a network that is sufficient in delivering the necessary volume of water to all inhabitants
- The production of a continuous or batch filtration system will both require some form of water storage facility. The inhabitants will be able to store the purified water without recontamination it
- The water is being treated after removal from the water reservoir, rather than treating the point source
- Operation and ongoing maintenance will be conducted by the Devikulam community

4 Literature Search

4.1 Purification Techniques

At present, there are a large number of water purification techniques that are used across a variety of situations. Each technique produces water with different levels of quality, flow rates, costs and labour intensities. Some of the current purification techniques include:

- Distillation
- Sand Filtration
- Ceramic Filtration
- Disinfection
- Sedimentation
- Plant Extracts
- Chitosan
- Carbon Absorption

- Chelating Agents

For a tabulated comparison of all purification options and their effects refer to Appendix 16.2.

Distillation

Distillation is the process by which water is evaporated and then condensed. This process removes bacteria, colloids and salt from the water. However, some organic chemicals, with boiling points close to 100°C, can also evaporate with the water vapour and become concentrated in the product water (Advanced Purification Engineering Corp n.d.). The use of solar distillation has been proposed as an environmentally sustainable method of water purification (Figure 4.1.1).

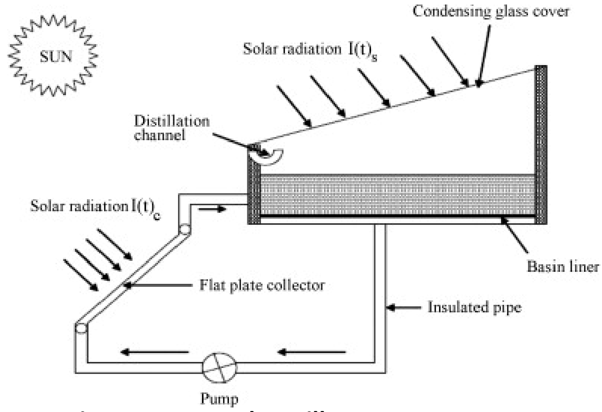


Figure 4.1.1 – Solar Still

Source: Arjunan, Pitchandi, Sampathkumar & Senthilkumar (2010)

However, even with an external heat source this option is unfeasible. In order to produce water when solar energy is limited, the system would also require energy saving cells. This is economically unfeasible. Currently there are no biogas facilities in Devikulam. Therefore, the use of an external heat source in order to power a still is not yet an option. If Devikulam develops the infrastructure required to produce and supply biogas, then distillation may become a more viable option.

Sand Filtration

Processes such as Slow Sand Filtration (SSF) remove smaller particles as they get caught in the spaces between granules or absorb onto surfaces with which they have chemical affinity. At the surface of the filter, a microbial slime layer develops which consists of decomposing organic matter, iron, manganese and silica, which acts as a fine filter to remove both organic and inorganic particles from the water (Figure 4.1.2). In addition, the World Health Organisation (1993) has proven that:

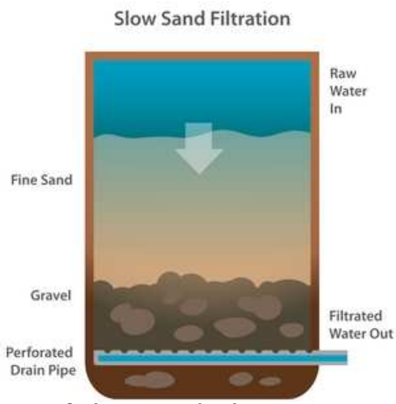


Figure 4.1.2 - Process of Slow Sand Filtration

Source: National Academy of Sciences, 2008

> 'when correctly loaded, slow sand filtration brings about the greatest improvements in water quality of any single conventional water treatment process. Bacteria removal will be 98-99.5% and E. coli will be reduced by a factor of 1000'

Ceramic

Ceramic water filters are an inexpensive and effective type of water filter, that rely on the small pore size of ceramic material to filter dirt, debris, and bacteria out of water. Ceramic pot filters are usually made from clay mixed with a fine-grained organic combustible material like sawdust, rice husks or coffee husks, and then fired in a kiln. The organic matter is burnt away, leaving only silica remnant and tiny holes in the filter.

Colloidal silver is sometimes used to help with pathogen removal. The silver helps to kill or incapacitate bacteria and prevent the growth of mould and algae in the body of the filter.

These filters have been found to remove between 96.4 to 99.7% of E.coli bacteria as 'silver ions interact with thiol groups in protein, which induce the inactivation of the bacterial proteins' (Chen et al., 2000).

Disinfection
The addition of chemicals to the water is a means of sterilisation on the household scale, which inactivates bacteria and other pathogens. The most common chemical additives include chlorine and iodine, which have been used for centuries as a means of disinfection (Chaudhuri & Sattar 1990). When these halogens come into contact with enzymes, they transfer a hydrogen ion which alters the cells properties, causing it to malfunction and die. After the addition of chemicals, the water must be held in a temporary stage to allow completion of the disinfecting process (Advanced Purification Engineering Corp n.d.).

Although this method could be efficient, the constant long term requirement of chemicals and the additional labour required prove it to be an inefficient means of purification.

Sedimentation
During sedimentation, the water is allowed to sit so particles are separated by gravity. The addition of a chemical coagulant during this process destabilises negatively charged particles so they clump together and separate faster. This process is capable of removing bacteria and other suspended solids from the water. However, the constant long term requirement of chemicals and the comparatively long time for purification proves it to be inefficient.

Plant Extracts
The village of Devikulam has at its disposal a large range of flora. Two local plants are of particular interest: jambolan (*Syzygium cumini*) and pomegranate (*Punica granatum*). Research conducted by Freitas et al., (2000), describes the antibacterial properties of the extracts from these plants. The experiment involved microorganisms that are both susceptible and resistant to antibiotics (Figure 4.1.3) and suggested that a wide range of bacteria is inhibited by plant extracts (Appendix 16.3). The experiment was conducted with concentrations of 5µg/ml.

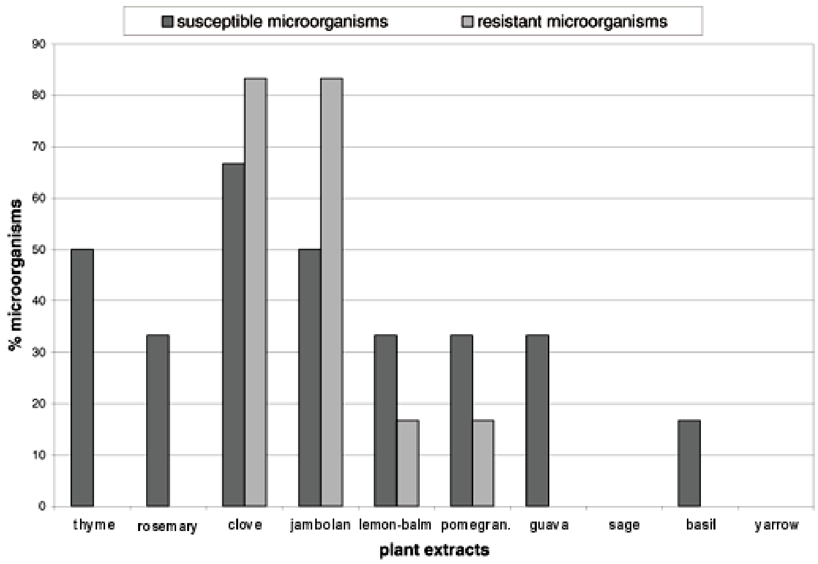


Figure 4.1.3– Antibacterial Properties of Plant Extracts

Source: Freitas, Locatelli, Nascimento & Silva (2000)

According to the Engineers Without Borders (2011) survey both jambolan and pomegranate are consumed within the village. As a result, the community would readily accept the use of these plant extracts.

Chitosan

An effective means of reducing turbidity is the use of flocculants to remove colloids from suspension. This is usually done with the addition of metallic salts that contain atoms with a valency of 3+. A naturally occurring alternative is the polymer chitosan, which has many favourable water purification properties (Appendix 16.4). Chitosan is classified as a bio-flocculent. “Bio-flocculents are safe and biodegradable polymers, and produce no secondary pollution”, Badot et al., (2009). In addition, Woodmansey (2002) reports that:

> The Chitosan causes the fine sediment particles to bind together and is subsequently removed with the sediment during sand filtration. Chitosan also removes phosphorous, heavy minerals, and oils from the water.
>
> Sand filtration apparently can remove up to 50% of the turbidity alone while the Chitosan with sand filtration removes up to 99% turbidity.

The addition of chitosan to the system would remove large quantities of all contaminants in the water, except for certain types of bacteria. To create a completely efficient system, these agents would have to be combined with another form of purification.

However, the integration of chitosan into the filtration process may not be possible for cultural reasons. With the vast majority of the Devikulam population being Hindu the addition of a crustacean by-product to the water filter may not be acceptable. Muslims and Buddhists also have restriction on the type of foods they are permitted to ingest. The filtration process leaves no traces of chitosan in the water (Woodmansey, 2002). It would be unethical to implement this technology without conducting a survey of whether chitosan use would be culturally acceptable. An education program could be run within the village to help the villagers understand and accept the inclusion of chitosan in their water filtration system. If this is unsuccessful, possible alternatives to using naturally sourced chitosan would be to use synthetised or isolated chitosan. In any case, if the filtration system is modular rather than communal, any families without objection to the use of chitosan could opt to use it as part of their unit’s filter media.

Carbon absorption

A carbon source is added to the water, generally as an individual filter system or as a material layer within a filtration system. The pores of the material trap microscopic particles and large organic molecules while small organic molecules absorb to the carbon surface. It also has the ability to remove disagreeable tastes and odours, and in some cases it has proven effective in the removal of microorganisms. The ability to remove these contaminants depends on the type and amount of carbon used, the design of the filter, the rate of water flow, the life of the filter and the types of impurities already removed (Chaudhuri & Sattar 1990).

Chelating Agents

A chelating agent is an organic chemical compound that can donate multiple pairs of ions to form several bonds to a single metal ion, holding it in solution as an inert substance (Shakhashiri 2008). Many chelating processes occur naturally, most commonly in biological processes within living cells, surface water and soil. It has been noted that some organic acids act as excellent chelating agents, with the ability to strip metal ions from salt molecules (Mosley 1998).

Although these acids would not improve the quality of the water on their own, if added to a filter bed, this could be an effective means of salt removal. The cheapest and most appropriate source of chelating agents would be peat, which is naturally produced and widely available all over the world, making it economically and environmentally feasible.

5 Initial Design Concepts

5.1 Summary of Initial Design Ideas

Although all of these techniques effectively remove a wide array of contaminants from the water, not all are suitable for use in the Devikulam community. Based on the design requirements, the most suitable methods for a water purification system in the Devikulam community are solar distillation, filtration and ceramic filters, as well as the use of carbon adsorption, plant extracts, chitosan and chelating agents. Complementing this selection, Johnson et al. (2008), have determined that the most appropriate solutions for water purification in rural areas of developing countries is sand filtration or chemical disinfection. As these processes are common techniques and have been highly documented, a solution to fix the water quality problem experienced by Devikulam is feasible and recommended to contain at least one of these processes.

5.2 System Requirements

Given Devikulam's limited resources as well as this project's support by the Pitchandikulam Forest organisation, the water purification system will not only need to be functional but also be suitable based on social, environmental and economic considerations. All of the aforementioned considerations can impact on the type of purification device selected and as such, the functionality of the device. Therefore, the criteria of functionality will be analysed alongside the other three. To compare their relative importance in deciding on a purification method, these factors were compared and weighted (Table 5.2.1).

Table 5.2.1 – Design Requirement Weighted Matrix

	Social	**Environmental**	**Economic**	**Functional**	**Raw Score**	**Percentage from Total**
Social	-	4	4	3	11	30%
Environmental	2	-	2	2	6	17%
Economic	2	4	-	4	10	28%
Functional	3	4	2	-	9	25%

Note: A higher value in any cell indicates that the requirement of the row was considered more important than the requirement of the column.

Key

5	*Much more important*
4	*More important*
3	*Same level of importance*
2	*Less important*
1	*Much less important*

Social and economic considerations of the device are measured to be the most important factors in decision making. This is due to the success of the device pinning entirely on whether it is affordable, as well being accepted, understood and used by the village.

5.3 Selection From Initial Designs

On this basis, a comparison of the initial ideas was conducted and marked across these requirements according to a measured scale (Table 5.3.1).

Table 5.3.1 – Design Marking Scale

Qualitative	Quantitative	Social	Economic			Environmental	Functionality			
		Use of Community Plan and Appropriateness of Method and Materials	**Capital Cost ($)**	**Ongoing Cost ($)**	**Expected System Lifetime (years)**	**Energy use**	**Bacteria Removal**	**Turbidity (NTU)**	**Flow rate (min/L)**	**Salt (ppm)**
Poor	1	Completely does not respect local culture and no community members educated	>140	Complete replacement	<1	Unnecessary	None	>20	>30	>3000
Below Satisfactory	2	Parts of local culture not respected and few community members educated	100-140	Substantial	1-2	Substantial	-	10-20	15-30	1000-3000
Satisfactory	3	Local culture not considered and only select community members	60-100	Moderate	3-4	Moderate	-	2-10	5-15	500-1000
Good	4	Respects majority of local culture and many community members educated	20-60	Minimal	5-6	Minimal	-	0.5-2	2-5	100-500
Excellent	5	Completely respects local culture and all community members educated	<20	None	>6	None	Complete	<0.5	<2	<100

A five point scale was used to mark the effectiveness of the device as this method provides a result that enables the expression of neutrality and is easily differentiable between grades. Quantitative results were chosen where possible to provide an easily measurable result that is not subject to bias or human error.

Its social compatibility was measured based upon how well the device could be incorporated into the community and whether or not it would impact on the villages lifestyle. Economic scores included considerations such as the expected lifetime of the system and its capital and ongoing costs. Environmental impact was measured considering the device's use of local and environmentally friendly processes and material options, as well as the device's use of energy. Energy was defined as the amount of energy used during the device's operation.

The functionality of the device was measured by its ability to perform to meet required conditions, such as flow rate, bacteria and salt removal, and turbidity reduction. The removal of bacteria was considered to be either complete or negligible. Although this does not account for partial bacteria removal, the system is required to remove 100% bacteria (Appendix 16.5) and any result other than this is well below satisfactory. Based on the water requirements of the village, the system is required to meet an output of at least 15L/day per household. This is equivalent to a required flow rate of 0.021L/min if it is to be run 12 hours per day (Appendix 16.6).

Using this scale, the initial design ideas were compared to determine the most suitable solution for the village (Table 5.3.2). In areas where marks varied across an individual section (e.g. different marks for bacteria and salt removal in functionality), the average value for these sections was taken to the nearest whole number.

Table 5.3.2 – Comparison of Initial Design Ideas

Method	Social	Economic	Environ-mental	Functional	Score	Weighted Score
Sand Filter	5	5	4	3	17	4.22
Clay Filter	5	5	4	2	16	3.97
Still (solar)	5	3	4	2	14	3.63
Still	4	3	3	3	13	3.30

Therefore, according to this scale, the most suitable purification technique would be through a sand filtration system, as it meets all of the requirements.

5.4 Material Options and Selection

The proposed system is to be based on a sand filtration system. As well as this, the device was decided to also contain elements of carbon adsorption and chelating agents to achieve higher water quality. To determine the most suitable materials for all components of the device, the most viable options were analysed and compared.

Foundation Materials
Many of the basic materials for the filter, including the sand and drainage gravel, are standard components and are therefore have no comparable replacement options. Other components such as chelating agents and materials for carbon adsorption have multiple options.

Sand and Drainage Gravel
Although sand and drainage gravel are integral parts of the system, the grain size of the material and bed depth affect the system's effectiveness. Typical grain sizes range between

100-1000 microns, however for the highest quality filtration the finest grain size is preferable (Chaudhuri & Sattar 1990). The system is most effective with a bed depth of at least 0.4m as this is where the majority of contaminants are removed (Chaudhuri & Sattar 1990). Therefore, the final system is required to have a bed depth of at least 0.4m.

Chelating Agents
There are a wide variety of chelating agents available, with various tendencies to attract different metal ions. One of the most widely available, natural chelating agents is the organic acids found in humus, a major component of all soils. Humus is formed by the decomposition of organic matter and contains a group of complex organic compounds including humic acid ($C_{187}H_{186}O_{89}N_9S$) and fulvic acid ($C_{135}H_{182}O_{95}N_5S_2$) (Mosley 1998).

These organic acids are found in higher concentrations in minerals such as peat, lignite and leonardite, which are by-products of the coalification process (Shakhashiri 2008). Out of these minerals, peat is the most easily formed and is therefore the most common and widely available throughout the world. In addition, it is non-toxic to both humans and the environment, making it the most suitable.

Carbon Adsorption Material
Conventional systems absorb contaminants using charged resins. However, these processes are economically and environmentally unfeasible. Any source of carbon exhibits active adsorption sites and can therefore be used to adsorb contaminants from the water (Chaudhuri & Sattar 1990). The Devikulam community uses wood as its major source of fuel, producing a large amount of unusable charcoal as a by-product. The use of charcoal as a carbon adsorption material would be economically, environmentally, socially and functionally suitable.

Infrastructural Components
As the device is required to be modular and implemented at the household level, the dimensions and specifications of conventional sand-based filters was chosen to be scaled down to produce a suitable device. On this basis, although the main body of a conventional sand filter would be made from a 250L steel or plastic drum, the materials selected for the proposed solution where chosen to be scaled down and made from 5L containers.

For the body of the system, there were a number of different housing options available, including ceramic and plastic pots (Table 5.4.1).

Table 5.4.1 – Comparative Analysis of Pot Material

Properties	Ceramic Pot	Plastic Pot
Melting Point	927-1230 degrees	150-175 degree
Young's Modulus	15-30 GPa	0.896 – 1.55 GPa
Yield Strength	5-14 MPa	20.7 – 37.2 MPa
CO_2 footprint	0.2-0.23 MJ/kg	1.09-1.18 MJ/kg
Embodied Energy	2.2-3.5 MJ/kg	35.7 – 44.1 MJ/kg

Adapted from: Granta, 1994

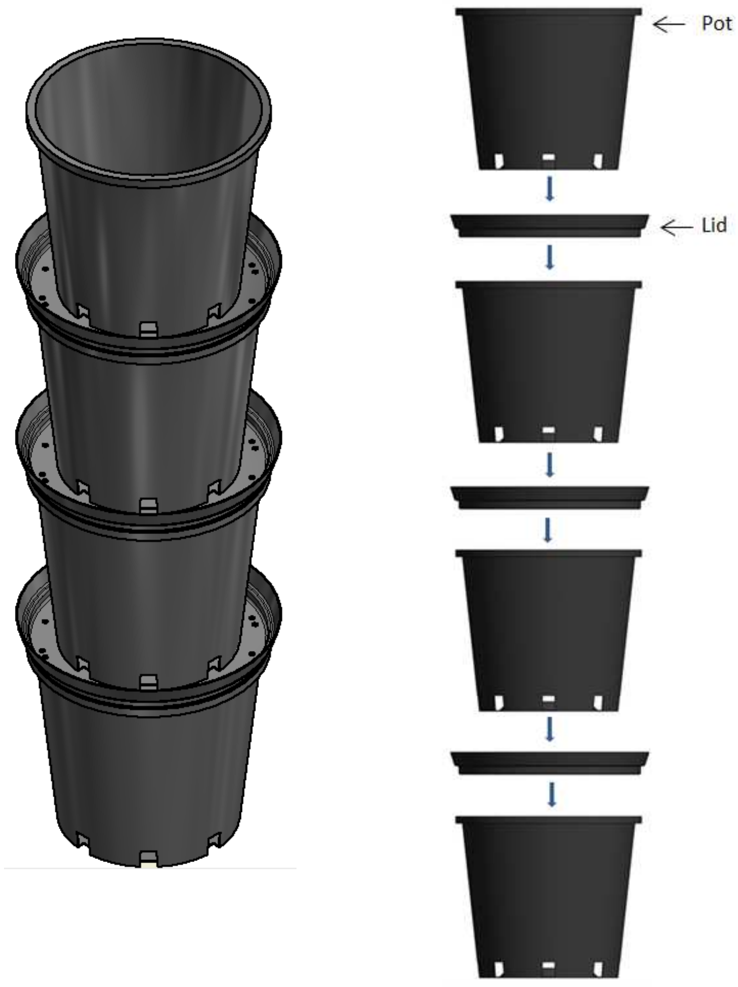
Ceramic has approximately half the embodied energy value of plastic and double the CO_2 footprint. However, it has a lower strength and is more difficult to source sustainability in India. Many of the firing processes used to make ceramic items in India are inefficient and use large amounts of charcoal, wood and coal as fuel sources. This makes plastic pots the most suitable housing option for the filter system.

A diffuser is required on top of the sand layers in order to leave the bio-layer undisturbed when water enters the system. The most suitable material for a diffuser plate would also be made of plastic based on the same justifications.

6 Final design

6.1 Summary

The final design is a variation on a gravity fed slow sand filter that also incorporates the use of chelating agents and aspects of carbon adsorption. From top to bottom it consists of four segments. Pots one and three contain compacted sand; with compartment three also containing the antibacterial plant matter. Compartment two consists sand, charcoal and peat. Compartment four contains sandstone atop of gravel. A diffuser plate will separate the layers (Figure 6.1.1).



Height: 743mm Width: 230mm

Figure 6.1.1 – Sketch of Final Solution

For wire frame view with dimensions refer to Appendix 16.13

6.2 Technical Understanding of Design

The combined layers of the proposed mixed media filtration system are capable of removing a large amount of contaminants from the water, including bacteria, salt and suspended solids.

Sand

The sand layers within this design are aimed to act as a slow sand filter system that will remove turbidity and bacteria from the water. The permeability of the compacted sand allows water to flow through at an acceptable rate, but absorbs particles with which it has chemical affinity and traps particles less than 5µm in diameter. This will capture sediments and microorganisms that are greater than 5µm in size.

At the surface of the filter, a microbial slime layer will develop over time, consisting of bacteria and decomposing organic matter. As bacteria contaminated water enters the system, it absorbs to this layer and becomes trapped in the natural food chain, where it is removed by predation. The bio-layer also acts as a fine filter by oxidising both organic and inorganic particles, removing them from the output water.

The bio-layer of the sand component will gradually become choked over time, reducing the flow rate through that section however the output water quality will remain the same. To restore the bio-layer to full working order, infrequent back flushing is required. However, the need for back flushing the system is significantly reduced due to the small cross-section of the device and the fact that it is gravity fed.

The sand can be obtained from any sandy soil within the area, provided it can be washed thoroughly with clean water. For the correct properties and grain size, it is recommended that it be taken from at least 30cm below the ground (Chaudhuri & Sattar 1990).

Peat

Peat is a naturally available source of highly concentrated organic acids, which act as chelating agents by absorbing metal ions from solution. Both the fulvic and humic acids in the peat become acidified in aqueous solution and then act to absorb the salt cations (Na^+, Ca^+, Mg^+) from the water. Each molecule of acid has fourteen active sides when acidified, which means that upon complete reaction, each molecule of acid releases fourteen hydrogen ions into the water, which therefore decreases the pH, forming an acidic solution.

However, as this layer absorbs contaminants from the water, it will reach a saturation point and will cease absorbing ions. The recommended amount of peat to be used in the proposed system is 500g of compacted material. During monsoonal periods, the salt concentration in the bore supply is expected to peak at 5000ppm (5g/L) and the peat will last approximately four days when operating at 95% efficiency to meet the WHO water quality standards (Appendix 16.7). At other times of the year when the salinity of the water is relatively constant at approximately 300ppm (0.3g/L), the peat will last approximately eight weeks when operating at 95% efficiency to meet the WHO water quality standards (Appendix 16.7).

As peat is a naturally forming component of many soils and bogs, it is widely available and relatively inexpensive to use, however it takes a very long time to regenerate. India is one of the world's largest exporters of coco peat, which is a fibrous material made from the wasted coconut husks of the coconut plantation industry, and exhibits properties similar to that of peat. Both are renewable sources, however the use of coco peat for the actual system may be more feasible for both environmental and economic purposes.

Charcoal

The charcoal layer within the system will be effective in removing small impurities from the water, including materials that affect the waters' taste, colour and odour. The charcoal acts as a source of activated carbon and as water passes through, the propensity of microorganisms and chemical material to bond with the carbon allows them to be removed from the water. This process will also aid in removing excess salt ions from solution.

Before placing it in the system, the charcoal was crushed and compacted down. This increases the surface area of the activated carbon and therefore increases the number of reactive sites, increasing its efficiency.

The charcoal could be sourced from the village's fires and wood based ovens. Making use of these waste products will be the most environmentally sustainable source of charcoal. However, if this supply is insufficient, charcoal could be easily produced. As the main source of income in the Devikulam community is through the agriculture of mainly plantation crops, the large quantities of by-product materials produced could be burned as a low grade fuel in the village's fires and wood based ovens to produce the charcoal layer. By-products such as wheat kernels, rice hulls and coconut husks are all of low nutritional and agricultural value, but when burned, these products produce a charcoal that is mainly composed of carbon and silica, and retains the original structure and porosity of the hulls (Chaudhuri & Sattar 1990).

The charcoal layer would require infrequent maintenance and is expected to have a useful operating life of six months. After this time, it could be disposed of with the other sand filtration media back into the natural environment with no detrimental effects. As the mixture could be produced locally, the system costs are reduced and any negative economic impacts that would result from the purchase of a more conventional carbon source.

Antibacterial Plants

The extracts from the jambolan plant and the pomegranate contain various phytochemicals, which inhibit the growth of certain microbial organisms. The combination of flavonoids and tannins from jambolan leaf combined with the ellagitannins and alkaloids from the pomegranate percarp inhibit the growth of 9 different bacterial species including Staphylococcus aureous (Freitas et. al. 2000).

The antibacterial plants available to Devikulam are capable of removing up to 85% of bacteria from the water (Freitas et. al. 2000). The types of bacteria immobilised include Enterobacter aerogenes, Pseudomonas aeruginosa and Bacillus subtilis (Freitas et. al. 2000). When these plants are combined with the effectiveness of the bio-layer to also remove E. coli and other harmful pathogens, a 3 log reduction in bacteria is expected (WHO 1993).

Sandstone

Sandstone has a tendency to leak anions into the water, forming a basic solution and thereby neutralising the pH change from the peat layer. In addition, it acts as a type of gravel to catch any large particles that may have fallen through the system. The addition of sandstone to the system does not affect the overall water quality except for the slight increase of pH. The slow release of cations into the water will result in this layer to become depleted over time, however due to the relative size and reactivity of the sandstone, this can be considered negligible.

Sandstone is one of India's major exports and one of India's largest sandstone quarries is located near Tamil Nadu (Granite Sandstone n.d.). As it is a locally produced resource in the area, there is local financial incentive with its use as funds are kept within the local economy. Therefore the use of sandstone within the system is environmentally, economically, socially and functionally feasible.

Gravel
The gravel layer at the base of the system acts as a final media bed to trap any larger particles or other filter media that may have fallen through. The use of larger sized (7mm) drainage gravel allows the flow rate through this section of the system to be higher, which does not affect water quality, as it has no additional filtration properties. As it is simply a tool to hold the system together, the gravel could be sourced from any rocky soil.

Cloth Lining
The addition of a cloth lining to each of the pots acts as an additional filter layer and the fine weave of the material holds all components of the system in place. Over time, the cloth will begin to weaken and eventually deteriorate, with an expected operating life of six months. Calico is an easily manufactured material that is widely available throughout the world.

Infrastructural Components
Polypropylene is a widely available material across the world. It is a relatively cheap material, which has many desirable properties such as durability and flexibility. These properties make this material quite versatile and suitable for the situation. Polypropylene's durability means that the system shell is resistant to wear and will require infrequent replacement. All materials have been chosen due to their long working lifespan, and the outer polypropylene shell is expected to have a useful operating life of 2.5 years.

6.3 Specifications

This device would collect water from the available village taps and store it in the raw water containers that are currently used. This water would then be fed through the purification device to produce clean water that is suitable for drinking, cooking and personal hygiene purposes (Figure 6.3.1).

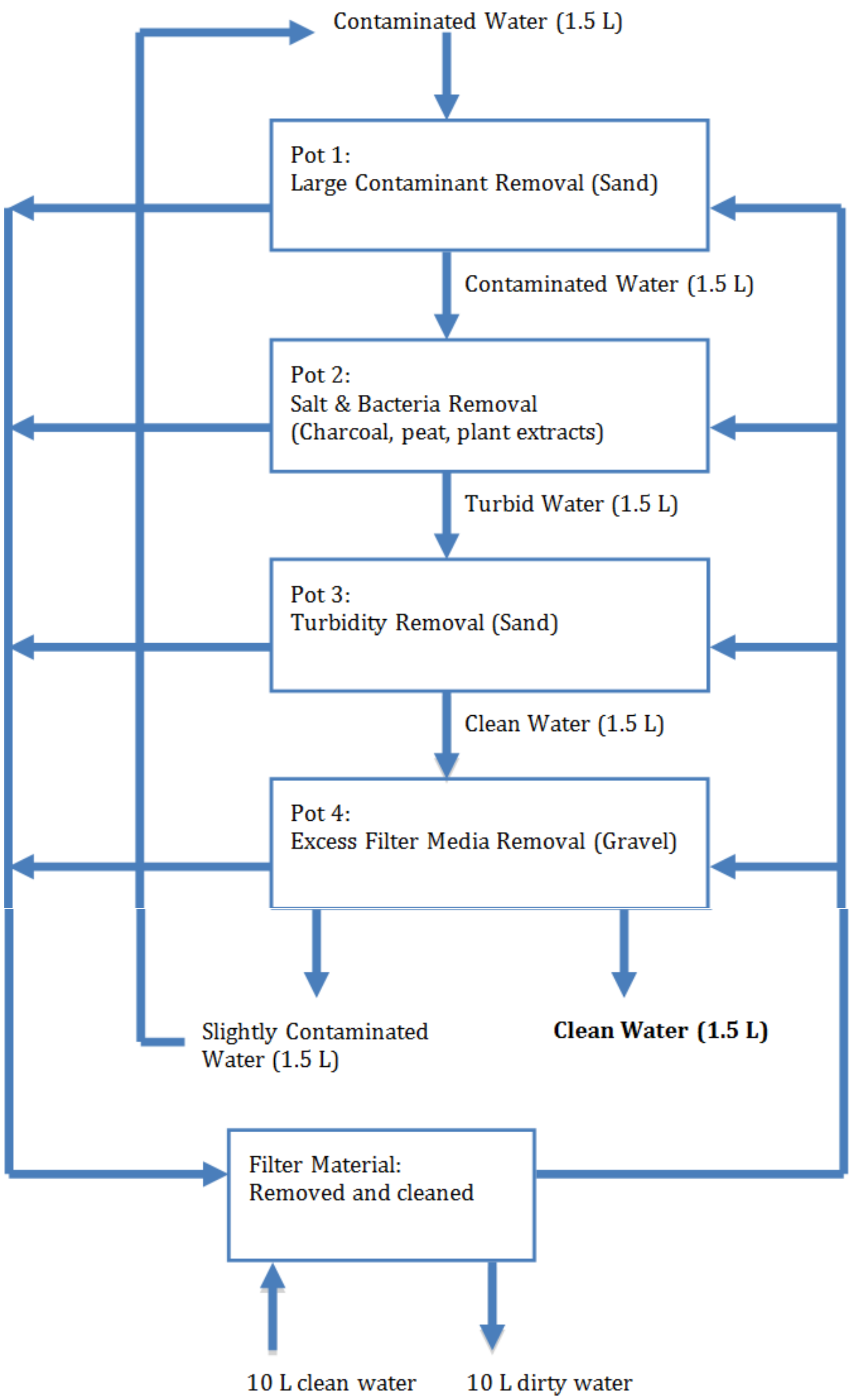


Figure 6.3.1 – Process Flow Diagram with Mass Balance

Modularity

The nature of the system allows for individual layers to be easily separated and rearranged if required. This feature would prove useful if the community's water conditions were to suddenly change, as more layers could be designed to suit the new conditions, and then easily assembled and placed within the existing system, without the need for complete replacement.

Intermittent back flushing is simplified as each component can be washed separately as required, with no loss of material as each section is sealed. Any required replacements or maintenance work that must be performed on the system is also reduced, as the specific problem area can be easily identified and treated.

Operating Conditions
The device is recommended to be used outside and placed in the sun as slow sand filtration has also proved to be more effective with higher water temperatures, as there is more biological activity within the filter bed (WHO, 1993). By encasing the system within a shell, there is another layer of air between the filter and the environment, providing insulation. To further improve the heat capacity of the filter, the external surface was chosen to be black, as this acts to absorb more heat rays.

6.4 Efficiency

To meet the drinking water expectations of the local villagers and the water quality standards set by the World Health Organisation, the device must meet a number of efficiency standards. The device must be capable of removing 100% of bacteria, 80% of turbidity and 70% of salt from the water (Appendix 16.5). The proposed system is designed to greatly improve the water quality in comparison to the current techniques employed by the Devikulam community and is expected to exceed WHO standards if operated correctly operated (Appendix 16.10). The calculated flow rate for the system is 0.096 L/min, which exceeds the required flow rate of 0.021L/min (Appendix 16.6).

6.5 Effects on community

By including a community plan to involve the community in the process from the initial design stages, combined with the use of local materials, labour and production, the costs and environmental impacts of the system are reduced. The Devikulam community is also able to understand their need for clean water. With their newfound understanding, the community would feel more inclined to use and maintain the purification device, improving the overall health of the village.

With the implementation of this device, it is expected that the community's overall health will improve and they will develop an understanding on the importance of using clean water. As the proposed design is to be implemented at the household level, the conservative nature of the Indian community is preserved, and there are no detrimental cultural effects.

The proposed solution is a socially, culturally, economically, environmentally and technically suitable device for use in the Devikulam village. If correctly loaded, it will meet all water quality requirements as defined by the World Health Organisation and will produce enough water to meet the needs of a household of ten people.

7 Community Engagement

From the beginning of the project, correspondence with the community is vital to determine key design conditions such as: the community perceptions of the current situation; the interest in and their willingness to accept change; the attitudes towards the reuse of natural resources; use of local labour and work delegation; and preferences to communal or private facilities. According to Kalbermatten et al. (1980), 'community involvement in the entire development of the proposed solution is key to its success'. By incorporating the community this way, the need for change comes from within the community, and it is more likely to be successful as they see its value and have a sense of ownership over the project.

7.1 Difficulties in Working Cross Culturally

There are difficulties in working cross-culturally, such as language barriers and the misinterpretation of vital information. However, these can be minimised or overcome by using English-local language translators and by working with counterparts from local organisations. This ensures that the community values are respected and the design is accepted.

Pitchandikulam Forest is the local organisation that is working in conjunction with Engineers Without Borders to implement the most suitable water purification device into the village. Any dealings with the community with surveys or education programs would be delivered via this organisation. This would keep the entire project within the local community, where it is more likely to be successful.

7.2 Project Approach

Due to the difficulties of working cross-culturally, the project should be approached on a strength versus needs basis, to first externally determine the requirements of the solution, considering social, environmental, economic, cultural and technical factors. Once viable solutions have been determined, the community should be consulted through the local organisation to determine their specific needs and requests.

There are many differences in how members of the Devikulam community would solve problems compared to how Australian engineers would find a solution. The project must develop a solution that meets the needs of the community, but must also consider the lack of infrastructure, technical skills and education of the villagers in the design, implementation, operation, maintenance and disposal stages of the system.

7.3 Survey to Determine Requirements

To assist with this strength versus needs approach, a sample survey has been developed to assess community perceptions and subsequent requirements for the design (Appendix 16.8). The results of this survey would be used to further aid in the design and implementation of this system, to increase its chance of success.

If this survey proves too difficult to employ, a village meeting could be arranged through the Pitchandikulam Forest organisation to help define these parameters orally. This could involve translators and either all of the local people or a select group of community representatives that are a true indication of all ages, genders, educational levels and technical abilities of people in the village.

7.4 Education

Education also needs to be coupled with the design to ensure that all villagers of all ages understand the importance of hygiene and using clean water. This education should then become embedded within the society, allowing the community to perceive the value of the proposed design and creating a high quality of life for years to come.

The proposed education program to be implemented alongside the system includes two sections. One includes information on safe water usage to promote hygiene behaviours and sanitation. The other encompasses an operations manual to aid in understanding and maintaining the system.

Water and Sanitation Program
As the water quality of Devikulam's supply is under constant pressure and easily contaminated, the local villagers need to be educated on the importance of using purified water and the protection of the water source. The main aim of this educational program is to achieve long-term acceptance and sustainability of the device within the community, by improving their understanding and belief in water health concepts.

This program should commence within the community several weeks before any implementation is started and should be completed when the survey is held. This will ensure the community has enough of an understanding to complete the survey.

The concepts that need to be understood by all members of the community include:

- Water taken directly from local sources is often highly contaminated by suspended solids, salt and/or bacteria
- Bacteria is a form of contamination and can cause serious sickness and disease
- Bacteria and other micro-organisms will not grow in the absence of water, therefore damp or wet things promote their growth and cause sickness
- Hands are the main route of disease, and need to be thoroughly washed with soap and clean water, especially before the handling of food or drinking water
- Washing of hands, clothes, animals, utensils etc. in raw water does not decontaminate them as this is raw water and highly contaminated

These concepts will be promoted throughout the village by encouraging:

1. Clean collection and handling of raw water
    - Water should be collected from the tap near the village bore in a suitable storage container with a lid to prevent further contamination
    - Cups or hands should not come into direct contact with this raw water
2. Hygienic storage of purified water
    - Livestock and domesticated pets need to be kept away from potable water
    - The storage container for the potable water needs to be covered and airtight, to prevent recontamination
3. Conservation of natural resources
    - The required volume of water to supply a household of ten people to ensure there is enough water but it is not wasted
    - If too much potable water is produced, it should be stored in another container and prioritised for use within the next few days
    - Large consumption rates may have adverse environmental impacts on the local water source
4. Protection of local water sources
    - The source water quality can be improved by the construction of fences and signs to limit its use by people and livestock, reducing the amount of contamination in the input water supply
    - As the pond is currently used for bathing, washing and watering cattle and washing machinery and clothes, water from the pond could be taken away in

large storage containers and these processes be performed off-site. This would reduce contamination but still not affect the local villagers' daily practices

5. Correct use of both raw and potable water
    - Raw water straight from the village tap is suitable to be used for cleaning, bathing, maintenance of livestock etc.
    - Signs written in the local language could be placed near the village taps stating what this water can be used for
    - Purified water that has come from the system is to be used for drinking, cooking and personal hygiene
    - Posters written in the local language and containing various images will accompany the implementation of this system and will state what the potable water can be used for (Appendix 16.9)

This education program will be communicated to the public in two ways:

1. Education in Schools

Children in the local schools would be one of the main focuses for this education program. They would be taught the basic concepts of sanitation and hygiene on a fun and interactive scale, including hands on activities, role play and puppet shows. By encouraging children from a young age to be 'water safe', they will be able to make well-informed decisions on their hygiene, aiding in creating the next generation of well-educated villagers.

2. Community Meetings and Discussions

These various educational aspects would be taught via regular community meetings, initially held with a health-aid worker. This will ensure that the community understands the need for clean water and hygienic practice and will receive full benefit from the purification device. Over time, voluntary members of the community would be taught safe water practices to a greater depth and supplied with water safety books and guides as reference tools. These villagers would then be put in charge of organising and holding regular meetings and helping other community members to understand the benefits of using safe water. By allowing a continuing program to be run by the village itself, they receive a sense of ownership over the project, further encouraging its success and promoting long term social sustainability of the device.

Operational Program

This program is based on ensuring that the device is implemented, operated and maintained regularly and correctly. It also aims to give the community ownership of the project by allowing them to understand how the system works and exactly what they are required to do.

Each household will be issued with a simplified operation manual, including detailed instructions and a troubleshooting section (Appendix 16.9). This will also provide basic information on how to assemble, operate and maintain the system.

Voluntary community representatives will be further educated on how the system works and asked to overview the implementation and construction of the device so they understand how it works and is put together. They will then be put in charge of the project and are required to perform regular checks and general maintenance of the system. These routine checks would occur monthly and include checking the filters and reservoirs for faults and leakage and ensuring the supply taps throughout the village are operational. They will also be encouraged to hold a dated logbook of when these routine inspections and maintenance occurred. In addition, emergency phone numbers of local counterparts and water experts will be provided so the villagers can receive outside help if they require it.

Often, the best technique to improve water quality in small communities is to protect the water source from further contamination (WHO, 1993). By quarantining the areas around the village pond and bore reservoir, human and animal contamination could be limited, and the initial water quality be improved. This would cause less stress on the filtration system, increasing its lifespan and producing a higher quality final product. However, as the pond is currently used for bathing, washing and watering cattle and washing machinery and clothes, water from the pond could be taken away in large storage containers and these processes be performed off-site. This would reduce contamination but still not affect the local villagers' daily practices.

8 Details of Prototype

The prototype has been developed to provide an accurate physical representation of our proposed system. It has been designed to be very similar to the final design but be slightly adapted to suit the conditions required of the system demonstration. These adaptations include:

- The removal of a water storage system within the design
- The use of materials from local Australian sources such as: sand, gravel, charcoal, peat moss, sandstone
- The simplification of the water collection method
- The removal of an outer casing from the system

As well as these adaptations, a few material substitutions have also been made involving the use of antibacterial plants.

8.1 Scaling of Prototype and Final Solution

The scale of the prototype to the final model is 1:1 and the majority of the materials and components are identical as they are available in both Australia and India. This allows an accurate representation of the final system with respect to its ease of use, removal efficiencies and flow rate, and its true dimensions and specifications.

Although the prototype device could be used 'as is' for implementation into the community, there is also the option of scaling the device to suit specific requirements, which could be achieved in one of two ways:

1. Although the proposed design is only one unit, it is a modular device and able to be connected with other units to create a grid. This grid system would be fed by water removed directly from the current storage tank and then divided across each of the units to purify the water. Once the water is clean, a series of valves and PVC pipe connections would direct the water from each unit to another large storage tank. By connecting the units together, the community could create a communal water purification system that would allow for larger volumes of clean

water to be produced and stored at any given time, allowing the entire village access to clean drinking supplies at any time of the day.

2. A single system could easily be scaled up to support the water requirements of the community at a village level. This scaling would involve the proportional increase of all components of the system and the addition of a support frame to hold the increased weight. If the larger device was positioned centrally in the village, it would be a communal water purification system that could be directly gravity fed from the storage tanks of bore water to eliminate the need for an additional water storage method above the device.

8.2 Substitutions

Antibacterial Plants

The antibacterial plants available to Devikulam are capable of removing up to 85% of bacteria from the water (Freitas et. al. 2000). The types of bacteria immobilised include Enterobacter aerogenes, Pseudomonas aeruginosa and Bacillus subtilis (Freitas et. al. 2000). When these plants are combined with the effectiveness of the bio-layer to also remove E. coli and other harmful pathogens, a 3 log reduction in bacteria is expected (WHO 1993).

However, due to the time required to create an effective bio-layer on the sand filter and the availability of the antibacterial plants, this method could not be employed into the system for preliminary testing. Instead, the prototype will use a bacteria removal tablet, *Aquatabs*, to create a realistic representation of the final solution.

The use of *Aquatabs* is a suitable alternative to the bio-layer and antibacterial plant purification combination as it has comparable removal efficiencies and effects on specific pathogens. The *Aquatabs* lead to a 3 log reduction in harmful bacteria such as E. coli, Pseudomonas aeruginosa and Bacillus subtilis (Medentech 2009). Therefore, it is a suitable replacement option for the prototype.

Water Collection Method

As proposed, the final solution would operate with a water storage facility at its base, where approximately 10L of water is able to be stored at a time and accessed via a valve at its base. For the prototype demonstration, this elaborate water collection method was deemed out of scope, and a simpler option was employed. The method involved the system resting on another pot base with a single hole drilled through, which allows water to fall directly into a catchment container, which is suitable for the demonstration of a prototype system.

External Casing

To reduce the chance of overflow, protect the system from harsh environmental conditions and to make it more aesthetically pleasing, the entire device would be covered in a type of external casing. This casing could be made as a solid structural unit or be as simple as a material covering such as cloth or tarpaulin. Although this would marginally increase the cost of the unit, this is subsidised by the extended lifetime of the system from this protection.

8.3 Additions to Final Device

Clay Base
To incorporate the favourable properties of a ceramic filter, a fired clay base could be added to the final pot of the system so the water has to pass through this porous filter upon exit. If fired with waste products such as coffee grounds and rice hulls, these organic materials will burn away in the extreme heat, leaving cavities and pores within the plug to trap pathogens and other contaminants. The ceramic plug can be easily and cheaply made from locally available clay, and have been shown to remove between 96-99% of E. coli passing through them (WHO 1993).

9 Cost and Bill of Materials

9.1 Bill of Materials

From the comparison of the composition and chemical parameters of the different materials, and their specific costs, the materials selected for the modular design are as below. The table shows cost price, relative cost for each modular filter, and quantities of materials used (Table 9.2.1).

Table 9.2.1 – Bill of Materials

Material	Unit Cost ($AU)	Units Used	Prototype Cost (SAU)	Final Village Cost ($AU)
Sand	0.67/shovel	1 shovel	0.67	-
Drainage Gravel	0.72/shovel	0.5 shovel	0.36	-
Aquatabs	9.95/50 tablets	2 tablets	0.40	-
Calico	4.00/m^2	1 m^2	4.00	4.00
Plastic Pots	1.78	4	7.12	7.12
Plastic Saucers (200mm)	0.95	1	0.95	0.95
Plastic Saucers (250mm)	1.37	3	4.11	4.11
Charcoal	1.64/L	0.25L	0.41	-
Peat	1.00/L	0.50L	0.50	-
Sealant Tape	0.16/m	2.5m	0.41	0.41
		Total	18.93	16.59
		Approximate Cost in India*	-	INR 850

Note: Approximate Indian cost correct according to global markets as at 02/06/2011

9.2 Cost of Final Solution

Based on the bill of materials, the capital cost of the village's device is $AU 16.59 per unit. The construction and maintenance costs of the proposed system are kept to a minimum by the use of recyclable, organic materials that are freely available and locally distributed. By using locally available materials, the local economy is supported.

It is assumed that the majority of the filter components are easily accessible and freely available for use to all members of the Devikulam community. At no cost, the charcoal, sand, gravel, sandstone and clay components of the filter can be collected from the natural environment or through the recycling of agricultural wastes.

The individual components of the system can be replaced independent of each other. The polypropylene pots will last approximately 2.5 years and will contribute $AU 0.00091 to the yearly cost. The calico will deteriorate within six months and will contribute $AU 0.00139 to the yearly cost. The resulting cost per litre is $0.0023/L (Appendix 16.10).

10 Failure Mode and Effects Analysis

10.1 Design Overview

An important measure of the efficiency of the device is its performance reliability and safety through operation.

Reliability

With suitable operation and maintenance methods employed, as per the device's operation manual (Appendix 16.9), the system will continue to produce clean water for its entire operational life. With infrequent media maintenance and disposal, the system could remain in effective operation for over ten years (Chaudhuri & Sattar 1990).

Safety

Overall, the system is of safe design as it has no moving parts and operates on a simple 'water in, water out' basis. This means it could be safely implemented, operated and maintained by all members of the village, no matter their age, gender, education level or technical ability. During the purification process, there are no harmful chemicals used or created by using this type of system, making it a low risk option for implementation into India.

10.2 Failure Mode and Effects Analysis (FMEA)

The quantification of a failure mode analysis, through a risk priority rating, is determined by predicting past, present and future implications of a specific failure mode occurring, based on its severity of occurrence, probability of occurring and post-occurrence detection capacity (Figure 10.2.1). All possible failure modes were analysed and compared to determine the overall safety of the device. Many of these modes involved degradation of materials, which can be easily resolved by conducting routine inspection and replacement of degraded materials if required. Note: The rubrics used to evaluate the design can be found in Appendix 16.11.

Figure 10.2.1 – FMEA

Item	Failure Mode	Failure Mechanism	Effects (L-local, S-system)	Risk Priority Rating (RPN)				Recommended Improvement	Risk Priority Rating (RPN)			
				S	P	D	RPN		S	P	D	RPN
Filter Media	Degradation	Prolonged use	L - Ineffective media layer S - Reduced water quality	3	2	2	12	- Use quality materials - Routine inspection and replacement if needed	3	1	1	**3**
	Clogged	Build up of sediment and contaminants	L - Reduced water flowing through S - Decreased flow rate	2	2	2	8	- Routine inspection and replacement if needed - Frequent cleaning and backwashing of system	2	1	1	**2**
Cloth	Weakened	Prolonged use	L - Degraded cloth filtration, filter media could escape system S - Reduced water quality	2	2	1	4	- Routine inspection and replacement if needed - Use of quality materials	2	1	1	**2**
	Moulding	Constantly damp cloth in air	L - Unpleasant odour S - Could decrease water quality	2	2	2	8	- Ensure system is always either entirely damp or dried out when not in use - Routine inspection and replacement if needed	2	1	1	**2**
Pots	Degradation	Exposure to environmental conditions	L - Degraded or broken pot S - System failure	2	2	1	6	- Encase system to reduce exposure - Routine inspection and replacement if needed	2	1	1	**2**
	Cracking	Material failure after prolonged stress	L - Degraded or broken pot S - System failure	2	2	1	4	- Design of a structure or frame to support weight - Routine inspection and replacement if needed	2	1	1	**2**
System	Overflow	Incorrect operation	L - Overfilled pot, decreased purification quality due to fast flow S - Wasted water	1	2	1	2	- Addition of storage pots to design to limit overflow - Limit amount of water able to enter system - Operating manual with diagrams for local community	1	1	1	**1**

11 Life-cycle analysis

A life-cycle analysis was undertaken in order to evaluate the sustainability of the proposed purification system. A material analysis was conducted to determine the sustainability of all components of the filter. A process flow was created and the inflow and outflow rates were determined based on the water demands of the village. In addition, the environmental impacts of the system were analysed, with limitations and future recommendations stated.

11.1 Material Analysis and Disposal Methods

Polypropylene Plastic (Pots)

It is a tough durable plastic, which allows only minimal water absorption. Material will not be subjected to heavy strain or heat during proper use. This coupled with the durability of the material should give it a lifespan of over 2.5 years. At the end of the life cycle the polypropylene can be recycled into other products or simple reused within the village. Compared to other types of plastic, polypropylene is the very durable and widely available, and causes limited detrimental effects to the environment (Table 11.1.1).

Environmental Impact

- Oil and natural gas are the primary raw products from which polypropylene plastics are made from
- Carbon-dioxide emission from production and recycling process
- Water use in processing
- Use of chemicals in production to reinforce structure

Table 11.1.1 - Comparison of Plastic Production

	Polypropylene	High-density polyethylene	Low-density polyethylene
Products			
Polyolefin (kg)	1000	1000	1000
Feed			
Electricity (GJ)	4.0	1.5	3.0
Propylene (kg)	1050	-	-
Ethylene (kg)	-	1020	1050
Oil (kg)	75	13	40
Refinery Gas (kg)	61	10	50
Total Emissions to Air (kg)	76.5	16	2.27
Total Contaminants to Water (g)	17.85	0.01165	20.838
Global warming (GWP100) (kg $CO_{2\ eq}$)	3530	2510	3040

Note: For complete plastic comparison see Appendix 16.12

Adapted from: von Blottnitz et al, 2007

Cloth

Any porous woven material can be used for this process. Natural fibres sourced from the local region can be used to produce this. Depending on the strength of the material used, useful life of the material could vary from 3 to 6 months. If natural fibres are used then the resultant product will be fully biodegradable at the end of its life cycle. The cloth does not need to be specifically manufactured for this application. Other cloths can be recycled and cleaned for this application.

Environmental Impact

- Carbon-dioxide emissions from harvesting the raw materials and producing them
- Emissions from transport of the material

Sand

Sand is naturally occurring material. It can be sourced from the regions surrounding Devikulam and washed before being used in the filter. At the end of its useful life cycle it can simply be returned to where it was sourced with no degradation of the environment or washed and reused in the filter.

Environmental Impact

- Water use from washing the sand

Gravel

Gravel is naturally occurring material. It can be sourced from the regions surrounding Devikulam and washed before being used in the filter. At the end of its useful life cycle it can simply be washed and reused in the filter or returned to where it was sourced with no degradation of the environment.

Environmental Impact

- Water use from washing the gravel
- Emissions from the transport from site to site

Charcoal

Charcoal is the by-product from the combustion reaction of animal or plant materials. It is primarily comprised of carbon with some organic impurities. For cultural reasons the charcoal used in the water filter would need to be derived from plant material. The charcoal would not need to be produced specifically for the water filtration system. Instead, charcoal could be collected from the village's ovens or wood based fires. After it has outlived its usefulness it can be disposed of in the same way as all the other charcoal waste in the village.

Environmental Impact

- Since it is a waste product that is being repurposed, there are no emissions associated with its production
- Essentially carbon neutral

Peat

Peat is one of the early stages in the production of coal. It is composed of decaying plant matter and it can also serve as a low-grade fuel. After use, it could be suitable for combustion in the village's fires after a thorough drying out period.

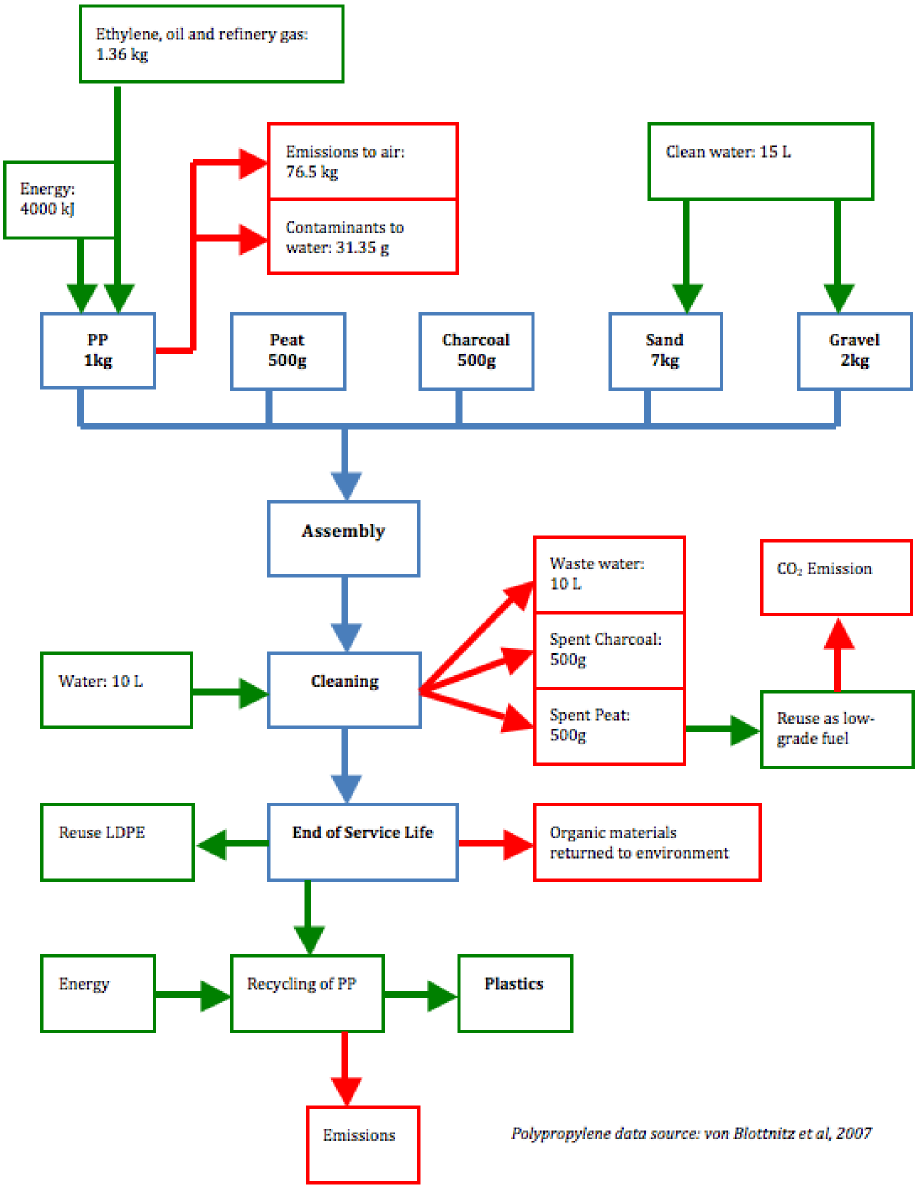
Environmental Impact

- Some carbon-dioxide is released when it is dug out of the ground
- Carbon-dioxide emissions from transporting the peat from the dig site to Devikulam
- Carbon-dioxide emissions from when it is burned (impact from reuse)

11.2 System Life Cycle Analysis

Figure 11.2.1 diagrammatically outlines the energy and mass inputs and outputs throughout the life of the system.

Figure 11.2.1 – System Life Cycle Analysis



12 Sustainability in Final Design

12.1 Environmental Sustainability

Excluding the plastic, all materials are either naturally forming, recycled or recyclable upon disposal, the proposed system is mostly carbon neutral. This further enhances the sustainability of the device and limits the detrimental environmental and economic impacts. The embedded energy of this filtration system will be approximately 4000 kJ (*Blottnitz et al, 2007).* All of this energy comes from the use of the polypropylene pots. Using recycled polypropylene will approximately reduce this embedded energy by a factor of 2 (University of Cambridge, 2005), and at the end of the system lifetime the pots could be reused. All other materials are either naturally derived, waste products or are readily available materials with negligible embedded energy. The environmental impact of this system could be further reduced if the village of Devikulam could create its own ceramic pot to replace the polypropylene ones. The embedded energy of ceramics is approximately one half of that of a polypropylene (Granta, 1994). Exact data on embedded energy cannot be given that it would depend entirely on the manufacturing process and materials used in Devikulam.

12.2 Economic Sustainability

As many of these components are locally available materials, have no ongoing maintenance costs, and use local labour where effort is required, this design is a low cost solution to the problem and subsequently decreases the overall economic impact. The only component that requires an investment is the external casing of the filter. Given polypropylene's durability, it has an expected 2.5 year useful service life. This adds an estimated cost of $0.00091 per Litre to the filtration system. All assembly and maintenance can be performed locally and does not require investment in specialist tools or training.

12.3 Social Sustainability

Given the proposed water filters environmentally and economically sound design as well as its simplicity there are no expected social barriers that exist for a successful integration. The implementation of the education and training program outlined previously should ensure that the community will successfully be able to use and maintain the system. Religious beliefs have been taken into consideration; and as such no animal by-products will be used in the filter unless the entire village explicitly gives permission.

13 Recommendations for future work and research

The proposed water filtration device will be sufficient to supply the village with clean drinking water for the foreseeable future. However, this does not preclude Pitchandikulam Forest from further developing the village's water infrastructure.

If in the future, Devikulam had a piping network that delivered water to each household, an upgrade to the current modular freestanding solution would be an integrated purification system. Using the villages water storage tank and distribution network a larger and more permanent filter could be fitted to service all of the villages water needs.

In the event that biogas facilities become available in Devikulam, distillation may become a feasible backup option. A distillation unit can be implemented in the event that the water filter breaks down or the water quality deteriorates so much that the water filter cannot effectively remove all contaminants.

The proposed water filter can be implemented almost anywhere. The only component of the proposed system that cannot be implemented on a wide scale is the use of jambolan and pomegranate fruit as antibacterial agents. These components could easily be replaced with either colloidal silver or the inexpensive antibacterial water tablets. If either of these alternatives were not available, the water could simply be boiled after filtration.

14 Conclusion

Research into current water purification techniques determined that there were a number of suitable options that could easily be incorporated into the design, all allowing it to be efficient, low cost and with little to no environmental impacts. A range of economic, social and cultural considerations, then determined the selection of the most appropriate technique for Devikulam. After comparison of each technique, it was concluded that a feasible solution could be developed to solve the water quality problem experienced and implemented with little detrimental effects to the Devikulam community.

The most economically viable solution for Devikulam is the use of a deep bed sand filter. The proposed filter can effectively remove turbidity from the village's water supply. However, in order for this to be an all-encompassing solution to the village's water problems some additions to the filter media is necessary. In order to effectively remove salt from the water, the filter be is doped with peat (humic and fulvic acid) and charcoal. Local fauna that contains antibacterial phytochemicals are added to eliminate and retard the growth of bacteria.

To ensure long-term sustainability of the system, an education program should accompany the device to ensure that all villagers understand the importance of hygiene and using clean water. This education should then become inherent within the society, allowing the community to perceive the value of the proposed design and creating a high quality of life for years to come.

15 References

Advanced Purification Engineering Corp n.d., *Water Purification Technologies Explained*, APEC, viewed 23 March 2011, <http://www.freedrinkingwater.com/water-education/quality-water-filtration-method.htm>.

Ahuja, S 2009, *Handbook of Water Purity and Quality*, IWA Publishing, London.

Arjunan, T.V., Pitchandi, P., Sampathkumar, K. & Senthilkumar, P. 2010, 'Active Solar Distillation – A Detailed Review', *Renewable and Sustainable Energy Reviews,* vol. 14, no. 6, viewed 22 March 2011, <http://www.sciencedirect.com/>.

Badot, PM, Crini, G, Sancey, B & Renault, F 2009, 'Chitosan for coagulation/flocculation processes – An eco-friendly approach', *European Polymer Journal*, vol. 45, no. 5, pp 1337-1348, viewed 5 March 2011, <http://www.sciencedirect.com/>.

BioSand Filter Organisation 2004, *Flow Rates,* BioSand Filter Organisation, viewed 23 March 2011, < http://www.biosandfilter.org/biosandfilter/index.php/item/317>.

von Blottnitz, H, Dennis, JS, Harding, KG & Harrison, STL 2007, 'Environmental analysis of plastic production processes: Comparing petroleum-based polypropylene and polyethylene with biologically-based poly-hydroxybutyric acid using life cycle analysis', *Journal of Biotechnology*, vol. 130, pp. 57-66, viewed 20 May 2011, <www.sciencedirect.com/>.

The Cambridge-MIT Institute & The University of Cambridge, 2005, *The ImpEE Project: Recycling of Plastics,* viewed on 1 June 2011, <http://www.eng.cam.ac.uk/research/groups.html>.

Census India 2001, *Population by Religious Community,* census data, viewed 22 March 2011, <http://censusindia.gov.in/Census_Data_2001/Census_data_finder/C_Series/Population_by_religious_communities.htm>.

Chaudhuri, M & Sattar, S 1990, *Drinking Water Microbiology - Domestic Water Treatment for Developing Countries*, Springer-Verlag Publishing, New York.

Doan, B 2008, *Most Dangerous Items in the Ocean*, ScienceRay, viewed 23 March 2011, <http://scienceray.com/biology/ecology/most-dangerous-items-in-the-ocean/>.

Engineers Without Borders Innovations Team 2010, *Water Innovations in Devikulum*, EWB, viewed 18 March 2011, <http://www.ewb.org.au/resoursces/download/1496P2011-02-23%2018:39:46>.

Engineers Without Borders 2011, *Water Context in Devikulam*, EWB, viewed 18 March 2011, <http://www.ewb.org.au/explore/initiatives/2011ewbchallenge/watersupplyandsanitationsystems>.

Freitas, P.C., Locatelli, J., Nascimento, G.G.F. & Silva, G.L. 2000, 'Antibacterial activity of plant extracts and phytochemicals on antibiotic-resistant bacteria', *Brazilian Journal of Microbiology*, vol. 31, no. 4, viewed 8 March 2011, <http://www.scielo.br/>.

Granite Sandstone n.d., Indian Sandstone Industry, Granite Sandstone, viewed 2 June 2011, <http://www.granite-sandstone.com/indian-sandstone-industry.html>.

Granta, 1994, *CES 2011Edupack, Granta Cambridge, UK, viewed on 22 April, 2011.*

Harter, T 2003, *Groundwater Quality and Groundwater Pollution*, University of California, viewed 19 March 2011, <http://groundwater.ucdavis.edu/Publications/Harter_FWQFS_8084.pdf>.

Jayaram, V. 2010, *The Significance of Animals in Hinduism*, Hindu Website, 25th May 2011, <http://www.hinduwebsite.com/hinduism/essays/animals.asp>.

Johnson, T 2007, *India's Threatened Water Supply*, Council on Foreign Relations, viewed 19 March 2011, < http://www.cfr.org/india/indias-threatened-water-supplies/p14597>.

Johnson, D, Hokanson, D, Zhang, Q, Czupinski, K & Tang, J 2008, 'Feasibility of Water Purification Technology in Rural Areas of Developing Countries', *Journal of Environmental Management,* vol. 88, no. 3, pp. 416-427.

Kalbermatten, J, Julius, D, Mara, D & Gunnerson, C 1980, *Appropriate Technology for Water Supply & Sanitation – A Planner's Guide*, Vol 2, Transportation, Water & Telecommunications Department, The World Bank, New York.

Kripalani, M 2002, *Rural India – Have a Coke*, Bloomberg Businessweek, viewed 18 March 2011, <http://www.businessweek.com/magazine/content/02_21/b3784134.htm>.

Medentech 2009, *Aquatabs Water Purification Tablets*, Medentech, viewed 31 May 2011, <http://www.aquatabs.com/aquatabs_products_range/aquatabs.html>.

National Academy of Sciences 2008, *Safe Drinking Water – Treatment Processes*, National Academy of Sciences, viewed 23 March 2011, <http://drinking-water.org/flash/en/water.html?_3_00_00>.

Pizzi, N.G. 2003, *Water Treatment*, 4th edn, American Water Works Association, Denver, Colorado.

Renjith, R 2009, *Agriculture in India*, India Study Channel Technologies, viewed 23 March 2011, <http://www.indiastudychannel.com/resources/68318-Agriculture.aspx>.

Tamil Nadu Tourist Office n.d., *Tamil Nadu Information*, WhereInCity India Information, viewed 23 March 2011, < http://www.whereincity.com/india/tamilnadu/>.

TORAY Industries 2011, Fibres and Textiles, TORAY Industries, viewed 23 March 2011, <http://www.toray.com/business/products/fibers/fibers/fib_014.html>.

United Nations Children's Fund 2002, *Learning From Experience – Water and Environmental Sanitation in India*, UNICEF, New York, viewed 19 March 2011, <http://www.unicef.org/publications/files/pub_wes_en.pdf>.

University of Wollongong n.d., *Permeability and Coal Mine Outbursts, University of Wollongong*, University of Wollongong, viewed 23 March 2011, <http://www.uow.edu.au/eng/outburst/html/permeability.html>.

Woodmansey, A. 2002, *Chitosan Treatment of Sediment Laden Water - Washington State I-90 Issaquah Project,* US Department of Transportation, Washington, DC, viewed 5 March 2011, <http://www.fhwa.dot.gov/>.

World Health Organisation 1993, *Guidelines for Drinking Water Quality V1-Recommendations*, 2nd edition, WHO publishing, France.

16 Appendices

16.1 Source Survey Data

Table 16.1.1 – Water Use Survey Data

	Total (L/day)	Average (L/day)
Drinking	227	0.70
Cooking	252	0.78
Washing	481	1.49
Flushing	320	0.99
Combined Useage	1280	3.97

Note: Village has 322 residents.

Source: Adapted from Engineers Without Borders 2010

16.2 In Depth Purification Process Analysis

Table 4.1.1 – Comparative Analysis of Current Water Purification Techniques

Method	Relative Removal Efficiency [1]* (none/low/high)	Maintenance [2]	Relative Cost [1]* (high/low)	Advantages	Disadvantages
Membrane Technology	• Bacteria – high • Salts – high • Turbidity - high	Membrane must be cleaned periodically to stop bacteria scaling	High	• High contaminant removal and efficiencies • Quick process	• Requires expensive materials and technology • Large energy input • Large quantities of wastewater
Distillation	• Bacteria – high • Salts – high • Turbidity – high	Periodic disposal of solid waste build-up	High	• Removes broad range contaminants • Quick process	• Requires energy input • Some contaminants in condensate • Time consuming
Filtration	• Bacteria – low • Salts – low • Turbidity – low-high^	Periodic backwashing	Low	• Low cost option • Environmentally suitable • Simple process	• Does not remove small particles
Slow Sand Filtration	• Bacteria – high • Salts – low • Turbidity – high	Infrequent media disposal or backwashing	Low	• Low cost option • Environmentally suitable – uses local materials [3] • Simple process	• Considered old-fashioned method
Ceramic Filtration	• Bacteria – high • Salts – low • Turbidity – moderate	Infrequent chemical and system replacement	Low	• Low cost option • Environmentally suitable • Simple process	• Use of chemicals – import cost, disposal • Requires infrequent system replacement
Sedimentation/ Coagulation	• Bacteria (S) – low • Bacteria (C) – high • Salts – none • Turbidity – high	Periodic disposal of solid waste build-up	Low	• Potentially low cost option • Environmentally suitable • Simple process	• Use of chemicals – import, cost, disposal • Time consuming

Disinfection	• Bacteria – high • Salts – none • Turbidity – none	Infrequent replacement of chemicals	High	• High contaminant removal and efficiencies • Simple process	• Use of chemicals – import, cost, disposal • Requires energy input
Carbon Adsorption	• Bacteria – high • Salts – low • Turbidity – high	Carbon regenerated by heating, washing or replacement.	Low	• Low cost option • Environmentally suitable –uses local materials [2] • Simple process	• Must be used in conjunction with other processes to be highly effective [2]
Chelation	• Bacteria – none • Salts – high • Turbidity - low	Infrequent media disposal	Low	• Low cost option • Simple process	• Use of chemicals – cost, disposal • Could decrease water pH • Must be used in conjunction with other processes to be highly effective [2]
Plant Extracts	• Bacteria – high • Salts – none • Turbidity – none	Infrequent replacement of plants	Low	• Low cost option • Environmentally suitable – uses local materials • Simple process	• Requires media replacement • Must be used in conjunction with other processes to be highly effective [2]
Chitosan	• Bacteria – none • Salts – high • Turbidity - high	Infrequent replacement of polymer	Low	• Low cost option • Environmentally suitable – locally available natural polymer	• Could be considered ethically inappropriate • Must be used in conjunction with other processes to be highly effective [2]

Note: Qualitative data has been used for the purposes of this table, merely to provide a comparative analysis, quantitative data will be used in detailed analysis of possible appropriate solutions. As there are many different types of filtration media available, their effectiveness to remove turbidity also varies.

Sources: [1] Adapted from World Health Organisation 1993, [2] Adapted from Chaudhuri & Sattar 1990, Adapted from Pizzi, 2010

16.3 Plant Extracts

Table 16.2.1 – Types of Bacteria Removed by Plant Extracts

Jambolan	**Pomegranate**
• Staphylococous aureus • Candida albicans • Proteus SPP • Klebsiella pneumoniae • P. aerouginosa • Enterobacter aerogenes • S. aureaus	• Pseudomonas aeruginosa • Bacillus subtilis

Source: Freitas, Locatelli, Nascimento & Silva, 2000

16.4 Chitosan Properties

Table 16.4.1 – Properties of Chitosan in Water Treatment Applications

Principle Characteristics	**Potential Applications**
• Non-toxic • Biodegradable • Renewable resource • Ecologically acceptable polymer (eliminating synthetic polymers, environmentally friendly) • Efficient against bacteria, viruses, fungi • Formation of salts with organic and inorganic acid • Ability to form hydrogen bonds intermolecularly • Ability to encapsulate • Removal of pollutants with outstanding pollutant-binding capacities	• Flocculent to clarify water (drinking water, pools) • Reduction of turbidity in food processing effluents • Coagulation of suspended solids, mineral and organic suspensions • Flocculation of bacterial suspensions • Interactions with negatively charged molecules • Recovery of valuable products (proteins) • Chelation of metal ions • Removal of dye molecules by adsorption processes • Reduction of odours • Sludge treatment • Filtration and separation • Polymer assisted ultra-filtration

Adapted from: Badot, Crini, Sancey & Renault 2009

16.5 Required Removal Efficiencies Calculations

$$\text{Removal Efficiency} = \frac{\text{Water Quality} - \text{Standard Quality}}{\text{Standard Quality}} \text{ x } 100$$

Adapted from: National Academy of Science 2008

Turbidity

Prototype:

Based on Assessment Task:

Maximum Testing Turbidity = 50NTU

$$\text{Removal Efficiency} = \frac{50 - 0.5}{50} \text{ x } 100 = 99\%$$

Minimum Testing Turbidity = 10NTU

$$\text{Removal Efficiency} = \frac{10 - 0.5}{10} \text{ x } 100 = 95\%$$

Based on World Health Organisation Standards:

Maximum Testing Turbidity = 50NTU

$$\text{Removal Efficiency} = \frac{50 - 10}{50} \text{ x } 100 = 80\%$$

Minimum Testing Turbidity = 10NTU

As the turbidity is already well below world standards, the prototype device is required only to not contribute to the final turbidity of the water.

Devikulam:

Turbidity = <0.1 NTU

As the turbidity is already well below the assessment requirements and world health standards, the final device is required only to not contribute to the final turbidity of the water.

Salinity

Prototype:

Based on Assessment Task:

Maximum Testing Concentration = 5000ppm = 5g/L

Removal Efficiency

$$= \frac{5000 - 100}{5000} \times 100$$
$$= 98\%$$

Minimum Testing Concentration = 2000ppm = 2g/L

€

Removal Efficiency

$$= \frac{2000 - 100}{2000} \times 100$$
$$= 95\%$$

€

Based on World Health Organisation Standards:

Maximum Testing Concentration = 5000ppm = 5g/L

Removal Efficiency =5000−2005000 x 100=96

Minimum Testing Concentration = 2000ppm = 2g/L

Removal Efficiency

$$= \frac{2000 - 200}{2000} \times 100$$
$$= 90\%$$

Devikulam:

Based on Assessment Task:

Concentration = 325ppm = 0.325g/L

Removal Efficiency

$$= \frac{325 - 100}{325} \times 100$$
$$= 69\%$$

Based on World Health Organisation Standards:

Concentration = 325ppm = 0.325g/L

Removal Efficiency

$$= \frac{325 - 200}{325} \times 100$$
$$= 38\%$$

Bacteria

As all of the bacteria must be removed from the water to meet assessment requirements and the world health standards, the required removal efficiency for both the prototype and the final device is 100%.

16.6 Flow Rate Calculations

Required:

$$= \frac{15L}{12hrs}$$
$$= \frac{15L}{720\min}$$
$$= 0.021L/\min$$

Measured:

$$= \frac{10.36\,\text{min}}{1L}$$

$$= 0.096L/\text{min}$$

16.7 Expected Rate of Use of Peat Calculations

Composition = 40-85% organic acids by weight
Average Composition = 62.5% organic acids by weight
Organic acids composed of approximately equal parts humic and fulvic acids, and small amounts of other acids.
Amount used in system = 500g = 0.5kg
Amount of organic acid in system = 0.5 x 0.625 = 0.31250kg

Molar Mass Humic ($C_{187}H_{186}O_{89}N_9S_1$) ≈ 4000g
Molar Mass Fulvic ($C_{135}H_{182}O_{95}N_5S_9$) ≈ 3400g
Assume organic acids compose of 50% humic acid and 50% fulvic acid.
Average Molar Mass organic acids = 3700g

Assume majority of salt in water is Sodium Chloride NaCl (molar mass ≈ 58g)
$NaCl_{(s)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$
Therefore, the dissociation of one mole of solid sodium chloride in water results in one mole of sodium ions and one mole of chloride ions.

Prototype

Maximum Testing Concentration = 5000ppm = 5g/L

Molarity = 5/58 = 0.0862M
Number of Molecules = 0.0862 x 6.022×10^{23} = 5.19×10^{22} molecules/L
As 1:14 reaction ratio acid:sodium ions → 0.0862 /14 = 0.0059 moles/L acid required
For operation at 95% efficiency:

0.0059 moles x 0.95 = 0.0056 moles acid/L required for removal
0.0056 moles/L = 20.7g/L (based on average molar mass)
20.7g/L x 15L/day = 310g/day required (based on 15L/day water usage)
500/310 = 1.61 days ≈ 2 days

Therefore, at this high salt concentration, to operate at 95% efficiency, 310g of peat would be required per day, which equates to it being changed approximately every second day.

Based on the WHO quality standards, which is salt removal down to 200ppm, double what the removal efficiency was calculated on, the peat would last twice as long. Therefore it would require changing every four days at this concentration.

Minimum Testing Concentration = 2000ppm = 2g/L

Molarity = 2/58 = 0.0345M
Number of Molecules = 0.0345 x 6.022×10^{23} = 2.07×10^{22} molecules/L
As 1:14 reaction ratio acid:sodium ions → 0.0345 /14 = 0.0024 moles/L acid required
For operation at 95% efficiency:

0.0024 moles x 0.95 = 0.0023 moles acid/L required for removal
0.0023 moles/L = 8.4g/L
8.4g/L x 15L/day = 126g/day required (based on 15L/day water usage)
500/126 = 3.97 days ≈ 4 days

Therefore, at this salt concentration, to operate at 95% efficiency, 126g of peat would be required per day, which equates to it being changed approximately every fourth day.
Based on the WHO quality standards, which is salt removal down to 200ppm, double what the removal efficiency was calculated on, the peat would last twice as long. Therefore it would require changing every week at this concentration.

Final Device
Average concentration = 650µS/cm = 325ppm = 325mg/L
Molarity = 0.325/58 = 0.0056M
Number of Molecules = 0.0056 x 6.022×10^{23} = 3.37×10^{21} molecules/L
As 1:14 reaction ratio acid:sodium ions → 0.0056 /14 = 0.0004 moles/L acid required
For operation at 95% efficiency:

0.0004 moles x 0.95 = 0.000378 moles acid/L required for removal
0.000378 moles/L = 1.59g/L (based on average molar mass)
1.59g/L x 15L/day = 20.85g/day required (based on 15L/day water usage)
500/20.85 = 23.98 days ≈ 24 days ≈ 4 weeks
Therefore, at this salt concentration, to operate at 95% efficiency, 20.85g of peat would be required per day, which equates to it being changed approximately every four weeks.

Based on the WHO quality standards, which is salt removal down to 200ppm, double what the removal efficiency was calculated on, the peat would last twice as long. Therefore it would require changing every eight weeks at this concentration.

The monsoonal season lasts four months (≈16 weeks) each year and the salt concentrations can be assumed to be close to the maximum concentrations (5g/L) during this time. Therefore, the peat would require changing weekly in these conditions. For the remaining 36 weeks of the year, the peat layer of the filter could operate on the eight week replacement method.

Assume 500g of peat used for each replacement.

The mass of peat required every year = 16 x 0.5 + (36/8) x 0.5 ≈10kg

Therefore, each device would require approximately 10kg of peat per year.

16.8 Devikulam Water Purification Project Sample Survey

Survey Questions:

1. What do you know about the importance of using safe water?
2. Where do you currently source your water from?
3. What do you use this water for?
4. How do you feel about the current state of the water?
5. Do you believe that there is anything wrong with it?
6. Would you like an improved system to purify this water?
   Yes No Undecided

If yes, please continue the survey. If no, please provide any additional comments at the end.

7. What kind of system would you prefer?

8. Are there any materials, chemicals or processes that you would not like used in this system? If yes, what are they and why?

9. Would you prefer private or communal facilities?
   Private Communal Undecided

10. Where would you like the system to be located?

11. Are the systems aesthetic qualities important to you?
    Yes No Undecided

12. If yes, what features are important to you?

13. Would you be happy to implement, operate and maintain this system?
    Yes, completely Yes, with aid No Undecided

14. If no, who would you like to implement, operate and maintain this system?

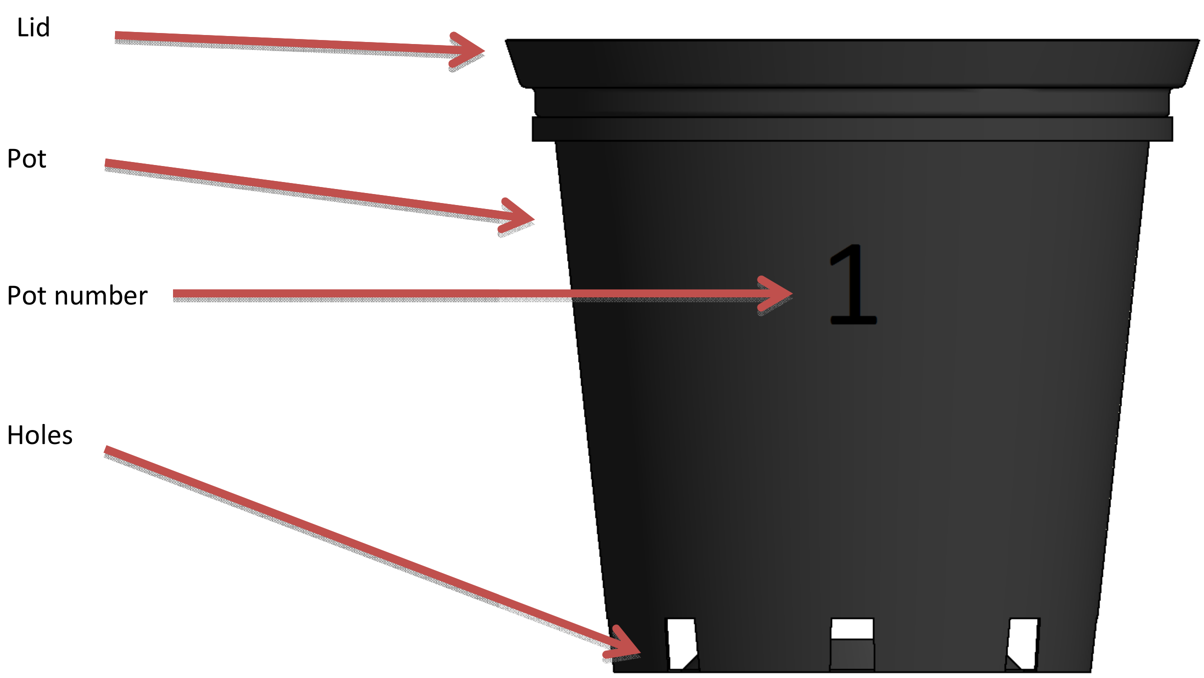
Additional Comments

16.9 Operation Manual
Instruction Manual

Construction Process:

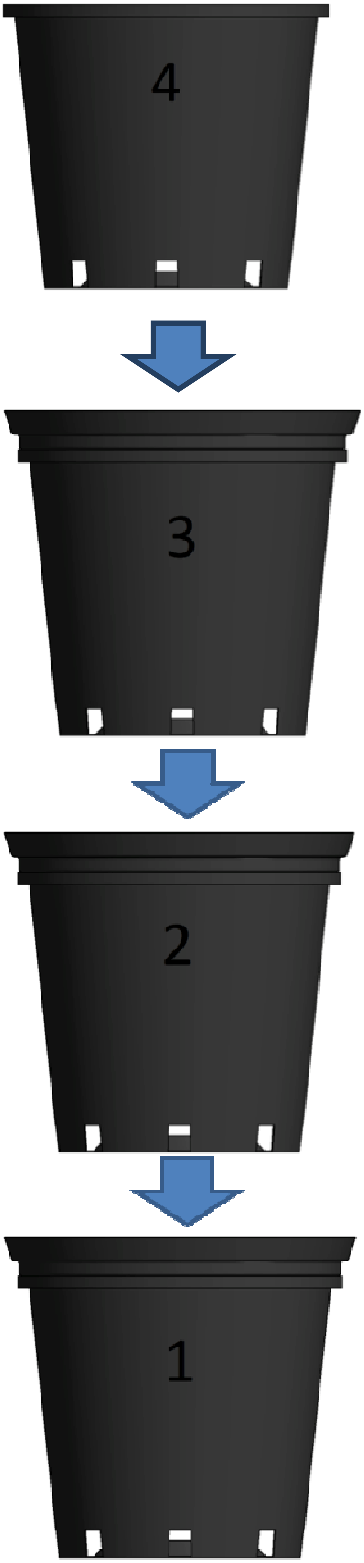
1. 8mm holes were drilled into the pot lids and bases of the pots
2. Pots were lined with a piece of calico 50cm x 50cm
3. Pot 2 and 4 were filled with sand and compacted
4. Pot 3 was filled with (In the following order):
   a. 1/6 sand
   b. 2/6 charcoal
   c. 1/6 sand
   d. 1/6 peat
   e. 1/6 sand
5. Pot 1 was filled (In the following order):
   a. ¾ gravel
   b. ¼ sandstone
6. Pot lids were placed on top of pots 1, 2 and 3 and taped on
7. Pots were placed on top of each other in the order 1, 2, 3, then 4

Parts:

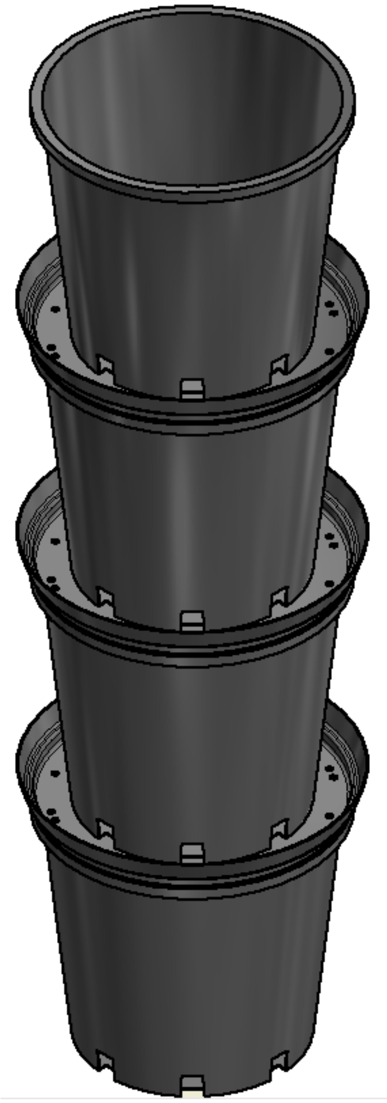


Operation:

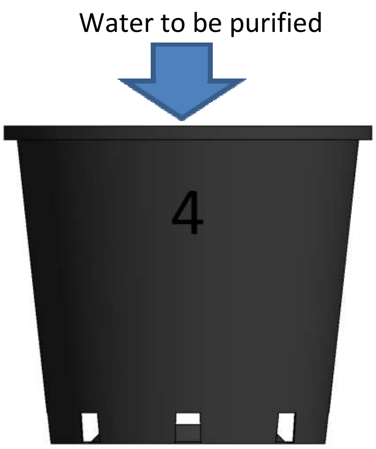
1. Ensure all pots labelled 1 through to 4 are available
2. Stack pots from the ground up starting with pot number 1 on the bottom and finishing with pot number 4 on top. (Note pot number 4 does not have a lid)

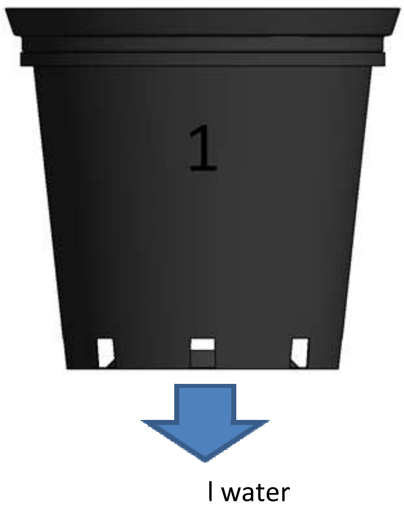


3. Once stacked the iPot assembly should look like the diagram below



4. Once the assembly is complete water that is to be purified can be added to pot number 4. The pot should not be overfilled. Water will move through the filter and can be collected from the holes of pot number 1 located at the base of the filter.





16.10 Cost per Litre of Treated Water Calculations

Calico Cost

$$= \frac{\$4.00}{\frac{365}{2}\,days \times \frac{15L}{day}}$$
$$= \$0.00146/L$$

Plastic Cost

$$= \frac{\$12.59}{(365 \times 2.5)\,days \times \frac{15L}{day}}$$
$$= \$0.00091$$

Total Cost = $0.0023/L

16.11 Marking Rubrics for FMEA

The severity of a failure mode occurrence is a measure of the significance of a specific failure mode occurring (Table 16.11.1).

Table 16.11.1 – Severity of Failure Mode Occurrence

Severity (S)		
Value	**Definition**	**Comments**
4	Catastrophic	Primary function of device completely compromised
3	Critical	Primary function of device compromised
2	Marginal	Primary function of device slightly compromised
1	Negligible	A function of device slightly compromised

The probability of a failure mode occurrence is a measure of the chance of a specific failure mode occurring (Table 16.11.2).

Table 16.11.2 – Probability of Failure Mode Occurring

Probability (P)		
Value	**Definition**	**Comments**
4	Expected	Will occur immediately or within a short period of time
3	Occasional	Will probably occur in time
2	Remote	Possibly may occur in time but not likely
1	Impossible	Very Unlikely to occur in time

The detection of a failure mode occurrence is a measure of how easily a specific failure mode can be detected after occurring (Table 16.11.3).

Table 16.11.3 – Detection of Failure Mode Occurrence

Detection (D)		
Value	**Definition**	**Comments**
4	Impossible	Impossible to detect under inspection
3	Possible	Some chance to be detected under inspection
2	Likely	Quite likely to be detected under inspection
1	Certain	Will be detected under inspection

16.12 Properties of Different Plastics

Table 16.11.5 – Plastic Comparative Table

	Polypropylene	High-density polyethylene	Low-density polyethylene
Products			
Polyolefin (kg)	1000	1000	1000
Feed			
Electricity (GJ)	4.0	1.5	3.0
Propylene (kg)	1050	-	-
Ethylene (kg)	-	1020	1050
Oil (kg)	75	13	40
Refinery Gas (kg)	61	10	50
Total Emissions to Air (kg)	76.5	16	2.27
Total Contaminants to Water (g)	17.85	0.01165	20.838
Abiotic depletion (kg Sb $_{eq}$)	41.4	35.3	39.4
Global warming (GWP100) (kg $CO_{2\,eq}$)	3530	2510	3040
Ozone layer depletion (ODP) (kg 1,4-DB $_{eq}$)	0.000862	0.000766	0.0018
Human toxicity (kg 1,4-DB $_{eq}$)	1870	2590	2890
Fresh water aquatic ecotoxicity (kg 1,4-DB $_{eq}$)	234	176	210
Marine aquatic ecotoxicity(kg 1,4-DB $_{eq}$)	1,850,000	1,230,000	1,610,000
Terrestrial ecotoxicity (kg 1,4-DB $_{eq}$)	44	33.7	40.3
Photochemical oxidation (kg C_2H_2)	1.7	17.5	3.92
Acidification (kg $SO_{2\,eq}$)	48.8	22.5	27.4
Eutrophication (kg $PO_4^{3-}{}_{eq}$)	5.84	0.811	0.951

16.13 Wire Frame View of Assembly Components

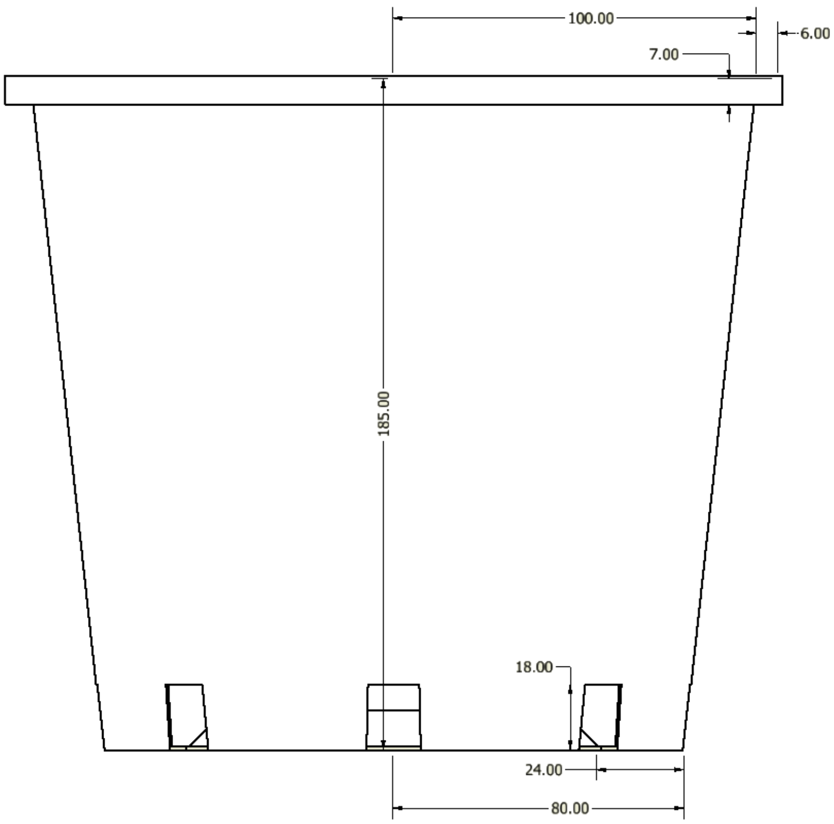


Figure 16.13.1 – Wire Frame View of Pot

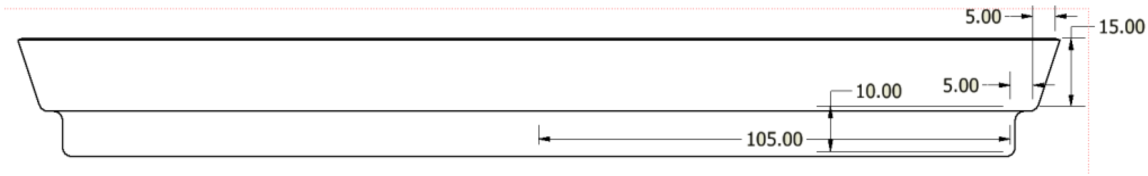


Figure 16.13.2 – Wire Frame View of Lid