Water Filtration

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Introduction to Engineering
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Executive Summary

The Engineers Without Borders (EWB) Challenge is a way for first year engineering students to apply the skills they are learning in a “real world” scenario, while providing communities with support and solutions to problems that they face on a day to day basis.

For this year’s challenge we have selected the task of designing a solution to the village of Devikulam’s water supply and sanitation systems. Devikulam is a small village in India that comprises of 86 families and a population of approximately 358 people.

This report outlines the concerns the villagers have about the availability of clean drinking water and contaminants entering their water supply. Through our research we have found that although there are many ways to solve these issues it is imperative that we design a solution that is cost effective, sustainable and easily maintainable by the local villagers.

The villagers of Devikulam have raised the issues of saline water, lack of constant supply of water due to power shortages, poor condition of taps and bacteria in the water supply. The poor conditions of the taps and plumbing, has been rectified in July 2010 (Buzza, 2011). The concern of bacteria within the water supply, we believe, is the most pressing issue that needs to be resolved.

As a group we each collected data on different filtration options looking at ease of use and maintenance, power requirements, costs, if the process will remove the bacteria that are present in the Devikulam water supply, availability of materials and the life expectancy of each process. This data was collated into a trade-off analysis template and the criteria was weighted from most important requirements i.e. the removal of the bacteria to the least important. This template then calculated the best options for the village from the information we entered.

Due to the simplicity but effectiveness, slow sand filtration is the most viable and cost effective option. It removes 90-99% of all bacteria from the water leaving behind safe clean drinking water. After contacting EWB about the availability of sand in the area it was found that there is enough sand within the village to be able to pursue this process. The other benefit to this method is it has been tried and tested in similar situations around the world.

There are many options available for slow sand filtration from large units that can supply the entire village with clean water to stand-alone units that can be placed in each household. After looking at these options the most cost effective and simplistic option is the individual household unit. This brings the onus of maintenance etc... back to the family whose unit it is. This can stop conflict from poor maintenance practises and disputes over water availability. It is also a less complex method, as the maintenance requirements are lower due to the size.

One issue with sand filtration is the sand granules need to be within a certain specification which can average around 0.15mm to 0.35mm depending on filtration requirements. (Biosand Filter.org, 2004) For this we have decided on using sieves with specific sized mesh to manage the correct size of sand.
The final design consists of a 65 litre plastic drum for the housing of the filter media. The media consists of various layers of sand and gravel. As the unit will be operated intermittently it is essential that a layer of water is left on the surface to ensure the sand does not dry out. To combat this issue a PVC pipe will start from the bottom of the filter and be raised to approximately 5cm above the water level in the filter. This will ensure a layer of water will always remain in the filter unit.

The construction of the unit is relatively simple and the materials are available either within the village or locally. Sand filtration units have been used worldwide and have had great success in developing countries with water quality issues. As the only current issue with the water in Devikulam is bacteria levels the sand filter is the most effective option to combat this.

Implementing the sand filtration unit will eliminate the symptoms of the current village practices, allowing the community to solve the issues in due course but still having access to safe, clean drinking water.

Figure 1 Pond in Devikulam Village (Engineers Without Borders, 2011)
Team Reflection

A Team can be defined as a group of people with many and varied skill sets coming together to complete a task. To be an effective team, each member needs to be able to work collectively for the common goal (Business Dictionary, 2011).

Working in a team is an essential skill in Engineering. The EWB project has been a challenging and rewarding experience. As first year students it would be fair to say no one expected to be involved in such a project so soon. To be involved in a real life project where the solution you come up with has the potential to better the quality of life for the less fortunate people in the world is a humbling experience.

The Team consists of six people coming from various backgrounds, some straight from school to the more experienced having worked within various industries for many years.

- The largest obstacles faced on the EWB challenge were, sourcing valid information, understanding the scope of the work required for the project and getting everyone together at the same place and time to discuss the work ahead.
- The impact of working within a team was positive as we were able to pool our broad knowledge base (brainstorming etc.) and come to a consensus within the group in solving any issues.
- To do it all over again the things we would change would be using better lines of communication, emphasize expectations from all so we are all working towards the same goal, the structure of the report would be set out from the beginning and more detailed timelines set out and make everyone accountable for their part.
- The most enjoyable parts of the project were new friendships formed, seeing the less experienced people within the team come out of their shells and develop as an effective team member. The computer skills obtained were very useful in setting up the reports and learning how to research effectively.

Looking forward we believe we will all take something from this experience and use the new knowledge and skill obtained and in time learn to be an effective individual within a team.
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**Introduction**

Engineers Without Borders (EWB) is an organisation that works with communities in Australia and overseas in developing countries to help improve their quality of life and their standards of living. (Engineers Without Borders Australia, 2011). The organisation aims to address issues such as clean drinking water, sanitation energy, basic infrastructure, waste systems, information technology and engineering education. (Engineers Without Borders Australia, 2011). One way of achieving this is by EWB carrying out the EWB challenge. This challenge comprises of first year engineering students from around the country coming up with innovative designs to contribute towards sustainable development. (Engineers Without Borders, 2011)

The location of the 2011 EWB challenge is Devikulam village in India. Devikulam is located in the state of Tamil Nadu and is situated 1800m above sea level. The village is in close proximity to Bengal Bay. The predominant religion for this region is Hindu and the main language spoken is Tamil. There are two main seasons for the area, they being the monsoon and dry seasons. In the monsoon season (June – December) the majority of the years rain falls between this time. The dry season occurs from January – May. There are approximately 358 people living in the Devikulam village and these people make up 86 families. The average age in the village is 28 years old with 30% being under the age of 18. The level of education is quite low. It is estimated that 60% of the district has attained primary school level or less. The main occupation for Devikulam is agriculture with most villagers owning their own land growing crops such as tapioca, rice, sugarcane, ground nuts and watermelon. They also own some livestock such as cows. (Buzza, 2011)

There is an area within Devikulam called the “colony” and the residents are generally labourers for the surrounding farms owned by the villagers. The average yearly income ranges from Rs 10,000 – Rs 60,000 and they can work in excess of 20 days per month. (Buzza, 2011) One of the areas this village requires addressing is the quality of water supply and sanitation systems. There are three bores that supply water to the village with one of these identified as having saline water. (Engineers Without Borders, 2011) There have been samples taken from the three main taps and these have been tested for quality including salinity and bacteria levels. The analysis has led to the conclusion that the areas requiring attention are the salinity levels and the presence of bacteria. (Engineers Without Borders, 2011). After discussions with the community the issues they believe need further investigations are the salinity in one of the bores, a solar pump on the larger tank, conditions of taps and a possible purification system. (Engineers Without Borders, 2011).

Within Devikulam there is a lack of infrastructure in relation to the waste water and sanitation systems (Engineers Without Borders, 2011). The practice of open defecation is wide spread creating the potential of disease and contaminating water supplies. (Engineers Without Borders, 2011). Under design area 4 – Water Supply and Sanitation systems we have looked at the requests from the villagers in the areas of sanitation, solar pumps, saline water and removal of bacteria from the water supply and storage systems.
Throughout this process we have constantly referred back to the requests of the villagers to ensure their needs are met with our design solution. We have used various tools and processes to assess the information i.e. Trade-off Analysis Template and then come out with an informed decision on the most suitable option for the village.

Through this report we will show evidence as to why sand filtration is the preferred option for the community. It will also explain the reasons behind our choice of design. The report will introduce the many different filtration options detailing their advantages and disadvantages. We believe this report demonstrates the systematic approach we have taken to identify sand filtration as the most viable option for Devikulam.
1 Problem Statement

1.1 Background

One of the issues for the residents of Devikulam is the quality of their drinking water. In April 2010 a water quality analysis of Devikulam’s three main taps was carried out by the Innovation Project team, which found some questions about the quality of the water (Engineers Without Borders, 2011). Although from this analysis it was found the water is suitable for human consumption, an area for concern was the bacterial contamination within the water supply.

The levels of Bacteria are shown in table 1 below. For the complete tables refer Appendix A.

Table 1 Water test results (Engineers Without Borders, 2011)

<table>
<thead>
<tr>
<th>Tap Location</th>
<th>Parameters</th>
<th>Results</th>
<th>Desirable limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Village Tap 1</td>
<td>Total Coliforms</td>
<td>124 N/100ml</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>E. Coli</td>
<td>12 N/100ml</td>
<td>0</td>
</tr>
<tr>
<td>Village Tap 2</td>
<td>Total Coliforms</td>
<td>142 N/100ml</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>E. Coli</td>
<td>16 N/100ml</td>
<td>0</td>
</tr>
<tr>
<td>Village Thopu</td>
<td>Total Coliforms</td>
<td>504 N/100ml</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>E. coli</td>
<td>184/100ml</td>
<td>0</td>
</tr>
</tbody>
</table>

It is believed that the contamination is coming from the surrounding areas of the village from cows (which are kept within the village), chickens and dogs (Engineers Without Borders, 2011). It is also possible that during the monsoonal period the pond may overflow into the ground water bores and contaminate the drinking supply. The Innovations Project team will be working with the villagers to isolate the pond from the ground water supply (Engineers Without Borders, 2011).

1.2 Devikulam Water Supply

The water for the community is supplied by three bores with two of these supplying a 30,000 litre storage tank. This tank is used for the village’s water supply including their drinking water. The people living in the ‘colony’ have described the third bore as having high salinity. They only use the water from this bore to wash and clean (Engineers Without Borders, 2011). In July 2010 the village water distribution network has received an upgrade with new piping and taps increasing water pressure and decreasing water loss by up to 10,000 litres per day (Buzza, 2011).
1.2.1 Village Water Supply

The residents living within the area known as the ‘village’ have their own taps which are directly linked to the Devikulam water supply. The water is supplied from the 30,000 litre storage tank and is currently suitable for human consumption. The concern is the evidence of bacteria within the water supply and the close proximity of the two bores that supply the tank to the village pond which is contaminated and unsuitable for drinking (Engineers Without Borders, 2011).

1.2.2 Colony Water Supply

The households within the colony are not directly linked to the ‘village’ water supply. The water supply within the colony comes from a water tank within their area. This water has a high salinity level therefore they only use this water for washing and cleaning. For drinking water the residents need to collect the water from a common tap that is linked to the ‘village’ supply. They are required to collect the water in large containers for their daily use (Engineers Without Borders, 2011).

Figure 2 Village tap (Buzza, 2011)

1.3 Current village practises

The community of Devikulam regularly wash in the village pond and livestock use it as a drinking source. The practice of open defecation is common within Devikulam, and it is not uncommon for livestock to live within the village area (Engineers Without Borders, 2011). This has the possibility of water runoff during the monsoon season to enter into the ground water supply. Although currently the water is suitable for human consumption, due to the present practises and bacteria levels, it is our belief that a filtration/purification system needs to be implemented to ensure the deterioration of the villagers health does not occur.
1.4 Expected Difficulties

Dealing with any community is always going to be challenging. There are many social, environmental and economic issues that need to be addressed.

The key to success is through detailed consultation and research to ensure the problem being addressed is the real issue of concern.

It is very easy as an Engineer to just walk in and say this is your problem and this is the solution to fix it.

Good engineering practice is to look at the problem, research methodically and provide more than one solution, highlighting the preferred option.

The issues we expect to appear when dealing with the Devikulam community are:

- The water supply we already have is drinkable so why spend money on a filtration system?
- The proposed idea costs a lot of money and we earn so little
- Are there any cheaper options available?
- I don't want one of those units in my house
- It's too complicated to build
- I don't want to maintain it

As you read through the report it will be evident that our report addresses all these issues and we believe the best solution has been identified.

We understand the implementation of the Slow Sand Filtration units will bring further concerns from the community. We are confident the points raised will be easily addressed and the people of Devikulam will see the value in implementing our proposal into their lives.

1.5 Design Requirements

For any design to be successful within Devikulam it needs to improve on the current water conditions. As there is little to no water filtration presently being used, it is essential to show the benefits of using a filtration system to enable the villagers to have access to clean, healthy drinking water. To achieve this we have measured each design option against specific criteria to ensure the best possible design option for Devikulam is used.
1.5.1 Removal of Bacteria

The World Water Council states that “Water related diseases are the most common cause of illness and death among the poor of developing countries” (World Water Council, 2010). For this reason it is crucial that the design removes bacteria, specifically E. coli. One of the areas of greatest concern for the villagers is the evidence of bacteria within the water supply (Engineers Without Borders, 2011).

Water reports carried out on the Devikulam water supply show two types of bacteria within the water. These being:

- Total Coliforms
- E. coli

If the filtration process does not remove these it will be ineffective for use within Devikulam.

1.5.2 Cost

An important consideration for the implementation of any filtration system within Devikulam is the cost of the overall project. There are many filtration and purification systems available but not all are affordable to the community. As most villagers are employed within agriculture the affordability in regards to the wages of the villagers needs to be taken into account. The main areas where cost is a factor are:

- Materials
- Transport of materials to village
- Ongoing costs i.e. maintenance requirements

For these reasons it is important that local products are used wherever possible. This will keep the eventual costs low plus allowing the design to be easily rebuilt and repaired as required.

1.5.3 Environmental

The environmental impact the project will have on the surrounding area will have great bearing on the decision of which design to implement. Due to Devikulam’s close proximity to Pitchandikulam Forrest it is important to ensure that the environmental issues are explored and resolved before any implementation occurs.

The factors to be taken into consideration are:

- Waste products produced from process
- Over use of local materials i.e. trees
- Use of chemicals and impacts of spills
- Disposing of materials at the end of their life span
For the community to want to implement our design these points will need to be addressed and proven that there will be minimal to no environmental impact to the surrounding region.

### 1.5.4 Social & Cultural

As the predominant religion within this region is Hindu,(Buzza, 2011), the cultural and social influences need to be investigated. There are various Temples situated throughout the village so placement of the project will be looked at. If the design clashes in any way with the communities values or beliefs it will be impossible to implement and ensure continued use of the system if they are not totally committed to the idea.

For this reason it is vital that a minimal impact design is used and it does not greatly affect their day to day life.

### 1.5.5 Sustainability

The issue of sustainability is a significant one. For the community to back the project it will be required to be sustainable and easy to maintain. If materials are difficult to obtain or there is a high degree of maintenance required the villagers will inevitably revert back to their old processes.

Some areas to examine will be:

- Longevity of design i.e. Lifespan – too short and it will be impractical
- Availability and lifespan of materials – possibility of excessive wastage if life span is too short
- Complexity – too complex and the community will not use it
- Maintenance requirements – too maintenance intensive will result in it not being used or repaired

### 2 Filtration Alternatives

The need to remove bacteria from the Devikulam water supply has led us to research different filtration processes. We have taken into account the villager’s requests from the EWB design brief and the Water Innovations report. This is an important part of our design solution as once implemented the villagers need to buy in to the design and want to continue using it. For this reason within each filtration process we have looked at costs and maintenance requirements as well as the effectiveness of the filtration process.
2.1 Carbon Filtration

Carbon is formed from sources like peat, wood, coal and nutshells (Which when burnt forms charcoal). Before the charcoal can be used as a filter media it has to be put through a process which changes its properties turning it into a carbon. Carbon is extremely porous, just 1 gram of the processed Carbon has a surface area of 500m squared (Wikipedia, 2011).

Carbon is good for removing organic contaminants. Organic contaminants are responsible for certain tastes in the water, odours and colour problems. Carbon will also remove chlorines from the water. Carbon is not good for removing microbes (E.coli), hardness, fluorides, nitrates and sodium’s. Only certain carbon filters will remove heavy metals. (Water, 2011).

2.2 Ceramic Pots

Ceramic pots are made from a mixture of dry clay, flammable materials (such as sawdust) and water (to create a homogeneous mixture) which is then shaped into a pot and fired in a kiln. The flammable material burns out and leaves the pot with pores in which water can pass through. A silver solution is then applied to the inside and outside of the filter which is absorbed into the pores, the silver acts as a biocide. The ceramic pot is then placed in a plastic container and when the contaminated water is poured into the ceramic pot, the water passes through the pores giving clean drinkable water.

2.3 Moringa Oleifera Tree

The Moringa Oleifera tree (also known as Drumstick or horseradish tree) is a fast-growing and small tree which has a straight trunk with whitish bark. The tree has a height between 5 to 12 meters, with an umbrella shaped crown. The tree’s leaflets are 1-2 centimetres in diameter, its flowers are white/creamed coloured and the fruits of the tree are light green eventually turning to a dark green. The kernels have three papery wings and are surrounded by a wooded shell. The tree is deep rooted therefore is able to handle drought weather(Schwarz, 2000).

The Moringa Oleifera tree works by crushing the seed, the protein within the seed is released causing the bacteria to be attracted to the protein. “Unlike other particles in the water such as clay, bacteria, and other toxic materials which are negatively charged, the protein in the Moringa seed powder is positively charged, thereby attracting the negatively charged particles like a magnet.”(Hupston, 2010)
2.4 Diatomaceous Earth

Diatomaceous earth filtration is a process involving the use of Diatomaceous earth, which consists of the fossilized remains of diatoms, a type of hard-shelled algae. DE is mined and then oven dried. The shells are primarily silica and have a great deal of surface area and porosity which helps filtration. DE filtration works via straining all particulate matter from the water, including bacteria and E.coli (Diatomaceous Earth, 2011).

To filter water with DE, first a cake is placed in the filtering mechanism. A thin layer of DE then builds up on the filter. As the filter is in use, particles on the water build up on the filter, gradually reducing flow. When the maximum amount of flow loss is reached, the filter is stopped and the DE is removed and typically discarded (Bhardwaj & Mirliss, 2001).

2.5 Slow Sand Filtration

A slow sand filter consists of a housing, water layer, filter bed and drainage system. The filter bed consists of sand varying in specification according to the quality of the water being filtered. The filter bed should be a minimum of 0.8m deep in smaller filters but more commonly between 1-1.5 m deep (Huisman L, 1991).

The drainage system that consists of gravel located at the bottom of the filter acts as a barrier to prevent the fine sand from washing away through the filter outlet (Huisman L, 1991).

Water passes through the filter from the top to bottom in a manner not to disturb the top layer of sand where the Schmutzdecke is located. Schmutzdecke, “a naturally occurring gelatinous layer of living biological matter on a sand-based water filter, for which it provides additional filtration” (Double-Tongued Dictionary, 2009), forms a film on top of the sand layer and is the coating that provides the effective purification to the water. The Schmutzdecke is formed in the first 10–20 days of operation and consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae (Wikipedia, 2011). The next step in the filtration process involves the water passing the layer of sand where any leftover suspended organic particles and bacteria will stick to the layers of slime that forms around the sand particles (Huisman L, 1991). Clean water passes through the filter and passes through the outlet.

2.6 Rapid Sand Filtration

Rapid sand filtration uses a similar process of filtering contaminants from water supply as slow sand filtration. The main difference between these two methods is the granule size used in the filter media, the need to pre-treat the water before the filtration process and the requirement of backwashing contaminants from the media bed. Due to the difference in media materials the water
output for rapid filtration can be as high as 100 times more than slow sand filtration. (John C. Crittenden, 2005). The concern with this process is its complexity and maintenance requirements.

The rapid filtration system uses a more uniform size granule material than the slow sand filtration allowing a higher flow rate through the media bed. In using these granules it creates cavities within the bed structure which allows particles to pass through these cavities. Whereas slow sand filtration mainly uses the top portion of the filter bed to remove contaminants, because of the larger cavities rapid filtration uses the entire filter to remove the contaminants (John C. Crittenden, 2005).

### 2.7 Process Selection

After researching the different methods of filtration and how each process works we then needed to find out the best possible option for the village. To do this we came up with some criteria that we believed to be significant to our decision making. The criteria were then weighted as to what we believed were the most important aspects for the villagers.

The most imperative of these was the removal of bacteria as the main focus of our project is to provide safe, clean water to the community. The other main issue was to keep costs to a minimum. After looking at other communities around the world that have had similar projects carried out, other issues that have arisen are; systems too complex, high maintenance requirements, short life expectancy, availability of materials, power shortages and the final output of water. By assessing each filtration system with these criteria we were able to come up with a solution that will work for the issues that the Devikulam villagers are facing.

#### 2.7.1 Carbon Filtration

Carbon filtration only requires a small amount of carbon per surface area but was found not to remove all the bacteria required, and can also form bacteria if water is not flushed through the media regularly (Water, 2011). This process is better suited for the purification of water that has already had the majority of the contaminants/bacteria removed. Carbon filtration is commonly used within households of the western world to remove the impurities of their drinking water. Due to it not removing the bacteria it would not be suitable for our design.

#### 2.7.2 Ceramic Pots

Ceramic Pots are a cheap option that can be made locally by the villagers themselves. This system has been used in other communities to varying degrees of success. The materials that are required can be found locally i.e. clay soil and the only maintenance required is to scrub the pots to clean them once a month to stop the forming of bacteria within the pot. One of the downfalls of this
process is the water output is quite low compared to the other options. The ceramic pots removed most bacteria from the water. Due to its simplicity this was a viable option for the village.

For the pots to be effective in the removal of bacteria they are required to be lined with silver solution (Brown & Sobsey, 2007). This solution acts a biocide. The manufacturing of the pots is a slightly more complex process than some of the other options due to the requirement of adding silver during the construction of the pot. Although this was definitely a viable option for the village we believe that there are less complex options that would be better suited to the village.

2.7.3 Rapid Sand Filtration

Rapid sand filtration works similarly to slow sand filtration with the exception being the water needed to be pre-treated. This required a process called coagulation which basically removes the bacteria before entering the sand filter. This is due to the filter media being processed to a specific size allowing the flow rate to increase (John C. Crittenden, 2005). The downfall being it does not remove bacteria alone and requires complex systems to pre-treat the water and regular backwashing of the filter is required.

The coagulation process is defined as “involving the addition of a chemical coagulant to condition the suspended, colloidal, and dissolved matter for the flocculation process (John C. Crittenden, 2005).” There is the possibility of being able to use the seeds from the Moringa Oleifera tree for this process but this will require a large amount of time and human resources to continually carry out this process.

The other issue with this process is the need to backwash the filter media. As this process uses the entire filter bed for the filtration process it is essential that the unit is backwashed regularly. The rapid sand filtration process will also be an expensive option due to some of the extra procedures involved.

Due to the complexity and maintenance requirements, we did not investigate the costs that rapid sand filtration may total as even if it was low we believe this would not be the most suitable option for Devikulam.

2.7.4 Moringa Oleifera Tree

This tree can be used to remove bacteria from contaminated water supplies. The seeds are crushed and the protein released from the seeds removes the bacteria. The cost for this is minimal as this is a tree found in India. The process to purify the water is a lengthy and time consuming process. It requires the seeds to be prepared and the water strained then left for a number of hours before it is ready for consumption. For this reason it is a less sustainable option.
2.7.5 Diatomaceous Earth

DE filtration is a process involving the use of Diatomaceous earth, which consists of the fossilized remains of diatoms, a type of hard-shelled algae (Diatomaceous Earth, 2011). This process involves the use of mechanical systems including pumps and valves to carry out the filtration process. There is also a safety requirement due to respiratory issues from the silica involved and the possibility of the skin being dried out. This requires Personal Protective Equipment to be used such as a dust mask, glasses and gloves. For these reasons we believe this process to be unsuitable for use within Devikulam.

2.7.6 Slow Sand Filtration

Slow sand filtration uses the same filter process as above but the sand media are of a smaller size causing a much slower filtration rate. This process does not require pre-treatment as the bacteria is removed from the water through the sand due to the much slower filtration rate (John C. Crittenden, 2005). This process is a simple and low maintenance system that does not require the need to backwash the media. This is also a low cost option as most of the materials can be sourced locally. This process of water filtration has been used in many communities throughout the world. It is also still being used in Europe on large scale water supply systems (John C. Crittenden, 2005).

Slow sand filtration has been tried and tested in many developing countries around the world with a great deal of success. The process is a basic design that is easily maintainable without the use of special equipment or tooling. Added to the fact that the removal of bacteria is very high, up to 99% (Biosand Filter.org, 2004), we believe that this is the most feasible option for Devikulam.

Table 2 Removal of bacteria data (Centre for Affordable Water and Sanitation Technology, 2009)

<table>
<thead>
<tr>
<th></th>
<th>Bacteria</th>
<th>Viruses</th>
<th>Protozoa</th>
<th>Helminthes</th>
<th>Turbidity</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>Up to 96.5%¹²</td>
<td>70 to &gt;99%³</td>
<td>&gt;99.9%⁴</td>
<td>Up to 100%⁵</td>
<td>95% &lt;1 NTU¹</td>
<td>Not available</td>
</tr>
<tr>
<td>Field</td>
<td>87.9 to 98.5%⁶⁷</td>
<td>Not available</td>
<td>Not available</td>
<td>Up to 100%⁶</td>
<td>85%⁷</td>
<td>90-95%⁶</td>
</tr>
</tbody>
</table>

2.7.7 Trade off Analysis

The filtration alternatives were measured against criteria as seen in the table below. The removal of bacteria and cost were the most significant criteria that needed to be addressed. These were given a higher weighting to ensure the correct filtration option for Devikulam was chosen. The data was then entered into a spread sheet which ranked the alternatives from most effective and suitable to least. The results are demonstrated in the following table.
### Table 3 Filtration Alternatives Trade off Analysis

<table>
<thead>
<tr>
<th></th>
<th>Carbon Filtration</th>
<th>Ceramic Pots</th>
<th>Rapid Sand Filtration</th>
<th>Slow sand Filtration</th>
<th>Moringa Oleifera</th>
<th>Diatomaceous Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Removal Of Bacteria</strong></td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Material Availability</strong></td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Water Output</strong></td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Power Requirements</strong></td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td><strong>Longevity</strong></td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><strong>Complexity</strong></td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>22</td>
<td>29</td>
<td>20</td>
<td>31</td>
<td>28</td>
<td>18</td>
</tr>
<tr>
<td><strong>Ranking</strong></td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

From this data it was evident that from the requirements of the villagers and the water purity issues, slow sand filtration would be the best avenue to follow and implement throughout Devikulam village. There have been many ways that slow sand filtration has been implemented in remote villagers throughout the world with large systems that support the entire village through to independent household systems that are used and maintained by individual families.

### 3 Design Solution

The results from the Water Quality tests (see appendix A) show that the significant problem with Devikulam’s water supply is the levels of bacteria in the water. The other parameters tested such as water turbidity are within the desirable limit range. Due to the geological composition of the area, it was not required to test for mercury and arsenic in the water (Engineers Without Borders, 2011).

From this information and through the trade-off analysis it was evident that the most suitable solution will be the use of a slow sand filtration system. Slow sand filtration removes bacteria, is a low maintenance and cost effective option and has been used successfully throughout the world.

While there are other issues within the village that are contributing to the water quality concerns that need to be resolved, by implementing a slow sand filtration unit, the villagers will be able to rectify these problems in due course while still having clean, safe water to drink. This design once
employed will immediately remove the issue of bacteria within the water and allow the community to confront and correct the additional problems which may be causing contamination of the water supply.

### 3.1 How Slow Sand Filtration Works

As described above in section 2.5, water passes through the filter from the top to bottom in a manner not to disturb the top layer of sand where the Schmutzdecke is located. Schmutzdecke “a naturally occurring gelatinous layer of living biological matter on a sand-based water filter, for which it provides additional filtration” (Double-Tongued Dictionary, 2009) forms a layer on top of the sand layer and is the film that provides the effective purification to the water. The Schmutzdecke is formed in the first 10–20 days of operation and consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae (Wikipedia, 2011). The next step in the filtration process involves the water passing the layer of sand where any leftover suspended organic particles and bacteria will stick to the film of slime that forms around the sand particles (Huisman L, 1991). Clean water passes through the filter and passes through the outlet.

Slow sand filters slowly lose their performance as the Schmutzdecke grows and thereby reduces the rate of flow through the filter. Eventually it is necessary to refurbish the filter. Two methods are commonly used to do this. In the first, the top few millimetres of fine sand is scraped off to expose a new layer of clean sand. Water is then decanted back into the filter and re-circulated for a few hours to allow a new Schmutzdecke to develop. The filter is then filled to full depth and brought back into service. The second method, sometimes called wet harrowing, involves lowering the water level to just above the Schmutzdecke, stirring the sand and thereby suspending any solids held in that layer and then running the water to waste. The filter is then filled to full depth and brought back into service. Wet harrowing can allow the filter to be brought back into service more quickly (Wikipedia, 2011).

### 3.2 Sand Specification

As there are numerous options for sand filtration (i.e. large design to small household designs) it is important to understand the required sand specifications. Understanding this enables us to implement the right option for the community.

Sand is characterized by the diameter of the individual sand grains. Sand used for the sand filtration process must be of a fine grade, 0.15 - 0.35 mm is recommended, and must be washed free of loam, clay, and organic matter. Fine particles will quickly clog the filters and frequent cleaning will be required. Sand that is not uniform will also settle in volume, reducing the porosity and slow the passage of water (Huisman L, 1991).
In order for a slow sand filter to be effective the water being treated should not be contaminated with heavy metals or excessive pollutants. The filter is also not designed to remove chemicals from water. Slow sand filters are designed primarily to remove bacteria and particles. “Provided that the grain size is around 0.1mm in diameter, a sand filter can remove all faecal coliforms (bacteria that originate from faeces) and virtually all viruses (Huisman L, 1991).”

### 3.2.1 Calculating Sand Sizes

As sand does not have the same consistency even if taken from the same source, two measures need to be taken into account to ensure efficient filtration.

**Effective particle size** is the diameter of the grains in the sample where 10% are smaller and 90% are larger than the sample. This is referred to as $d_{10}$. When 40% of the particles are larger and 60% are smaller this is $d_{60}$. These figures are used to work out the uniform coefficient (Huisman L, 1991).

**Uniform coefficient (UC)** is described as the difference between the largest and the smallest particles within the sample. The uniform coefficient should always be less than 3 and preferably less than 2. The ratio can be worked out using the following formula (Huisman L, 1991).

\[
UC = \frac{d_{60}}{d_{10}}
\]

To find the figures for $d_{60}$ and $d_{10}$ a sieve analysis is necessary.

**Sieve analysis (ITACA Sandfiltration, 2005)**

- A set of analysis sieves stacked on top of each other are required
- Sand needs to be mixed well and dry and 200g placed on top sieve
- The stack of sieves are shaken for 10 minutes
- The sand in each sieve is then weighed and added to give a combined weight
- To work out the percentage of sand retained in each sieve subtract the weight retained by the individual sieve from 100. This will give the cumulative weight of each sieve

This process can become complex as well as needing special tooling. To combat this problem we will make use of a sieve with uniform holes to ensure the correct sized sand is used for the filter media. Using two sieves with a hole size 0.17mm and 0.30mm will make sure that the correct size sand is used. This can be built by the villagers while building the sand filter units. The construction of the sieve will be discussed in more detail in the implementation plan.
3.3 Sand Filtration Design Options

There are a number of options to consider in regards to the final design of the sand filter. The options of large or small units as well as the materials needed were all researched in order to come up with the best possible sand filter. Safety concerns and maintenance requirements were all taken into account while ensuring that the community’s needs were met.

3.3.1 Large Scale Filtration System

Slow sand filtration can be achieved in various ways including using a system that will supply the entire village with clean water from one large filter. The same process is used for this system but on a larger scale. As the name suggests this method of filtration will take up significantly more area than smaller individual household units. The large scale unit can either be dug into the ground or some type of containment be built i.e. tanks or concrete holding pens.

The media bed is required to be between 0.9m to 1.5m deep. The media bed is usually supported on a layer of graded gravel approximately 0.3m to 0.6m deep. The water level is required to be several feet above the filter media to create head pressure. This can be achieved by using storage tanks at a higher level than the media or a dam type setup where the water is on top of the filter (i.e. at an elevated level such as on a hill). The filter effluent is then collected in a drain type system. This may be constructed of perforated pipes or concrete blocks. (John C. Crittenden, 2005)

As the system loses head pressure the filter would need to be drained and the top layer of sand be removed (the Schmutzdecke layer). This is the layer that does the majority of the filtering. It can then take up to several days to reform the Schmutzdecke layer. The sand that has been scraped off can be cleaned and put into stockpiles for future reuse.

Due to the size of this option a few problems arise such as water containment, increase in manual labour and maintenance requirements, increase in costs, sufficient land space and possible contamination from other water supplies. Due to the amount of water required for this large scale filter the best place to construct it would be near the water tanks and use these for the water supply. The downside to this is that it will also be near the village pond that is contaminated and during the monsoon season it could be possible to overflow and contaminate the filter.

This system will require monitoring and maintenance at various times. Due to it being for the entire village people will need to be delegated to carry out the required maintenance from time to time. This could possibly cause conflict within the village if not handled correctly. Once the water has been filtered due to the larger quantity it will need to be stored in a containment area. Depending on the size and amount of water used there is a possibility that the filtered water could once again become contaminated with organisms etc... before being used.

The large system can create many issues including safety concerns with larger equipment and materials being used. It also causes logistical problems of transporting and finding materials locally...
as well as increased costs. For these reasons we did not investigate costs or availability of materials as we believe this is not the best option for the water quality issue within Devikulam.

### 3.3.2 Shared Units (3-5 households)

The advantages of this system are that 3 or more families will have a combined effort to purify and store the water for their use. Water, not purified yet, will be acquired from one of the water sources in the village and brought to the slow sand filter. The water will then be manually poured into the top of the slow sand filter and be collected as it passes through the outlet.

The disadvantages of this system is however a concern. It is inevitable for conflict to arise over the maintenance and distribution of water. The location of the water filter could also cause disputes among the community, as the filter would have to be stored inside a house or secure building or location as it will be subjected to possible vandalism of theft.

One possible solution to these disadvantages could be to provide each individual family with their own personal water filter. This option has less disadvantages, and also more advantages making it a likely viable solution.

The costs of this unit would be similar to the individual household unit as it would be the same process only using larger containment drums. The costs for the individual unit are discussed in section 3.3.3.

### 3.3.3 Individual Unit

This system requires each individual family to acquire their own drinking water from a water source in the village. This process will be basically the same as the filter system process for three or more families the only difference being that the size of the filter for the individual families will be slightly smaller.

The advantage over this system is that it gives the individual family ownership of their filter, which means they only have to purify the amount of water needed and eliminate water wastage. This process will also prevent maintenance and water distribution conflicts among the community.

![Figure 3-Slow sand filter in family home (Hibbard, 2009)](image-url)
3.4 Construction Materials

The sand filtration unit can be constructed with various materials. As for the filtration option we needed to be sure that we use the most cost effective, available and durable materials to create the filter housing. Once again we used measures to determine the most suitable option. The table below shows the results and ranks the materials from least to most suitable.

Table 4 Construction materials Trade off Analysis

<table>
<thead>
<tr>
<th></th>
<th>Concrete</th>
<th>Plastic</th>
<th>Ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Transport</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Life Expectancy</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Material</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Availability</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Maintenance</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Ease of build</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Mobility</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Totals</td>
<td>24</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>Ranking</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Ranking (0 - 5) 0 being Low impact 5 being high impact

3.4.1 Concrete

Concrete was a very viable option as it has a long life expectancy. It is said that “Concrete can have an infinite lifespan under the right conditions” (University of Illinois, 1995). Concrete sand filter units have been used in many developing countries with great success.

The major downfall for this unit was the requirement to build a mould. This required metal work fabrication including welding and cutting of metal sheets. The metal for the mould would also need to be sourced and the cost would need to be factored in to the price of the units.

Due to the requirement of tooling that would need to have been purchased or hired plus the complexity of building the mould it was decided that this was not the most suitable option for Devikulam.
3.4.2 Ceramic

The possibility of using ceramic pots for the housing was investigated. This option would need the use of kilns or open fire to treat and cure the pots. There is a neighbouring town that has means of building and firing ceramic pots but due to the shorter life expectancy and the quantity of pots needed it was deemed to be an impact on the environment with the wood being burned for the firing process.

The need for silver lining as discussed earlier in the report as well as the pot needing to be cleaned regularly made the ceramic alternative less attractive for the village. If the pot was not cleaned the possibility of bacteria building up lower in the filter media is a distinct risk. To clean the pot the filter media would need to be removed and in doing so would destroy the Schmutzdecke layer.

3.4.3 Plastic

Although not seen as the most environmentally friendly of materials, due to the life expectancy of up to 50 years (U.S. EPA, 2007) plus the ease of maintenance and availability this was the most viable option for the community. There is no construction required only transport logistics to be investigated (see Implementation Plan).

The construction of the filter unit using plastic is a relatively simple task that requires minimal tools. As the villagers have repaired the pipes and taps in July 2010 (Buzza, 2011) it is presumed that they would have access to the necessary tooling.

Once the filter is constructed, as long as it is looked after, the drum should last for many years without any ongoing maintenance.

4 Sand Filtration Design Specification

The sand filtration unit we believe will suit the community is an intermittently operated unit. This means that water will not continually flow through it. In the past it was believed that this option was unfeasible as there is a need for continuous food and oxygen supply for the Schmutzdecke layer to form (Biosand Filter.org, 2004).

To overcome this issue the drain pipe is required to be raised between 1 and 8cm above the sand level. This guarantees the water level in the filtration unit will always be slightly above the sand allowing the biological layer to form and not die off because of lack of water.
4.1 Water Requirements for the Village

It is said that an adult male in the US has a recommended daily water intake of 3.7 litres per day and 2.7 litres per day for women (Wikipedia, 2011).

There are 86 households within Devikulam and they contain on average between 4 – 7 people (Buzza, 2011). Working on the fact of each person requiring up to 4 litres per day and the household having a maximum of 7 people the individual filters will be required to produce 28 litres of water per day.

Sand filtration units generally have a flow rate of between 0.1 and 0.4 m/hour. This equates to approximately 22 to 25 litres/hour (Biosand Filter.org, 2004). This flow rate will be more than sufficient for the individual households.

4.2 Filter Housing

The filtration unit will be housed in a 65 litre cylindrical drum. This drum is made of a blow mould design using HM-HDPE raw material for maximum chemical resistance. The drum also complies with FDA regulations for direct contact with Food and Drugs (Sharda Containers, 2011).

A removable cap is fitted to the top of the drum with a galvanised steel locking ring. It also contains a UV stabilizer to protect from sun damage (Sharda Containers, 2011). This will house the filter media.
4.3 Filter Media

As discussed earlier in the report slow sand filtration uses different sized sand granules to filter the water. To ensure that this sand does not flush through or enter the outlet pipe it needs to have a gravel base at the bottom of the drum.

The sand and gravel is readily available within the village (Engineers Without Borders, 2011). The sand will need to be sieved to sizes between 0.15mm and 0.30mm. The gravel will also need to be of different grades to provide a solid base to ensure sand does not enter the outlet pipe. The procedure to sieve the sand and gravel will be discussed in detail in the implementation plan. See Appendix C for a guide to the sand and gravel required.

4.4 Filter Specifications

As discussed in 4.1 the filter will be required to produce up to 28 litres of clean water per day. Ensuring that our design meets this requirement is essential for its successful use within the local households. Another factor is to make sure the flow rate is not too fast. If the rate is too fast the biological layer will not have enough time to remove all the contaminants.

Darcy’s law states “that the rate in which a fluid flows through a permeable medium is directly proportional to the drop in vertical elevation between two places in the medium and indirectly proportional to the distance between them” (American Heritage Science Dictionary, 2011). This law can be used to describe the flow of water through a sand filtration unit.

Darcy’s equation (Biosand Filter.org, 2004):

\[ Q = K \frac{Ah}{L} \]

Using Darcy’s equation enables us to work out an approximate flow rate for our filter design. The flow rate for this unit is approximately 30 litres per hour. This flow rate is sufficient for the water requirements of the community. For a more detailed explanation of the calculation see appendix E.

5 Design Implementation

An advantage of this design is that implementation is quite simple. The drums and filters and other equipment will need to be delivered. After this is done some time will need to be spent educating the villagers on how the filters work and how to construct them. Some work will then need to be done by the villagers on constructing the filters. After this is done no further implementation should be needed, though occasional monitoring and advice may be needed should any problems arise.
5.1 Implementation Plan

It is envisioned that this project should be able to be implemented in a single phase. Firstly the drums and other equipment listed need to be sourced and bought. After this is done the equipment will need to be transported to the village. As none of the equipment is particularly fragile, transport by any common trailer truck or flatbed truck will suffice. Once transport has been arranged and carried out it will be a relatively simple matter to educate the villagers on the construction and use of the filters. Once this is complete further implementation beyond monitoring the filters should not be required.

5.1.1 Safety Considerations

Given the simplicity of the design and implementation there are relatively few safety considerations that need to be taken into account. The sand itself is not harmful unless breathed in, and is heavy enough that it does not float in air, making this unlikely. The plastic used in the construction should not leech into the water or emit any gases. A concern is that water could leak from the container if it is damaged, but it is unlikely to cause damage to any property and will be promptly replaced. It is possible that the container could fall or be tipped over, but as a 65 litre container of sand would weigh approximately 120kg this is unlikely to happen provided the drum is on a stable surface. As it is so heavy it is unlikely that a child could pull it over.

These units will be situated on the floor to ensure the possibility of it falling is removed. As most of the components will be manufactured off site any safety concerns with these materials has been removed. The assembly procedures require minimal handling that could result in injury.

The only possible concern is the collection of the required sand. There is a risk of manual handling injuries while moving sand and gravel. As most of the villagers are employed in the agricultural industry it is presumed that the community knows about the possible injuries of manual labour.

5.1.2 Obtaining Materials

The drums we plan to use are available from Sharda Containers in New Delhi India. They supply numerous barrels and plastic containers of all sizes. As it has been difficult to find information on suppliers in India for various reasons we will use the information supplied by Sharda Containers for our cost analysis. There is the possibility that the community may find closer and cheaper options than this.

The address of Sharda Containers is 363 Fie Patparganj Industrial Estate, New Delhi India. Using Google maps it was found that they are approximately 2566km from Devikulam. At this stage we are still waiting for information on shipment costs. To be able to approximate the costs for transport we were able to find a generic price for freight costs within India. As stated before it is possible that the villagers may find cheaper prices or have access to a vehicle to transport the materials.
On July 21\textsuperscript{st} 2010 work was carried out to repair the piping and taps within Devikulam. The piping used for this project was ¾ inch (Buzza, 2011). It is probable that there will be excess piping left over from the work. If so we propose to use that piping to reduce the costs. If not we have factored in this cost within the cost analysis in section 5.1.4.

5.1.3 Transport

Transport to the village is possible year round, however during the monsoon seasons a longer route must be taken. The monsoon seasons are October to December for the North East monsoon and June to September for the South West monsoon. The route is 26km longer as the diagram below shows (EWB Australia, 2011). See appendix D for the map.

As discussed in section 5.1.2 the distance from the supplier to Devikulam is approximately 2566km. The freight costs are supplied in the cost analysis table in section 5.1.4. The costs are based on either a Semi trailer low bed truck or a low bed truck. The rate is for any distance greater than 600km in which Devikulam is.

5.1.4 Cost Analysis

Table 5 Cost Analysis Table

<table>
<thead>
<tr>
<th></th>
<th>Plastic drums</th>
<th>¾” PVC Piping &amp; Fittings</th>
<th>Transport – Low bed trailer</th>
<th>Transport – semi low bed trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUD Per Unit</td>
<td>$60</td>
<td>$2.07 per/m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per unit Rs</td>
<td>2,877.69Rs</td>
<td>99Rs</td>
<td>171 per km &gt; 600km</td>
<td>103 per km &gt; 600km</td>
</tr>
<tr>
<td>Total Costs Rs</td>
<td>247,481.34Rs</td>
<td>6,948 Rs</td>
<td>438,786Rs</td>
<td>264,298Rs</td>
</tr>
<tr>
<td>Per household Rs</td>
<td>2,877.69 Rs</td>
<td>217Rs</td>
<td>7979.85 Rs</td>
<td>3073.23 Rs</td>
</tr>
<tr>
<td>Totals Rs Per Household</td>
<td>11,074.54 Rs</td>
<td></td>
<td>6,167.92 Rs</td>
<td></td>
</tr>
</tbody>
</table>

The generic freight prices were found from information supplied on Slideshare.net (Atma Prakash, 2010). These figures do not take into account any insurance if required.

The prices for the drums are from Sharda Containers. We have contacted them for bulk pricing but as of this report being finished we have not received any information on the costs. In our previous communication with them they have stated that buying bulk will result in cheaper costs.

The PVC pipe costs are from Australian suppliers. Once again we have found it difficult for suppliers in India to get back to us with the information required. It is probable that the villagers will be able to get cheaper prices than those quoted above.
The average yearly wage per household for the community of Devikulam is between 10,000 Rs – 60,000 Rs per year (Engineers Without Borders, 2011). The median yearly income could be said to be approximately 35,000 Rs.

Using 35,000 Rs for our calculations we are able to approximate the percentage of cost per unit versus income. This is not taking into account the possibility of an organisation funding the project.

These costs are approximations and may be cheaper or more expensive. We have also factored in that there are no resources on hand. If the piping or other materials are on hand the costs will decrease. It is also understood that not all households earn 35,000 Rs per year so that will similarly change the final figures.

Although the initial outlay may seem an expensive option considering the lifespan of the unit the relative cost is low. Once implemented the ongoing costs are negligible. Any expenses incurred would be due to damage. The following table shows costs per litres filtered plus daily cost for a conservative ten year lifespan.

<table>
<thead>
<tr>
<th>10 Year Lifespan</th>
<th>Initial Costs Rupee</th>
<th>% Of yearly median income (35,000 Rs)</th>
<th>Cost per Litre Rupee</th>
<th>Cost per Day Rupee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low bed Trailer</td>
<td>11,074.54Rs</td>
<td>31%</td>
<td>0.15Rs</td>
<td>3 Rs</td>
</tr>
<tr>
<td>Semi low bed Trailer</td>
<td>6167.92 Rs</td>
<td>17%</td>
<td>0.8 Rs</td>
<td>1.68Rs</td>
</tr>
</tbody>
</table>

### 5.2 Build Process

The building of the sand filtration unit is a fairly simple process. It requires minimal tools that would be available within the village or local area. For the build process we have taken into account safety concerns and laid out a plan for the best way to construct the filter. Any areas that we believed could pose a high safety risk we have eliminated and redeveloped a new process.

#### 5.2.1 Assembly of Filter Unit

The unit build can be broken into 5 stages:

1. Locating and preparing the place for the unit.
2. Collecting all the required tooling.
3. Gathering the sand.
4. Preparing the sand and gravel.
5. Constructing the unit.
It is recommended the unit be placed inside the home, located somewhere out of the way with good access. The unit would need to be placed on the ground so there will be no issues of it toppling over. The unit can be placed outside although not recommended (Placing the unit outside will reduce the life span of the plastic container, also providing opportunity for vandalism).

Tooling required is listed in section 5.2.5.

The villagers need to determine the best site where the sand will be collected from. Our recommendation would be all the sand to be collected comes from the one location and well away from where people or livestock frequent. Gathering the sand from multiple locations would create safety concerns as there would be a lot of holes where people and livestock could trip causing injury.

Once the sand is collected and put through the sieve process the sand needs to be washed before being placed in the filter unit. To clean the sand a couple of large containers would be needed. The sand is placed in the container and a larger volume of water is added. The water will become cloudy, this needs to be drained off and the process repeated until the water becomes clear. If the sand which has been cleaned is suspected of being contaminated with microorganisms it would be recommended it be placed in the sun until dry.

Constructing the unit is a simple process which is broken into 4 stages.

1. Building the outlet pipe
2. Preparing the containment unit
3. Adding all the filter media to the unit
4. Flushing the unit

**Outlet Pipe**

You will require:

- 2.2m poly pipe 3/4
- 4 x 90 deg bends 3/4
- 3 x tee piece 3/4
- 4 x blanking caps 3/4

Cut the 3/4 pipe into 1 x 530mm, 4 x 250mm, 2 x 145mm, 1 x 200mm and 1 x 100mm. The pipes will need to be assembled in a 2 part configuration (refer appendix F). The 4 pipes located at the base will need to be drilled with plenty of holes using the 3mm drill bit. Once glued the piping is ready to be installed into the unit. To allow sufficient curing of the glue it is recommended not to drink the water for at least 24 hrs.

Note: Only use the glue on the pipe, not in the elbow and tee (This prevents excess glue forming on the inside of the pipe).

**Containment Unit**

Measure from the base up the side of the unit 535mm and place a mark. Set up the drill with the 19mm hole saw. Where you have marked the unit drill the 19mm hole, cleaning off all swarf left behind. On the inside of the unit place marks from the base at 100mm, 250mm and 500mm (These
marks are for the sand filter media levels as discussed in section 5.2.4). The unit is now ready for the outlet pipe to be installed.

Install the outlet pipe sitting it firmly onto the base of the containment unit (To make it easier the gravel can now be place over the piping too the 100mm mark to lock it in place). The second piece of the outlet pipe can now be passed through the 19mm hole and glued to the main riser pipe (silicone should be used to seal the pipe to the drum). It is now recommended the unit be placed in its final resting place to save any injuries moving it when full of sand.

*Filter Media*

Now the unit is ready to have the filtering sand added. Firstly add the 0.30mm sand up to the 250mm mark levelling it out. Now add the 0.17mm sand up to the 500mm mark again levelling it out. For more detailed description see section 5.2.4.

*Note;* The sand level needs to be 25mm lower than the outlet pipe.

*Flushing the unit*

To ensure any glue residue (fumes) which may be present in the water as it comes out of the unit it is recommended flushing water through the unit until there are no smells present in the filtered water.

*Diffuser*

A bucket with a diameter of 320mm will need to be obtained to fit into the top of the drum. This can be used as a diffuser. Holes can be drilled at the base of the bucket to ensure that the top sand layer does not get disturbed when pouring in water.

To ensure the correct hole sizes draw a 2.5cm grid on the base of the bucket and drill holes using the 3mm drill bit at the intersecting points. Using the bucket enables the bucket to be removed and the lid placed back on to seal the unit.

If the bucket is not used the lid can take its place as the diffuser. The disadvantage of this would be that the water would need to be poured in slowly as it does not have the same capacity as the bucket.

*5.2.2 Sand & Gravel Sieving Process*

A sand sifter will drastically reduce the overall cost of the project, as residents of Devikulam will be able to acquire sand for their filters from their surroundings, eliminating the cost of purchasing sand with correct grain size. Sand for the sand filters cannot simply be collected from the earth and placed inside the filter, due to the fact that the grain size may be larger than 0.1mm and the sand may also be filled with small rocks and other material that might hinder the filtration process such as
tree roots and other organic material. In order to use the sand from the village for the sand filters, the sand would have to undergo a sand sifting process. This involves passing the raw sand filled with contaminants through a sand sifter, which will separate the fine sand from larger particles.

To ensure that the most efficient media filter is used, two different sized sieves will be required. One sieve should be of 0.17mm and the other of 0.30mm. The smaller sand granules will make up the top layer of approximately 250mm. The larger sand will make up the rest of the filter bed. This ensures that the majority of the filtration process is carried out in the top layer of the media bed. If it filters too low in the sand the filter will eventually clog and the sand will need to be replaced.

To sieve the correct size gravel sieves of 6mm and 1mm can be used. The larger 6mm gravel is used for the base. This gravel will be filled to 50mm from the bottom. On top of this layer the 1mm gravel is placed to 50mm (both levels will measure 100mm).

These sieves can be made from wood and mesh. The materials to make these frames should be able to be sourced from the village. The mesh may need to be purchased from a hardware store or a similar retailer in the local area. If the mesh needs to be bought the price can be divided between the 86 households.

A basic step by step process for the sieving of gravel and sand follows:

- Construct sieves as pictured with mesh of 6mm, 1mm, 0.3mm and 0.17mm
- Sift gravel through 6mm sieve onto 1mm sieve. Throw away any gravel that does not fall through. Gravel that is caught by the 1mm sieve is used for the base.
- Sift gravel through 1mm sieve onto 0.3mm. This will provide the next layer.
- Now using the sand sift through 0.3mm and 0.17mm sieves to catch the sand for the filtration layers.
- The sand should be placed in separate piles as shown in the picture above. This will make it easier when filling the drums with the gravel and sand.
5.2.3 Washing Sand & Gravel

It’s important to wash the gravel and sand which will go into the filtration system, to get rid of any dirt or contaminants that will affect the process of the slow sand filtration. This may include soil and any other organic substances that are found with the sand. When the sand is being washed it is important that the water within the container/bucket is not completely clean and that it is slightly dirty, however with the gravel, the water within the container/bucket must be completely clear.

How to wash the gravel (CAWST, 2009):

- Place about 2-3 litres of gravel in a container/bucket
- Put twice as much of water into the container/bucket
- Using your hand, swirl the gravel around until the water becomes quite dirty
- Pour the dirty water out of the container
- Repeat the process until the water in your container is clear
- Wash the rest of the gravel, using the same method (a little at a time)
- Place all of the gravel on a cover or concrete surface in the sun to dry
- Once dry store the gravel under cover

How to wash the sand (CAWST, 2009):

- Put a small amount of sand in the container/bucket
- Put twice the amount of water in the container/bucket
- Using your hand, swirl the sand around the container 10 times very quickly, making sure your fingers touch the bottom of the container and get all of the sand moving
- Quickly empty the dirty water
- Repeat steps 1 to 4 as many times until the water is slightly dirty
- Wash the rest of the sand using the same method (steps 1 to 5)
- Place all of the sand and gravel on a tarp or concrete surface in the sun to dry.
- Store the sand under cover once it is dry.
5.2.4 Distribution of Filter Media

Once the correct size sand and gravel have been collected we need to fill the drum up with the correct measurements. The following procedure will ensure that the filter is set up correctly.

- The gravel will make up the base containing 100mm. It is important to note that there should be little gaps to make sure sand cannot fall through and enter the outlet pipe.
- Next the larger sand is required to sit on the gravel base. There needs to be 150mm of sand placed in the drum.
- On top of this layer place the finer sand for the final level. This top layer will do the majority of the filtering.
- An easy way to ensure the correct heights are obtained would be to measure and mark the levels inside the drum before filling.

See the following diagram for the dimensions.

![Figure 6 Dimensions for filter media](#)
5.2.5 Required Tooling

To construct the water filter a small number of tools will be required. As the community have just carried out improvements on their water supply it is assumed that they have access to basic tooling. The following tooling list is:

- Hand or electric drill
- 3 – 6mm drill bit
- 19mm hole saw
- Knife
- Measuring tape
- silicone
- Plumbers glue
- Handsaw
- Marking Pen
- Shovels
- Wheel barrow

5.3 Educational Plan

Education is vital for our design project to be successful, it is important that the people of Devikulam know and understand how to use the filtration system. There are three main areas that need to be addressed, they being, construction of the system, maintenance and how to use the system. The system is designed for household usage therefore each family would need to be educated for our design to be successful.

An option to roll out this plan would be for a member from EWB or an associate in Devikulam to conduct a workshop for the community on the areas of construction, maintenance and use of the filtration unit.

The following points would need to be addressed;

Construction

They would be shown how to construct the filtration unit in the workshop

- Ability to collect and prepare the appropriate sand
- Knowledge of the water issue in Devikulam
- Knowledge of how the system operates
- Ability to construct the filtration system
Maintenance

The maintenance of the filter is important for our design to be successful, one or two members of each family will be educated in how to maintain the filter to ensure the flow rate is acceptable.

- Ability to remove top layer of sand
- Ability to clean system when necessary
- Knowledge of how the system operates
- Knowledge of water issue in Devikulam
- Ability to set the system to the correct water level before use

System use

The whole village would need to be educated in how to use the system, although the system is quite easy to use, it is important that the people of Devikulam understand that when collecting the water from the system they are unable to use the same bucket/container they use to carry the contaminated water.

- Ability to fill the system at a certain level
- Ability to collect and store water from the filter
- Knowledge about hygiene
- Knowledge of the system’s purpose

6 Impact Assessment

During the design process our team has always thought about the impacts that our design might have on the Devikulam village. We were able to divide the impacts into three areas environmental, economic and social. The environment impacts must be identified and then resolved in order for our design to be acceptable, for the impacts to be identified our team looked at the life cycle of the design from the materials being used to the disposal of those materials. The economic impact is based upon the funding for the filtration system during its life span in the village and the social impact must be minimal in order for the design to be accepted into the community this includes their beliefs and values.

6.1 Environmental Impacts

Throughout our design process our team has kept in mind the impacts that our design may have on the environment. We researched many different materials in which we could make our external structure of our design have the least amount of impact on the environment; our team was to decide whether to use plastic, ceramic or concrete. However with various criteria to consider, our team looked into each option.
It is well known that plastic is durable and can therefore affect the environment. To minimise the impact our team researched into how we can dispose of the plastic after it has reached its life span. The lifespan of the plastic drums should be in excess of 50 years if cared for (U.S. EPA, 2007). Our design proposes that the filters be kept indoors to keep the drums out of the sunlight.

As the drums are made of polyethylene which is easily recycled it is envisioned that the drums will be sold to a local recycling plant. Not only is this environmentally friendly, but potentially there may be further incentive provided via being paid for the used drums. There is a recycling plant located in Kadapakkam, which is located 22 kilometres from the village. Another option that has been used elsewhere in the world is the option of using the drums as pots for a vegetable patch.

Our design is on a small scale, so each household will have their own filtration system, therefore there will be minimal to no impact on the surrounding environment. The sand used in our design is available in the Devikulam village and is able to be returned to the local riverbed once used. This is beneficial to the environment as it has minimal impression on the surrounding area, and no site would need to be created in order to store imported sand.

### 6.2 Economic Impacts

The filtration system is designed for household usage only therefore each family must maintain and provide their own system, this can impact the families on an economic level as they have a small amount of income and must pay the initial and ongoing cost for the filtration system. However with the use of local materials such as the sand, the cost is decreased and jobs are created within the village. The other construction materials are available in India therefore the system is helping local communities.

As described above in the cost analysis we have approximated the costs per litre of water filtered plus the daily cost over a 10 year period. Clean drinking water is essential for a healthy community so the benefits outweigh the initial expense and once in use the ongoing costs are negligible. Any costs incurred after implementation will be due to damage.

### 6.3 Social Impacts

Devikulam villagers are Hindu (Buzza, 2011) so it is imperative that our design did not impact on their religious and cultural beliefs. There are two castes within Devikulam, the Scheduled Class (SC - formerly Dalit) and the Most Backward Class (MBC)(Buzza, 2011). The MBC live within the village and the SC live in the colony. The two classes generally get along and come together at certain functions (Buzza, 2011).

Making use of the household water filtration unit we believe coexists with the community’s ideals. The filter does not vary the day to day workings of the community as the water is still gathered in the same way and there is no land required to be used for the construction of the units. The only
difference being that there will be a filtration unit in each household. As these will provide the entire community with clean water, we believe the community will embrace the concept and continue to use it into the future.

7 Team Structure

In our first meeting we decided to break our team up into sections. We believed this would enable us to stay on track throughout the project plus allow people to use their strengths during the process. It also allowed each individual to concentrate on specific tasks while still being able to input in decisions when we were together.

Team Leader - Our Team leader’s role is to make sure we keep on track and if difficulties arise, reallocate tasks accordingly to make sure timelines are met and the people that are struggling are being supported so we as a group succeed in achieving the final goal.

Researchers – The task of the researchers is to gather the relevant information and provide documentation to provide us all with the evidence to base our decisions and lead us to our design ideas. With this information we were then able to discuss the ideas as a group and move forward in our design process.

Formatting – The person carrying out the formatting was assigned to gather all the information supplied and incorporate it into our reports. They formatted the reports and made sure that it was laid out in a logical process and was easy to follow and read.
8 Conclusion

It is stated that “Water related diseases are the most common cause of illness and death among the poor of developing countries”. (World Water Council, 2010). Therefore the issue of clean water supply and sanitation are areas that require attention as they have the potential to cause widespread illness within the village and surrounding areas. For this reason we believe it to be an important issue to be able to supply the village with clean drinking water.

In this report we have explored different types of Water Filtration System including Activated Carbon, Ceramic, Moringa Oleifera Tree, Diatomaceous Earth, Rapid Sand and Slow Sand Filtration vs. options that can be used for the Devikulam villagers. Through our research we have investigated and discussed the advantages and disadvantages for each of these options, taking into account the cost/benefit ratio, maintenance/technical expertise required and equipment/infrastructure needed.

After analysing these systems and reviewing all data collected and in view of the communities concerns, we have come to a conclusion that an Individual stand-alone Sand Filtration Unit can remove up to 99% of the bacteria and other unnecessary contaminants from the water supply. Providing good drinkable water to the village will help to improve the health in the village (Children will be able to go to school, the men will be able to work, and the women will be able to contribute to the village). These benefits mean a stronger economy which will in turn make the village move forward and come up with their own solution to problems.

To add strength to our design solution you can go back as far as the Roman Empire where slow sand filtration has been used. Even today in remote villages like Devikulam the slow sand filtration method is the preferred option due to its simplicity in design and maintenance.

Throughout this process we have constantly referred back to the issues raised by the community as detailed in the Design Brief and the Innovations report supplied by EWB. This has been an important factor in our decision making as it is vital that the community believes our design will help them now and into the future.

Our aim as Engineers is to come up with a solution to improve the quality of life to all people making our experience and expertise available to all walks of life no matter their background and financial status.
Works Cited


Water Filtration


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http://www.oasisdesign.net/water/treatment/slowsandfilter.htm

http://www.naturalnews.com/029229_moringa_drinking_water.html


http://www.lenntech.com/sulfates.htm


http://matse1.matse.illinois.edu/concrete/prin.html


http://en.wikipedia.org/wiki/Activated_carbon


### 9 Appendices

#### 9.1 Appendix A

**Table 6 Village Tap 1 Water Results (Engineers Without Borders, 2011)**

<table>
<thead>
<tr>
<th>S1 No.</th>
<th>Parameters</th>
<th>Units</th>
<th>Results</th>
<th>Drinking Water Standard (IS: 10500 - 1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH (at 25°C)</td>
<td>6.8</td>
<td></td>
<td>Desirable limit 6.5 - 8.5; Permissible limit in the absence of alternate sources.</td>
</tr>
<tr>
<td>2.</td>
<td>EC (at 25°C)</td>
<td>μS/cm</td>
<td>650</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>TDS (at 153°C)</td>
<td>mg/l</td>
<td>372</td>
<td>500; 2000</td>
</tr>
<tr>
<td>4.</td>
<td>Colour</td>
<td>HU</td>
<td>&lt; 5</td>
<td>5; 25</td>
</tr>
<tr>
<td>5.</td>
<td>Turbidity</td>
<td>NTU</td>
<td>&lt; 0.1</td>
<td>5; 10</td>
</tr>
<tr>
<td>6.</td>
<td>Colour</td>
<td></td>
<td></td>
<td>Under detectable; Under detectable; No relaxation</td>
</tr>
<tr>
<td>7.</td>
<td>Total Hardness (as CaCO₃)</td>
<td>mg/l</td>
<td>332</td>
<td>500; 600</td>
</tr>
<tr>
<td>8.</td>
<td>Calcium (as Ca)</td>
<td>mg/l</td>
<td>53</td>
<td>75; 200</td>
</tr>
<tr>
<td>9.</td>
<td>Magnesium (as Mg)</td>
<td>mg/l</td>
<td>25</td>
<td>30; 100</td>
</tr>
<tr>
<td>10.</td>
<td>Chloride (as Cl)</td>
<td>mg/l</td>
<td>111</td>
<td>230; 1000</td>
</tr>
<tr>
<td>11.</td>
<td>Nitrate (as NO₃)</td>
<td>mg/l</td>
<td>1.3</td>
<td>45; 100</td>
</tr>
<tr>
<td>12.</td>
<td>Sulphate (as SO₄)</td>
<td>mg/l</td>
<td>20</td>
<td>200; 400</td>
</tr>
<tr>
<td>13.</td>
<td>Fluoride (as F)</td>
<td>mg/l</td>
<td>0.33</td>
<td>1.0; 1.5</td>
</tr>
<tr>
<td>14.</td>
<td>Total iron (as Fe)</td>
<td>mg/l</td>
<td>0.34</td>
<td>0.3; 1.0</td>
</tr>
</tbody>
</table>

**Bacteriological Parameter**

<table>
<thead>
<tr>
<th>S1 No.</th>
<th>Parameters</th>
<th>Units</th>
<th>Results</th>
<th>Drinking Water Standard (IS: 10500 - 1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>Total Coliforms</td>
<td>N100/mL</td>
<td>124</td>
<td>0; No relaxation</td>
</tr>
<tr>
<td>16.</td>
<td>E. coli</td>
<td>N100/mL</td>
<td>12</td>
<td>0; No relaxation</td>
</tr>
</tbody>
</table>
### Table 7 Village Tap 2 Water Results (Engineers Without Borders, 2011)

![EMS lab logo]

**Customer name:** Pichandikullam Forest  
**Sample ID:** Davanippam Village 2 Tap water  
**Sample collected:** 03/04/10  
**Analysis completed:** 03/04/10  
**Sample collected by customer:**  
**Lab ID:** 0382

#### Physical Chemical Parameters

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Parameters</th>
<th>Units</th>
<th>Results</th>
<th>Drinking Water Standard (IS: 10500 - 1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>pH (at 25°C)</td>
<td></td>
<td>6.7</td>
<td>6.5 - 8.5</td>
</tr>
<tr>
<td>2.</td>
<td>EC (at 25°C)</td>
<td>µS/cm</td>
<td>650</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>TDS (at 15°C)</td>
<td>mg/l</td>
<td>578</td>
<td>500</td>
</tr>
<tr>
<td>4.</td>
<td>Colour</td>
<td>HU</td>
<td>&lt; 5</td>
<td>5</td>
</tr>
<tr>
<td>5.</td>
<td>Turbidity</td>
<td>NTU</td>
<td>&lt; 0.1</td>
<td>5</td>
</tr>
<tr>
<td>6.</td>
<td>Colour</td>
<td></td>
<td></td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Parameters</th>
<th>Units</th>
<th>Results</th>
<th>Drinking Water Standard (IS: 10500 - 1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Total Hardness (as CaCO₃)</td>
<td>mg/l</td>
<td>128</td>
<td>300</td>
</tr>
<tr>
<td>8.</td>
<td>Calcium (as Ca)</td>
<td>mg/l</td>
<td>52</td>
<td>75</td>
</tr>
<tr>
<td>9.</td>
<td>Magnesium (as Mg)</td>
<td>mg/l</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>10.</td>
<td>Chlorides (as Cl)</td>
<td>mg/l</td>
<td>110</td>
<td>250</td>
</tr>
<tr>
<td>11.</td>
<td>Nitrate (as NO₃)</td>
<td>mg/l</td>
<td>1.3</td>
<td>45</td>
</tr>
<tr>
<td>12.</td>
<td>Sulphate (as SO₄)</td>
<td>mg/l</td>
<td>21</td>
<td>200</td>
</tr>
<tr>
<td>13.</td>
<td>Fluoride (as F)</td>
<td>mg/l</td>
<td>0.42</td>
<td>1.0</td>
</tr>
<tr>
<td>14.</td>
<td>Total Iron (as Fe)</td>
<td>mg/l</td>
<td>0.21</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Bacteriological Parameter**

<table>
<thead>
<tr>
<th>SI No.</th>
<th>Parameters</th>
<th>Results</th>
<th>Drinking Water Standard (IS: 10500 - 1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>Total Coliforms</td>
<td>142</td>
<td>0</td>
</tr>
<tr>
<td>16.</td>
<td>E. coli</td>
<td>16</td>
<td>0</td>
</tr>
</tbody>
</table>
**BORING REPORTS BREAKDOWN ANALYSIS**

1) pH @ 25 deg C: The definition for the letters pH is Potential of Hydrogen. pH is a measure of any solutions Acidity and Alkalinity. The measurement range is 1-14. Pure water has a pH of 7. Between 1-7 is acidic and 7-14 being Alkaline. (The Free Dictionary)

2) EC @ 25 deg C: The definition for the letters EC is Electrical Conductivity. EC measures the current flow between 2 metal plates in the water sample. The more salt in the water the more the current flows. (Wikipedia, 2011)
3) TDS @ 103 deg C: The definition for the letters TDS is Total Dissolved Salts. TDS is linked with EC and is just another way of determining the salinity of water. TDS is measured by using a known quantity of water and evaporating it and weighing the solid residue left behind, the unit of measure is in milligrams per 1 litre of water Mg/l. (Dept Of Primary Industries, 2010)

Water guidelines are;

Between 0-800 is suitable for drinking water.

Between 800-2,500 is ok for drinking water, just not ideal.

Between 2,500-10,000 is not recommended for drinking water. Would only use if desperate.

4) Colour: Water decolourisation is measured in HU (Hazen units). Decolourisation is caused by suspended organic compounds called (Tannins) resulting in dark brown colours, algae will cause a green appearance in the water. Colour in water does not necessarily indicate it is not drinkable. Slow Sand filters are the best method to remove colour from the water (Color of water, 2011).

5) Turbidity: Turbidity is measured in NTU. Turbidity is the cloudiness in the water which is caused by suspended particles. The suspended materials have the ability to absorb heat which will cause the water temperature to rise quickly. The particles also provide a home for unwanted nasties in the water (Bacteria). Turbidity is not related to Colour. There are many causes of Water Turbidity ie; Bed disturbance, soil type etc. (Water Watch Australia, 2005).

6) Odour: Water can take on the smell of its surroundings. Natural smells would be earthy and industrial smells may be from chemicals.

7) Total Hardness (As CaCO, 3): CaCO, 3 is a unit of Calcium, Carbonate. Total Hardness is a measure of the total Calcium and Magnesium in water measured in units mg/l. Water hardness is easily evident by how easy soap lathers up in the water (Less lather the harder the water). Soft water contains less Calcium and Magnesium (Soft = <60mg/l CaCO,3). Hard water is not harmful for drinking. Where hard water is a problem is in the pipes, between 60-200mg/l is considered ok, between 200-500mg/l will cause slight scaling and 500mg/l up will cause severe scaling. (Wikipedia, 2011)

8) Calcium: Calcium is measured in CaCo, 3. The more calcium in the water the harder the water becomes. Also causing scale build up, this can lead to high maintenance.

9) Magnesium: Magnesium Mg is also like calcium where it contributes to water hardness. It can occur naturally from sources like surrounding rocks. (Lenntech)

10) Chlorides: Chloride CL can occur naturally from sources like rocks and soils. It can also be present from fertilizers leaching into the water supply. Chloride increases electrical conductivity therefore increasing it corrosiveness (Chloride in drinking water).

11) Nitrate: Nitrate NO, 3 is a naturally occurring from nitrogen in the soil. Nitrate is also derived from fertilisers. In small amounts is it harmless. High levels are very dangerous for infants causing a medical condition known as Blue Baby Syndrome. (Colorado State University, 2010)
12) Sulphate: Sulphate SO₄ is naturally occurring from certain minerals in the ground. When combined with calcium and magnesium it can cause a laxative effect. Sulphate is only a concern for humans if the levels are high. (Lenntech)

13) Fluoride: Fluoride F is generally added to the water supply to minimise tooth decay. Fluoride does not affect smell or taste. Fluoride is also a naturally occurring product which occurs when calcium is deficient (soft water). (Wikipedia, 2011)

14) Total Iron: Iron Fe is a naturally occurring product which comes mostly from the earth’s crust. There are many types of iron found in water so to treat the water you need to identify what type of iron you are dealing with. A certain amount of iron is considered good for health. The limit of 0.3 mg/l is based more on taste and appearance than health concerns. (Wisconsin (Dept of Natural Resources), 2003)

15) Total Coliforms: Are a combination of many types of bacteria found in water derived from human faeces of warm blooded animals. Many of these coliforms are not considered to be harmful to humans

16) E.coli: There are a few forms of E.coli and of these the 0157:H7 is the most dangerous strain to humans. Ideal conditions for the growth of E.coli are 37degC.

9.2 Appendix B

Figure 8 Specification sheet of plastic drums (Sharda Containers, 2011)
9.3 Appendix C

Filtration Sand and Gravel Sizes

- Discard rock > 12 mm (½")
- Drainage Gravel 6 mm (¾") - 12 mm (½")
- Separating Gravel 6 mm (¾") - 1 mm (0.04")
- Concrete Sand 1 mm (0.04")
- Filtration Sand ≤ 0.7 mm (0.03")

Figure 9 Sand and gravel sizes (Centre for Affordable Water and Sanitation Technology, 2009)
9.4 Appendix D

Figure 10 Transport route for monsoon period (EWB Australia, 2011)
Darcy’s Equation:

\[ Q = K \frac{Ah}{L} \]

\( Q \) = The flow rate

\( K \) = The hydraulic conductivity of sand

\( A \) = Cross sectional area of filter media

\( h \) = Head loss

\( L \) = Length of filter media

\( K \) = Hydraulic conductivity of sand can be given the figure of 1.2 (Environmental Protection Agency, 1986)

\( A = \pi r^2 \) Diameter of drum is 360mm so radius = 180mm

\[ A = \pi 180^2 = \frac{101.787602}{1000} = 101.79 m^2 \]

\( h \) = Head loss is approximately 10cm. It becomes greater as the biological layer increases (Indian Institute of Technology Madras, 2009).

\( L \) = Length of sand media is 400mm.

\[ Q = 1.2 \frac{101.79 \times 0.1}{0.4} = 30.537 \text{ l/h} \]
9.6 Appendix F

Figure 11 Pipe dimensions

Pipe length 250mm
Joiners 45mm
Riser Length 530mm
Outlet Pipe 200mm
Pipe length 100mm
Figure 12 Assembled pipe layout