The 2011 EWB Challenge

Project For The Community Of Devikulam

UoN

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Chemical Engineering Group 2

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Executive Summary

The context of this design project is the Engineers Without Borders (EWB) 2011 Challenge. EWB is an organisation of Australian engineers with a social conscience aiming to improve living standards in disadvantaged communities worldwide with their engineering skills. EWB coordinate an annual challenge for teams of first year engineering university students to come up with creative, sustainable, culturally responsible and economically viable design solutions for different community partners. This year, the challenge is aimed at providing a solution for a number of community specific problems within the village of Devikulam in Tamil Nadu, India.

The University of Newcastle chemical engineering group two have chosen to target Devikulam’s water supply problems. The community relies on three bores, two of which are not functional while the third bore is becoming increasingly saline and is contaminated by poor sanitation and agricultural practices. Due to the necessity for potable water in terms of drinking and sanitation value, the group felt this problem area was the most important, requiring urgent action.

After much team deliberation and brainstorming, a number of creative solutions were generated. Upon weighting these alternative solutions with what the group felt the community needed most, one design solution stood out with the strongest results. This design involves strategically implementing three rainwater catchment and storage systems
throughout the village. These systems are completely independent of the already existent water sources and aim to lessen community reliance on them.

The catchment component of the system consists of a large aluminium upper ring 10 m in diameter connected to a smaller pebble filter at a lower height by a tarpaulin. The upper ring is supported by bamboo struts which can be folded outward effectively collapsing the catchment system for adverse weather conditions. This catchment system is expected to perform very well with a catchment area of 78.54 m$^2$ and an annual collection of approximately 140 000 L of water.

The collecting tank is made of circular rows of earth filled waste tyres with a radius of 2.82 m and built up to form a 2.58 m high tank. For further strength, amidst the tyres, star pickets are inserted. The external surface is overlayed with chicken wire and covered with an indigenous earth-clay-sand concrete mixture while the internal surface will be coated with a brush on waterproofing agent. A tank lid will be built from local wood and will be submerged 1 m underground. It has a storage capacity of approximately 42 000 L and can be accessed by a tap at the base of the tank with the water flow being powered through gravity.

Economically, the design is highly advantageous and viable through implementation of free locally sourced materials such as dirt, sand and waste and the lack of specialised skill needed to construct the system. The total capital cost for the implementation of three tanks is $3708. The main contributing factors to the price are tyre transport and hiring of labourers. The ongoing costs due to regular maintenance are $68.50 per year. In terms of the design’s value to the community, the amount of water collected each year equates to $8 835, when
compared to bottled water pricing in India. In comparison to the upfront cost of $3 708, the tanks will have paid for themselves within 5 months.

Being bound by a group ethical mindset, the design also seeks to be sustainable in terms of environmental implications. The large proportion of recycled, renewable and locally sourced materials coupled with the minimal energy use in the lifespan of the design, makes the design highly effective at minimising its impact on the natural environment.

The group ethical mentality also necessitated that the design be socio-culturally responsible. This is greatly aided through secondary community consultation via EWB who had been in direct contact with the community. Because Hinduism is the major religion in Devikulum, it has implications on our design in terms of the Hindu social hierarchy known as the ‘caste’ system. Thus, the design seeks to minimise unfavourable social interactions with respect to this system. Finally, the safety of those involved in the project is another social implication the design places high value on.

As is seen, the design is sustainable in terms of its economics, environmental impact and socio-cultural integration. This, together with fitting nature of the design to the water problems in Devikulam and its ease of realistic integration, gives the project a very real practical value. As such, the group highly recommends actual implementation in Devikulam.
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Team Reflection

The 2011 EWB project was an ideal situation for our group to learn and put into practice important lifelong teamwork skills with the most important being responsibility and reliable and effective communication.

The most important of these was responsibility. Each group member had to learn to carry their individual weight for the benefit of the whole team. The group working experience was another mindset we had to adjust to. No longer were we working just for ourselves where we could put our head down and get to work and finish the report on an individual level. The EWB challenge required meetings, collaboration and discussion, peer review and more.

Communication was another important skill which we already had but was strengthened in the group environment. It was firstly reinforced by the constant group meetings that were necessary which we had in person, through Facebook, or through text messaging. There was
never a time where a person’s absence was unaccounted for. It was also strengthened through criticism of each other, we had to learn to give it humbly but also take criticism.

Responsibility and communication are the most significant lessons and skills the group has developed and improved. These will continue to be relevant at university, our careers and the rest of our lives and it has been highly advantageous to improve them in the context of the 2011 EWB challenge.
1.0 Introduction

1.1 Engineers Without Borders (EWB)

Created by a small group of Australian engineers in 2003, the Engineers without Borders organisation works in joint venture with disadvantaged communities, both in Australia and overseas, to provide access to education, technology and resources which are essential for the achievement of social equality. EWB Australia frequently combats matters relating to access of basic necessities including sanitation, waste systems, fundamental infrastructure and drinking water in places such as Cambodia, Nepal, Vietnam, India and remote parts of Australia (EWB, 2011).

EWB has a strong focus on community action and involvement in an effort to make the projects they implement as sustainable and beneficial as possible. In this way the solutions are community driven, meet the area’s needs, and align with the cultural aspects of the population. Another aim of EWB is to educate Australians about the difficulties disadvantaged communities face and provide young engineers with training and a chance to implement their skills in an underprivileged environment (EWB, 2011).

1.2 The EWB Challenge

As part of their work, EWB also coordinates a design program for first year university students within Australia. It began in 2007 where students were asked to come up with ideas to expand a children’s home in India. Each year the design brief changes and focuses on different EWB community partners around the world who are experiencing difficulties in areas such as infrastructure, waste management, water supply, energy and communication technology. Students work in small groups to develop conceptual proposals which contribute
towards EWB’s real development projects. The proposals aim to address the identified design areas in a way which is culturally responsible, sustainable and economically viable for that region.

2.0 Background to the 2011 EWB Challenge

2.1 Regional Information and Context

This year, EWB has selected the community of Devikulam, India, as the subject of the EWB challenge. Located within the Pitchandikulam Forest region, Devikulam has many issues which could benefit greatly from the implementation of small-scale engineering solutions.

2.1.1 Geographical Information

Devikulam Village is situated in India, one of the largest and most highly populated countries in the world. The village is located in the state of Tamil Nadu and the region of Panchayat, with its closest major city being Pondicherry.

Figure 2.1: Map of Tamil Nadu, India (Renaissance Reizen, 2011). (InterKnowledge, 2005). (See Fig 2.1)
Tamil Nadu is physically divided by the hilly/mountainous regions in the northwest and the flatter areas in the east (Encyclopaedia Britannica, 2011). Devikulam is positioned close to the eastern coast and so it is relatively flat.

The area of Devikulam is separated into three main zones: the village, colony and thoppu. As shown by the map (Figure 2.2), the population is concentrated in each of these areas. Land ownership in the village is largely between 2 and 5 acres per family on average (EWB, 2011).

2.1.2 Climate

The state of Tamil Nadu is effectively tropical with the warmest months being May and June and the coolest December and January. The average maximum temperature in the warmer months reaches around 38 °C and the average minimum in the colder months is 21 °C.
Rainfall in Tamil Nadu varies between the mountainous regions and the flatter, coastal areas due to variations in monsoonal rains between these localities. Average yearly rainfall in the west is upwards of 1800 mm but in the flatter eastern expanse annual rainfall is closer to 650 mm (Encyclopaedia Britannica, 2011).

Wind speeds in the Devikulam community are also dependent upon season. In Figure 2.3, the graph of wind speed vs. month of year shows a significant decrease in wind speed during October and March. In the months of January, December and June however, there is an increase in wind speed which corresponds to the cooler and warmer months.

![Figure 2.3: Wind speed in Devikulam (3TIER, 2011)](image-url)

**2.1.3 Access to Water**

At present, water is obtained from three bores, two are for drinking and the other is used for cleaning and flushing. The two drinking bores are used to supply a 30 000 L tank which
distributes water through a system which would eventually supply to the people of the village. Currently one bore is not operational and consequently the storage tank is supplied by only one bore. The village water supply is not connected to the households and so villagers rely on a common tap for drinking water, that’s use is restricted at certain times of the day to conserve water (EWB, 2011).

Analysis of water from the three main taps has shown that salinity and bacterial levels are not at the appropriate levels (EWB, 2011). Both of these problems have a potential to negatively impact human health if their levels increase due to saltwater intrusion or pollution from contaminated monsoonal runoff. Current bacteria levels are low but their presence in the water is cause for unease because it may indicate the beginnings of a contamination issue.

2.1.4 Social Context

Tamil Nadu is highly built-up compared to other states of India and yet more than half of its population still live in rural areas. The state is highly industrialised with a vast array of industries including the production of cars, oil refinement, textile milling, food processing and the production of pharmaceuticals (Encyclopaedia Britannica, 2011). The village of Devikulam however, exists in one of the many rural parts of Tamil Nadu and so villagers do not benefit economically from the industrial sector through employment, etc.

With many residents owning their own land, agriculture is the main industry in Devikulam. Crop cultivation is the main type of farming practiced, with inhabitants growing rice, sugar cane and tapioca. Annual income per household in Devikulam is in the range of 10,000.
rupees ($215) to 60,000 rupees ($1300). In the colony this range is much lower - between 15,000 rupees ($300) and 30,000 rupees ($650) (EBW, 2011).

Waste management is a further concern, with no real system in place in Devikulam or nearby villages. Devikulam resembles other populated areas of India in that garbage litters the land due to the dumping of waste behind houses. There is a need for a waste management system that incorporates waste reduction and recycling with livelihood and energy generation and it has been identified that many waste streams in Devikulam could be reused in the making of a viable product (EBW, 2011).

Cement, mud, burnt brick, thatching and palm leaves are some of the materials commonly used for housing in Devikulam. In the colony, houses are constructed using mud which is cooler but also requires repair and maintenance. However, most housing in Devikulam consists of cement floors, burnt brick walls and roofs of palm leaves or thatching.

Devikulam does have access to electricity however it is not reliable, with frequent power outages disrupting daily life. Electricity is not utilised for cooking but people instead use kerosene, firewood or LPG. This use of firewood to run stoves is often inefficient, contributes to deforestation in the area and causes many health problems due to improper ventilation of smoke (EBW, 2011).

2.1.5 Culture and Religion

India has a grand cultural legacy and is one of the oldest civilisations on Earth and now lays claim to being among the most industrialised countries in the world. It has 22 national
languages, of which Hindi and English are official and which branch into hundreds of different dialects (Indian Government, 2011).

The major religion in India is Hinduism and this is also the case in the state of Tamil Nadu, where Devikulam is located. Their culture revolves around their religion and as a consequence being Hindu generally indicates a following of the ‘Caste system’. While this cultural system is abolished in Indian law because of its correlation to human discrimination and social division, it is entrenched in years of assumed cultural law and religion, meaning it is still widely embedded in India’s culture (Encyclopaedia Britannica, 2011). Most small villages and rural areas have a strong caste system and Devikulam is no exception, people of different social ‘castes’ do not associate with each other (EWB, 2011). People are grouped into categories according to Hindu legend and the lowest of these is the ‘achuta’, also known as ‘untouchables’. The untouchables are given the worst jobs in society and such are prejudiced against and seen as impure by higher castes.
3.0 Project Definition

The group decided to deal with the problem of water supply within the community. We believe that this is an area that can have a great deal of improvement and be of great benefit to the community.

3.1 Scope of the Problem

The quality of the water in the community of Devikulam is extremely poor. The community has an approximate population of 350 people using about 4 L of water daily per person and approximately 1280 L per day on behalf of the whole village (EWB, 2011). The entire community relies on three main bores. At the present time, two of these bores are not fully operational and one is extremely saline. The only operational bore at the present time is located close to the community pond. The water in this pond is of terrible quality because the community uses it for many different operations such as bathing in it and washing their livestock. The livestock also defecate into the water, thus contaminating it with many harmful bacteria. Human waste is sometimes also deposited into the water, adding to this problem.

It is for these reasons that our group has chosen to design a rainwater catchment system for the community. Whilst it does not solve the problem of the contamination and degradation of the existing water supply, it provides a sustainable alternative to the existing supplies. Because of the size of the community, there will need to be at least 150 000 L in order to supply the community with an adequate water supply for an entire year and replace the reliance on existing supplies. Another possibility would be to simply supplement the water supply with tanks that don’t have the entire capacity needed for the community.
3.2 Criteria for Evaluation

There are many criteria with which this project needs to be evaluated against in order to choose the most appropriate project for this community. However, some of these criteria aren’t as important as others and as such, a weighting system will be used, this will be discussed later.

Availability

The availability of the project will need to be assessed including issues such as who will have access to the project, where the project will be placed, and whether the project is able to be used by all the community.

Cost

Cost will be a huge factor in determining which project will be chosen. As the community of Devikulam is relatively poor, and mostly comprised of self-reliant farming, there is not very much money on hand. Not only will the initial start-up costs and the cost associated with construction need to be analysed, but also ongoing costs and those associated with maintenance and general up keep will need to be considered. Another point to be considered is whether there needs to be a trained operator and if he/she needs to be paid and/or trained, which would also cost money.

Benefits

The overall benefits of the project will need to be considered. The following questions must be considered: how will the project benefit the community? Does it suit the unique needs of the community? Does the project fix a problem, or does it just cover over the existing problems? Will people actually use the project? What additional benefits (such as education) can it supply?
Cultural Considerations

In Hinduism according to the ‘Caste’ system, certain classes of people are unable to perform certain jobs or duties. Will this have an effect on the project and limit its scope. There is also the possibility that the reason tasks and resources are managed in a particular way is due to long standing cultural tradition within the community and change to this may not be well received within the community.

Education

The level of education required to run the project may limit the projects that are feasible. Complex projects could require skilled labour to construct, limiting community involvement and driving up costs. Simple projects can create community involvement while providing potential opportunities to for locals to gain new skills. There is also the possibility of people needing to be trained for the general running or maintenance of the project.

Reliability

The project needs to be fairly reliable in order to be worth its cost. Are there only certain times when the project can be used? Whether the project will rely on certain conditions is also a factor needed to be analysed e.g. does it rely on defined environmental factors such as sunlight, rainfall or wind levels. The longevity of the project will also need to be assessed. There may be no point building something if it needs to be fixed constantly or replaced every few years.

Environmental Impact

In the last few decades there has been a push towards sustainable development and this should be considered for this project. Does this project promote sustainable development and will it set the example for developing communities like this in the years to come? The
sourcing of materials is another environmental factor to be considered, this may also limit the scope of the project. The impact on the local ecosystems will also need to be analysed for this project. There are resources in the area such as water that are already of poor quality and further damage to these would be greatly detrimental to the community.

4.0 Design Options

4.1 The Design Options Process

4.1.1 Refining the Project Scope

The group engaged in multiple substantial brainstorming sessions where we did not only synthesize our collective ideas into a series of solutions but also refined the scope of the problem we were going to tackle in the Devikulam community.

The first brainstorming session occurred when the group first met together and we had all read up on the context of Devikulam and its problems as outlined in the 2011 EWB participants’ handbook. Initially we aimed to tackle multiple problems in the community including waste management, water treatment and energy primarily because these problems seemed the most relevant to our discipline area (chemical engineering). It was soon realised however that the potential solution was going to have too large a scope if it tried to fulfil three multiple problems directly. This was evidenced during the second brainstorming session a week later when it was realised that with a greater project scope comes a greater difficulty to solve three community problems directly. It seemed during our initial
brainstorming that whenever we came up with a solution to one problem, another problem would arise.

Accordingly, in the end of our second brainstorming session, we decided to narrow the scope of our project and aim to solve one problem directly and if possible solve other problems but to a lesser extent with the focus being on our main problem. Collectively, it was decided the main problem that Devikulam had was a lack of sustainable, clean and accessible water.

### 4.1.2 The Solutions Process

The solutions process began with the use of a hierarchical mind map (Figure 4.1), which defined two ways of approaching the water problem. We could modify the pre-existing water sources (bores) or we could create a completely new water source. For the modification of pre-existing sources, there was the overall problem associated with their current water source that as water is drawn from the ground the water table will sink. Any solution implemented would only be temporary as the more the water table is drawn from, the more it will sink causing an increase in salts as they dissolve from the earth making the water increasingly unfit for drinking (EWB, 2011). Ultimately this approach is unsustainable.

The most obvious approach is the collection of rainwater; however, another idea was suggested of collecting the water released by transpiration of plant material. Whilst the idea was original, to produce enough water for the community it would require a lot of land, a lot of plant foliage, and a lot of time making it less viable than the rainwater option that produced fewer problems.
Relying on our pre-existing knowledge and the EWB handbook, the group decided that the best method for providing sustainable, clean, reliable and safe water was the harvesting of rainwater.

### 4.2 Design Proposals

#### 4.2.1 Rainwater Storage

Three potential ideas were suggested and expanded upon by the group in the third brainstorming session. These included storage of water in bladders, large wooden storage tanks, and finally ‘Earth ship’ style water tanks.
**Option 1 – Rainwater Bladder**

This idea included the production of multiple plastic based, flexible water storage tanks otherwise known as bladders. According to Waterplex, Australia’s leading bladder manufacturer, the greatest advantage of rainwater bladders is that they take up minimal space (Waterplex, 2011). Ideally in Devikulam these bladders would be installed at each house and would minimise the spatial and even aesthetic impact that say a large metal tank would have on their property as these bladders would be hidden buried in an underground chamber and unseen. This would be beneficial especially in not taking any more land from what is already used and not impacting the community’s way of life.

For the housing in the colony, only three houses have land at approximately ¼ of an acre and even in the village, this land is already occupied by animal grazing and agriculture (EWB, 2011). Further to this, these tanks when unfilled are much easier to transport and set up than a normal rigid water tank, Waterplex quote “if a person can get to the location, then a bladder tank can get to the location” (Waterplex, 2011). Another advantage is that these bladders being stored underground greatly minimize the growth of algae being away from sunlight and heat.

These bladders are typically made from large amounts of UV resistant, reinforced, flexible polyvinylchloride (PVC) (Wet Earth Irrigation Systems, 2003) and supported by a rigid steel frame to which piping is attached to prevent damage of pipes by the flexible bladder as shown in Figure 4.2 (Waterplex, 2011). Because of this construction, rainwater bladders are very expensive. Pricing for a basic model ranges from AU $720 for an 1120 L model to AU $2200 for an 11 400 L model (Wet Earth Irrigation Systems, 2003). Implementation of these
bladders would also require skilled labourers (plumbers), which would also provide an extra cost.

**Option 2 – Wooden Storage Tanks**

This idea was inspired by the large wooden alcohol storage vats pioneered and still being used in fermentation of spirits. An example of this is at the Bundaberg Rum factory in Bundaberg, QLD. Their oak vats have a 75 000 L capacity and each hold their product for at least two years within a controlled environment (Bundaberg Rum, 2011). This is a testament to the effectiveness of the timber construction of these vats at storing large amounts of liquid for long periods of time. These vats are handcrafted from Canadian oak and bound together with metal cable (Bundaberg Rum, 2011).

For implementation in the Devikulam community, these tanks would ideally be made from locally sourced palmyra which is abundant in the village and could potentially be sourced for very cheap or even for free which would significantly lessen the cost of implementing this idea (Pitchandikulum Bio Resource Centre, 2011). The use of Palmyra will also keep the project on a local scale without the need to import wood. These storage tanks being handcrafted would require skilled labour ideally from carpenters for their onsite construction.
Their placement would need to consider who would be using the tanks and the effects of local weather patterns, however, the flat landscape of the Devikulam region will make permanent placement of the tanks easier (Encyclopaedia Britannica, 2011). Being so large, these tanks would not be constructed at every household. Instead approximately five would be constructed and strategically placed throughout Devikulam for communal use. The tanks would be lined with a flexible waterproof plastic.

Whilst being functional, these tanks are very spatially and aesthetically intrusive being so large, rigid, and bulky and will no doubt require getting use to by the community. The effects of the hot and humid local tropical weather as well as potentially insects would have an adverse effect on the organic wood and may limit the lifespan of these tanks furthermore creating a need for regular maintenance by skilled labourers.

**Option 3 – ‘Earth Ship’ Style Tank**

‘Earth Ships’ are a sustainable structures built from materials occurring naturally in the area such as dirt, sand, clay, as well as the by-products of our wasteful society namely rubbish such as tyres, glass bottles and tin cans. “These materials and the techniques for using them must be accessible to the common person in terms of price and skill required to use them” (Earth Ship Biotechture, 2010).

This construction could be used to create approximately three water tanks of four metre diameter for the community. The circumference of the tank would be constructed out of rows of waste car tyres interwoven with a wire mesh and filled with densely packed earth as seen
in Figure 4.3. In between tyres and in odd spaces would be earth filled bottles and cans to add to the overall structural integrity of the tank walls. This dense core is then further filled in and smoothed out by ‘adobe’ (a mixture of mud, clay and local plant material such as palmyra fibre) and then covered in multiple layers of plaster followed by a tank liner on the inside. The result is a thick, strong and heat regulating circular tank wall that is “virtually indestructible” (Earth Ship Biotechture, 2011) and again favourable for tropical and monsoon weather.

With quality construction, these tanks can be expected to last for decades (Pushard, 2011). To provide earth for packing, each tank will be half built into the ground with a stairwell leading to the bottom of the tank where a gravity fed tap will release water. Whilst being permanent and immovable, the tank can be constructed to hold large amounts of water and provide a partial solution to the waste problem in Devikulam whilst allowing the everyday man to join in construction without specialized skill. Use of indigenous materials and the lack of a need for specialized skill, will greatly reduce the cost of building and keep the project on a local level.

Devikulam is a region of the state Tamil Nadu. Tamil Nadu is among India’s most industrialized states wherein the automobile manufacturing industry is among the state’s
major industries (Encyclopaedia Britannica, 2011). This is highly favourable to the acquiring of large amounts of waste tyres and waste in general if it cannot be found within the Devikulam community itself. The tanks being made of plaster surface will unfortunately have the potential for cracking (Pushard, 2011) which will bring the need for maintenance at certain intervals; fortunately however this will not require skilled labour and can be undertaken by community individuals. The tanks will be visually and spatially intrusive to an extent however being half submerged in earth will minimize this.

### 4.2.2 Rainwater Catchment

Four potential catchment options that would connect to the water tank were suggested in the third group brainstorming session. These included a gutter system, an ‘umbrella system’, and a flattening funnel system.

**Option 1 – Gutter System**

The gutter system involves attaching PVC gutters to the households that contain roofs that can catch rainwater and not contaminate it. Most houses contain palm or thatched roofs which would not effectively catch water. Only 21 households have a roof that may support water runoff made of metal, plastic, cement or tile (EWB, 2011). Only the houses within a certain short distance of the communal water tank would have gutters installed to avoid the intrusiveness to the community of gutters running all throughout the town to a central tank. Particularly because only a relatively small amount of houses will a) support gutters and b) be within a certain range of the tank, this will mean only a few will have gutters attached. This will not be too expensive; however, it cannot provide enough water for a whole community as well.
Option 2 – Umbrella System

A system of catching water similar to an upside-down umbrella has been patented in America. As in Figure 4.4, it consists of an inverted umbrella section that collects rainwater which runs through a central tube and out the bottom where it is to be collected. The umbrella section can be folded downward and into the tube either by hand or motor (Couterier, 2005). Ideally a multitude of these could be implemented above water tank level on plot of land to create a ‘water farm’ collecting water into a central pipe that would run to a tank fed by gravity. In adverse winds (monsoon) the surface area would be removed by folding the umbrella section down into the pipe.

To collect a large amount of water through these individual ‘umbrellas’, a large plot of land (or even multiple plots) would be needed making this method spatially and aesthetically intrusive. To wind down the system in adverse weather would also take time and put the person’s life at risk that was responsible. Whilst this system is still in development and only patented, it consists of a complex “mechanism consisting of a system of pulleys and an optionally electric motor” (Couturier, 2005) which would likely make the final individual system relatively expensive. In the case of developing a ‘water farm’ with multiple systems, this would be even more costly.

Option 3 – The Flatten System

Figure 4.5 below shows that this system consists of two rings, one larger than the other, both made out of lightweight but firm and rigid material (for adverse weather) such as aluminium.
The larger ring is held higher by a wooden bracket system likely made from local palmyra wood. The smaller ring is then placed below the larger ring. A tough, flexible and UV resistant plastic, possibly PVC, then connects the two rings. This creates a large funnel system which will funnel the water along the surface and downward by gravity. As the water reaches the lower ring, it enters a column of small locally sourced stones through which debris is filtered out. The water then runs out the bottom of this column into a designated collector.

This ‘Flatten’ system employs brackets holding up the top ring which can be folded outward and downward to become parallel with the bottom ring. As these brackets fold outward, the upper ring moves downward on top of the lower ring effectively flattening the whole system removing surface area to be affected by adverse weather. This system poses a risk to those responsible for packing down the system in bad weather as it will take time to do. The plastic sheeting and ring material (most likely aluminium) will also be moderately expensive but ideally one will be built per tank hopefully meaning no more than four to five will be constructed. Again these systems especially when combined with the tank will be very visually and aesthetically intrusive.

Figure 4.5: The Flatten System
(Our design)
5.0 Evaluation of Options

5.1 Weightings & Values for Evaluation Criteria

Although the criterion defines the individual elements to determine the success of a particular potential solution, it does not give a true value unless the elements of success are weighted. Through analysis and group discussion of the key elements, rankings of the value of each element were formulated; as seen in Table 5.1 below.

Table 5.1: Weighting of Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to benefits</td>
<td>4</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
</tr>
<tr>
<td>Benefits</td>
<td>5</td>
</tr>
<tr>
<td>Socio-cultural Considerations</td>
<td>3</td>
</tr>
<tr>
<td>Education</td>
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<td>Reliability</td>
<td>4</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>2</td>
</tr>
</tbody>
</table>

The score for a potential solution in a particular element was again formulated by critically analysing the solution in a group environment. By comparing each individual element, with a defined weight, a score representing its accurate worth could be determined. We chose the benefits to the community and the cost to be the highest weighted factors, as we believe they are the major factors of success for any project in the Devikulum community. It is the total of the scores which provide an accurate representation of potential success.
5.2 Evaluations

5.2.1 Rain Water Storage Systems

With an abundant source of water in the form of monsoonal rain, creating a rainwater storage system would be an effective strategy to provide the Devikulam with a reliable source of water. This seems to be the most effective way to provide the population with a clean source of water, separated from disease causing agents like animal faeces that are washing into bores and lakes. There are many methods of retaining water and all have particular advantages and disadvantages. We focused on solutions that provided a means of isolating the water from possible sources of contamination. Through applying our criteria to a select few, we can select our particular design.

Table 5.2: Scores of Tank Systems

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Bladder</th>
<th>Wooden Vat</th>
<th>Earth Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to benefits</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Benefits</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Socio-cultural Considerations</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Education</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Reliability</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total- (weight × score)</strong></td>
<td><strong>82</strong></td>
<td><strong>78</strong></td>
<td><strong>119</strong></td>
<td></td>
</tr>
</tbody>
</table>
**Water Storage Bladders**

Flexible vessels that expand to accommodate water are highly portable, robust and take minimal installation effort. In this way, they are quite suited to being implemented in Devikulam. Although a limited education program could be developed, its main attribute is simple and rapid installation, with a long lasting and effective device. It requires limited educational knowledge, and limited technical experience for installation. Such ease of implementation comes at a significant price with costs exceeding $2000 (not including plumbing and installation) for an 11 400 L model (Wet Earth Irrigation Systems, 2003), hence the low rating of 2 in the total cost criterion as seen in Table 5.2. The cost to storage ratio is also quite low. It uses no local resources, thus must be imported from another country. This means it accumulates a carbon footprint not only from manufacturing but through international movement. It achieved a weighted evaluation score of 82.

**Wooden “Bundaberg” Storage Vat**

Devikulam has an abundant source of the timber palmyra; this timber could be implemented in the construction of timber tanks. The dark timber of palmyra is dark and heavy; it is well suited in construction. It is valued particularly in the high moisture environments such as wharf pillion. It is also highly resistant to insects like termites (Sanon & Sacande, 2007). While this method uses readily available resources, these resources are the already damaged forests. As a result, the agreed score for environmental impact was lowest of all solutions, with a score of 1. Also the cost of properly felling and planking the tress, and then manufacturing the complex structure will be quite high. Building a wooden vat, at such a large scale is no simple task. It would be unlikely any of the local people would have the necessary wood working skills to build a complex design like this, hence the low score of 1 for technical complexity. Conversely, the local people could be taught how to build such
tanks, and therefore create a sustainable community industry. A flexible tank liner would also need to be used, driving up the cost once again. This system achieved a weighted evaluation score of 78.

**Earth Ship Tank**

Earth Ship styled structures are an example of re-use and environmentally conscious buildings. These styles of buildings have proven exceptionally successful as houses across the globe. Focusing heavily on tyres as the main structural units, the shape is made by overlaying the tyres and packing them full of the soil found on-site, therefore they are very environmentally friendly. The high score in the criterion of “cost” is due to tyres being able to be sourced from India at quite a low cost, as little as 10 cents per metric ton. All other materials (excluding the liner and plumbing) can be sourced locally.

The structures can be built by people with no real experience, therefore the local people can assist in the construction. This not only makes the project move faster, but provides them with an effective basis for manufacturing structures that can be applied to almost anything. This resulted in a high score for technical complexity of 4. As there is no organic matter, they are not susceptible to rot. The walls become quite strong, giving it high durability and reliability. Ultimately Earth Ship tanks provide exceptionally low cost tank, through our approximations of total cost, with a score in the “cost” criterion of 5. This design achieved a weighted evaluation score of 119.

As a consequence of our evaluation criteria, we have concluded that we will research and design a project around the Earth Ship styled tank. It provides exceptional quality and value, while allowing the scope for an education program that provides local with new
sustainable building techniques. The other designs had many fatal flaws, either complexity as in the wooden vat, or cost in both the vat and bladder.

### 5.2.2 Water Catchment

Water catchment systems are necessary to collect substantial amounts of water for the tanks. They are simply a structure, with a rain collecting area that is usually larger than that of the tank. Several potential options came to mind, but collectively we reduced that to the three with what we felt had the most potential.

<table>
<thead>
<tr>
<th><strong>Table 5.3: Scores of Solutions</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criteria</strong></td>
</tr>
<tr>
<td>Access to benefits</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Benefits</td>
</tr>
<tr>
<td>Socio-cultural</td>
</tr>
<tr>
<td>Technical Complexity</td>
</tr>
<tr>
<td>Reliability</td>
</tr>
<tr>
<td>Environmental Impact</td>
</tr>
<tr>
<td><strong>Total - (weight × score)</strong></td>
</tr>
</tbody>
</table>

**Gutter System**

A gutter catchment system uses an existing structure, usually a roof, as the collecting area. A drain is connected to the run-off edge and is drawn into the tank. This idea is one of the most popular methods for collecting rainwater, commonly implemented for primary or secondary sources of water.

The possibility of modifying an existing structure seemed promising. It would have provided a cheap, effective and well proven solution. This system is also extremely reliable and durable as it merely uses the existing dwelling. However the limited number of buildings
with a solid sealed roof in Devikulam was a concern. Most houses have a thatch roof which is ineffective for this design. It would be extremely costly to replace the roofs. This became the fatal flaw for this solution as placing guttering or developing the community to suit guttering is extremely impractical. Placing community water supplies next to and using what may be someone's home, is also not ideal as it may disturb the owners. This design achieved a weighted evaluation score of 95 as seen in Table 5.3

**Reverse-Umbrella System**

This solution involves the implementation of inverted umbrella like structures. These could either be placed over a tank, or it was suggested to configure several into a ‘rain-farm’.

During the monsoon season, when winds can get quite high, they can be folded up to reduce their surface area to the wind. This technique may prevent damage to the system. While they have a high potential for providing a unique solution, their unproven, high cost in developing, and mechanically difficult nature leaves them to be quite unappealing. The technical difficulty of construction means it scores the lowest in that criterion with a score of 2. They would also likely provide a low catchment area to cost ratio. Placing experimental and possibly flimsy structures into the harsh environment in India may prove fatal to the scheme, hence the score in “reliability” of 2. It is likely the locals could not repair the complex “umbrellas” in the event of failure. This design achieved a weighted evaluation score of 70.

**The Flattening Ring System**

This catchment system uses a funnel like system formed by two different sized rigid rings and a flexible membrane forming the catchment. It would likely be placed over the tank. Although quite simplistic in design, it provides a cheap but quite large catchment area that
does not depend on existing structures. The materials are commonly found and also incorporate some local materials into the rigid supporting struts. Like the Earth ship tank, the design is relatively simple and may be taught to the local people so that they can repair or create new systems if needed. Although more complex than the gutter system, its relative simplicity results in a favourably high score of 4. Having a flexible structure that can be reduced in size reduces the risk of damage to the system in high winds. This ability enhances its reliability in tropical weather, as shown by the score of 4. It also allows a cheaper supporting structure to be used, with less need for high load bearing materials.

As we came up with this novel design, it is unproven. In theory it should work but there may be unforeseen issues with the design. This design achieved a weighted evaluation score of 112. As a consequence of our evaluation criteria; we have concluded that we intend to further develop our solution with our flattening ring system. Ultimately it's the simplicity and low cost decided this. We predict that it will be very reliable. If the gutter system had not been hindered by the lack of existing infrastructure, which may have been the winning solution. Given the resources that are available and the limitations of the other systems, the flattening ring provides the best all round solution for the catchment of water.

6.0 Interim Conclusions

Several designs for the tank including the water bladders, wooden vats, and ‘Earth-ship’ tanks, have been put forward with a variety of separate designs for the water catchment, including the gutter, inverted umbrella, and flattening ring systems. These potential solutions have been assessed through critical analysis and application of our weighted criteria. While all designs would be beneficial, the combination of the ‘Earth-ship’ styled tank, in conjunction with the flattening rings system seems to provide the best solution. This
combination offers high performance in water collection and storage with few compromises in the quality of the product. This solution also costs very little, should be highly resilient, uses cheap and abundant waste products, and offers opportunities for the local people to learn new methods of construction in the “Earth-ship” style. ‘Earth-ships’ are growing in popularity across the world and it is greatly beneficial to teach these quality skills to these people. For these reasons, we have chosen the “Earthship-style” tank and flattening catchment to provide a solution to Devikulam’s water needs.

7.0 Final Design Solution

7.1 Summary of design

Our proposed solution incorporates two main sections; the water storage tank and water catchment area, these two systems form a stand-alone system that provides an additional source of safe, clean, drinking water for the Devikulam community. The water catchment will consist of a large outer ring, 10 m in diameter, attached to a much smaller inner ring via a polymer sheet that increases the effective rain catching area. When fully extended the sheet forms a funnels which directs water onto a rough filter mechanism and then into the water storage tank.

The tank will be formed from an earth-ship styled wall, constructed of tyres rammed with soil. This tank will have an external diameter of 5.64 m. A coating of an adobe like mixture will coat the tyre structure, forming an even surface. The tank will effectively store captured water until removed for use. The tank structure will be placed into the ground to a depth of
one metre. Each tank will hold ~ 42 412 L of water. An overview of the design can be seen in Figure 7.1. Design calculations can be seen in appendix 16.1.

**Figure 7.1: A 3D representation of the tank at eye level**

### 7.2 Detailed design

#### 7.2.1 The Tank

**Tank body**

As mentioned, the tank is constructed from tyres rammed with earth. They act as the bulk of the wall, equivalent to a brick in a normal structure. The lay out is shown in the scaled diagram in appendix Figure 16.3.2 & 16.3.4. The tyres must be of the same size. While variations will be prevalent (due to the nature of using an uneven, recycled product), using the same tyre ensures uniformity. The tyre that we have used for calculations is the P215/60R16 tyre. This is a popular sized tyre, found on many cars such as the Toyota Camry (Toyota Motor Corporation, 2011). To form a cylinder with a radius of 2.82m (from centre to external edge), 30 tyres are required per layer. The tank will be 2.58m in height, requiring 12 layers. Thus 360 tyres are required per tank.
Figure 7.2: The ground floor plan for the first layer (Black circles being tyres, brown being adobe)

To help form a uniform shape, $12 \times 2.4$ m long star pickets will be used. These will strengthen the walls against shearing forces. The pickets will be arranged so that there will be one picket within each tyre. The external surface will be covered in 35.5 m of 1.8 m wide chicken wire, secured using zip ties. This wire will help the adhesion of the adobe to the walls. The walls will be coated in adobe, created from soil (a clay sand mixture available on site). The entire tank structure will be recessed partially to a depth of 1 m under the ground. The ground beneath the tank will be rammed, and like the inner adobe walls, treated with Thoroseal - a concrete based, safe water-proofing agent.
**Tank lid**

A tank lid will be created from the locally abundant source of palmyra. As it is available locally, it is likely that it may be procured cheaply or for free. The palmyra lid will need to cover an area of 25.34 m$^2$. The quantity of wood will depend on what size plank is available. At the very centre, a 30.5 cm hole will be cut to accommodate the filter. The filter will be secure to the wood lid by epoxy glue. The design can be seen in Figure 16.3.1 in the appendix.

**Plumbing**

The tank will feature an over-flow pipe (shown in red in Figure 8.3 top right corner), to release excess water without damaging the tank. It is constructed of 600 mm of 100 mm diameter pipe. It will be inserted through the tyre-wall 300mm from the top of the wall. The water may be accessed via a tap (shown in Figure 7.3 bottom left corner), placed 300 mm from the bottom of the tank. The plumbing of the tap will consist of a 25 mm tank outlet with a gasket attached to a ¾ inch × 750 mm threaded riser. The riser will pass through the tyre wall to a 20 mm brass tap, where the water can be accessed.

![Figure 7.3: Cross-section showing plumbing (shown in red)](image-url)
As the bottom of the tank is submerged partially to 1m below the surface, access to the tap will be provided by a dug out section to the foundation of the tank (See appendix Figure 16.3.3).

7.2.2 Water Catchment.

The water catchment has three sections - the sliding ring, catchment funnel and the filter.

Sliding Ring

The sliding ring will provide the rigid frame to support the polymer sheeting to hold its cone shape when extended. The ring will have a diameter of 10 m, effectively giving the tank a collecting area of 78.54 m² per tank. Aluminium was selected as it is quite a strong metal, largely resistant to corrosion, yet light weight and relatively cheap. The outer ring will be constructed of $5 \times 6.28$ m lengths of 16 mm (external diameter) aluminium tube. The pieces will be welded, end to end, together. The tube will then be bent into a ring and welded, forming a rigid aluminium ring.

As the funnel is completely supported by this ring, it will collapse when not supported. Four bamboo struts, 2.47 m long, ~ 2 cm wide (minimum, use larger if available), may be sourced locally, or at low cost elsewhere. The bamboo ends will have a groove cut into them, roughly supporting the hoop. The support set-up can be seen in Figure 7.4. These struts are intentionally a weak point. In the event of high winds, when the funnel is not lowered manually, the bamboo will fail and the hoop drop over the tank, protecting it from further damage.
**Catchment Funnel**

The section captures and funnels the water down into the filter through to the tank. In this design, waterproof, UV resistant tarpaulins modified to create the required shape will be used as the funnel as in Figure 7.4. Two 5.49 m × 7.3 m tarps will be attached to one another along the 5.49 m edge, by plastic welding. The shape will be cut from this, and attached to the aluminium hoop via 8 tabs cut from the excess tarp. The centre will have a 30.5 cm diameter hole cut, so that it can be welded and then glued using a quick set two part epoxy, to the filter.

![Figure 7.4: A 3d model of funnel and supporting bamboo poles](image)

**Filter**

The filter is simply a rough, pebble bed filter that will prevent much sediment and large objects from entering the tank. It will be constructed from a 30.5 cm PVC end cap and a 10 cm PVC end cap. The 10 cm end cap will be drilled at 5 mm intervals using a 5 mm drill bit,
to make 10 holes (See appendix Figure 16.3.5 & 16.3.6). The small cap will fit into a hole in the centre of the large cap, and then be secured with glue. The up facing, large cap will be filed with small pebbles, as in Figure 7.5.

Figure 7.5: A 3d model of the pebble filter

8.0 How it Works

The tank functions on very simple processes of collecting, sliding, filtering, holding, and releasing.

**Collecting** - The 10 m diameter funnel extends the collecting potential of the tank. By being at an angle of 10°, the water is directed downward to the filter and tank opening.

**Sliding Mechanism** - The ring supports the flexible collecting funnels, which is in turn kept taut at an angle of 10° relative to the top of the tank by bamboo poles. When the bamboo is removed the structure will collapse over the tank.
**Filtering** - The filter is quite coarse, and will only prevent large objects and some sediment to be trapped. It causes particles to become stuck within the arrangement of pebbles, as the water flows over and through them. The water then drains into the tank.

**Holding** - The tank acts as a vessel to hold the water until it is needed. The tyres and adobe form the physical barrier, using Thoroseal as a water-proofing agent.

**Release** - A standard 25 mm tank outlet, with the supplied gasket, provides a mean of releasing the water. This outlet has a gasket that tightens to become water proof. A threaded riser will screw into this outlet, so that it can penetrate the thick tyre wall completely. A standard brass tap will then screw onto the riser, acting as a valve to release water when needed.

### 9.0 Performance Analysis

The predicted performance of the tank was analysed in terms of amount of water collected on a yearly and daily basis.

### 9.1 Potential for water collection

Using a catchment with a 10 m diameter and an average rain fall of 1800 mm per year, the amount of water collected per year (excluding evaporation) is ~141 371.7 L of water (Appendices 16.1). This means an average collection of 38.73 L per day. With three tanks planned to be constructed, this amounts to 116.2 L of drinking water collected per day (on average). While this system does not provide bountiful amounts of water, it supplements the village water supply with safe drinking water, which is currently not available. The water availability varies with the wet and dry seasons, so the tanks will provide a reserve of water when it is not abundantly available.
10.0 Implementation

10.1 Tank Construction

The construction of this tank itself is fairly basic and doesn’t require the hiring of skilled labour for the majority of the project. This makes it ideal as a project to be undertaken by the community and possibly also volunteers. There are however, a few parts in the construction of the catchment system that require the hiring of a skilled worker, depending on the tools available in the community as well as their skill level.

The first step in construction is to dig the hole in which the tank will be housed. The depth of the hole should be 1 m and the base diameter of the hole should be 5.7 m in diameter with a recess on one side in order to access the tap at the bottom of the tank. The base of this hole needs to be even as it will form the bottom of the tank. This then needs to be rammed in order to create a solid surface. This is a relatively easy process that will require manual labour. The simplest way to ram the earth is to get a sledgehammer or other such heavy, blunt implements with a fairly large surface area and continually hit the earth until the layer has compacted. This is most easily done by holding the sledge hammer upright and hitting the earth with the top of the sledgehammer in a vertical fashion.

At this point you can begin to stack the bottom tyres for the walls of the tank. These are then filled with soil that has been excavated from the hole. Once the first layer is down and filled with dirt, star pickets need to be hammered into the ground in order to reinforce the structure. Once these pickets are in, the earth inside the tyres needs to be rammed. At this point, the tap assembly needs to be placed in the structure by a qualified plumber, and tyres placed next to
it in order to keep it in place. The process of layering tyres needs to continue all the way to the top, with each layer of tyres filled with earth and rammed as the tank is being constructed. An overflow pipe will also need to be installed underneath the top layer of tyres. This is just simply a pipe that goes between two layers of tyres.

After the main structure is completed, the outside of the tank needs to be lined with chicken mesh and held in place through tension using cable ties. The external and internal sides are then plastered over by an adobe mixture that will need to be made on site with a 70:20:10 mixture of clay, sand, and silt respectively which has been sourced locally. Once both sides are plastered with adobe and fully cured, the inside is coated with Thoroseal, which is similar in consistency to cement when mixed up.

The next step is to build the lid for the tank. This will consist of planks of palmyra wood joined together by a carpenter to form the lid and cut into a circular shape that is the same size as the tank. A smaller hole in the middle then needs to be cut in order to house the filter for the catchment system.

The hoop for the catchment may need to be constructed in a work shop as it requires sections of aluminium tube be welded together and bent into a hoop of 10 m diameter and welded to stay rigid. The tarps for the catchment will need to be joined by epoxy and plastic welding in order to create the size needed. The diameter of the tarp needs to be slightly larger than that of the hoop so that the excess can be folded around via tabs under the hoop and sewn together in order to hold the tarp in place. A hole also needs to be cut in the centre of the tarp to accommodate the filter.
The filter then can be constructed by drilling 5 mm holes in the smaller PVC end cap. A 100 mm hole is drilled in the larger end cap and the two open ends glued together. The hole in the centre of the tarp can then be glued to the inner edge of the larger end cap. A groove is cut in each bamboo strut to support the aluminium ring. Four 30 cm cylindrical holes will then be dug to accommodate the four bamboo struts and once the ring is held in place in the struts, it is hoisted up and each strut placed in its respective hole.

**10.2 Safety and Management Concerns**

As stated before, this project has been designed in order to minimise costs to the community by involving the community as much as possible during the construction. This also keeps in line with one of EWB’s main goals of community action and education (EWB, 2011).

During construction, a site first aid/safety officer will be either elected or hired. This is to ensure that the participants in the construction act in a safe manner. Some of the main concerns are heat stroke, exhaustion and dehydration. These are especially important during the hotter months. This person will also train the participants in safe work practices such as how to lift heavy loads correctly and operate equipment correctly.

Another consideration is to provide proper protective equipment. This is mainly a problem with the use of the Thoroseal. Thoroseal can give alkali burns during prolonged exposure to the skin and can also damage eyes. When in its dry powdery state, care needs to be taken not to inhale the dust as this can cause irritation (Thoroseal MSDS, 2004). Because of this, safety glasses will need to be used as well as low grade chemical resistant gloves to protect the
hands of the workers. When the powder is initially mixed with water an exothermic reaction occurs, resulting in a hot alkali paste, caution needs to be taken with this to avoid injury.

11.0 Economics of the Design

11.1 Capital costs

Table 11.1 below details the cost of materials used in the design. The total cost per tank is $1236 or Rs.52 046 (Indian rupees). Because we are installing one tank in each of the three areas of the community, the total capital cost of the design is $3 708 or Rs.156 138 (appendix 16.2). The largest cost involved with implementing the design is hiring a carpenter to help with installation and the cost of sourcing the waste tyres from Chennai as we were unable to identify a closer source of waste tyres in the rural area surrounding Devikulam.

Table 11.1: Material Costs (Multiple sources-see complete list in references)

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Total Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P215/60R16 Tyres</td>
<td>360 (approx. 4 tonnes)</td>
<td>400</td>
</tr>
<tr>
<td>Star picket-tar coated</td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>Chicken wire mesh (1.8 m width)</td>
<td>35.5 m</td>
<td>64</td>
</tr>
<tr>
<td>Adobe</td>
<td>-</td>
<td>Acquired from site</td>
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<tr>
<td>Heavy duty tarpaulin</td>
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</tr>
<tr>
<td>Thoroseal waterproof</td>
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<td>Aluminium rod</td>
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</tr>
<tr>
<td>Cable ties</td>
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</tr>
</tbody>
</table>
### 11.2 Operating Costs

Although the Earthship tank does not require a cost to run, certain ongoing costs must be included to allow for maintenance over the tank’s lifespan. These will most likely include replacing the tarpaulin on the water catchment surface because of UV damage and upkeep of the tap at the base of the tank by a qualified plumber. We envisage the tarpaulin will need to be replaced approximately every two years and the plumbing maintained once a year. This equates to a cost of $68.50 per year for maintenance or Rs.3282.8 (appendix 16.2).

### 11.3 Value of the design

Although we don’t propose the community sell the water, equating the amount of water collected by the tanks to a value per litre for bottled water in India allows a monetary value of the design to be calculated. Using the data that 116 L of water is collected by the three tank system each day on average and approximating the value of one litre of bottled water in India to be 10 Rs. (Bhushan, 2006), the value of the water collected each year is $8 835 or Rs. 423 400. When this value is compared to the upfront cost of $3 708, the tanks will have essentially paid for themselves within 5 months (appendix 16.2).
Because it is the community who eventually approves the design and decides if it is affordable, the upfront cost of the design can be compared to the total income of the community to gain a quantitative idea of how practical the idea is economically. The community has a combined income of roughly two million rupees ($40 000) (EWB, 2011) so the capital cost of the design represents ~ 9% of this (appendix 16.2). It may also be possible to gain funding from outside sources such as the Indian Government or find cheaper local sources of waste tyres which would reduce this cost of implementation.

Figure 11.1 below shows the flow of money over time. Green represents the value of the water collected and red represents the upfront and maintenance costs over the tanks lifespan. For the purpose of this diagram the lifespan is estimated at 50 yrs but it is quite feasible that the lifespan will be much longer. Assuming an interest rate of 10%, the net value of the tank systems is $91,902 which is calculated by subtracting the present worth costs from the present worth benefits (appendix 16.2).
The group felt it necessary not just to minimally fulfill a set of ethical rules known as the Minimalist Model (Shallcross, 2011), but go above this and create and occupy an overarching ethical mindset for the whole project – this is known as the Good Works Model for ethics (Shallcross, 2011). Upholding this model of ethics is important in order to merit trust within the community as well as in the professional environment.

The group ethical mindset was developed firstly from discussing communal group morals which were necessary to become ethical guidelines. Secondly, the codes of conduct for Engineers Australia and the Institution of Professional Engineers New Zealand were consulted. It was found both codes of conduct place an emphasis on the health, welfare and
safety of the community involved, the responsibility to act with honour and integrity, to work within the level of your engineering competency and to care for the environment (Engineers Australia, 2010; IPENZ, 2011). Combining communal group morals and aligning them with the ethical tenets found in the two codes of conduct, focus areas for upholding ethical behaviour in our project were created.

As the diagram below shows, this is an overarching mindset we intend to uphold with no set order of importance which is very much open to interpretation. This illustrates the group desire to do more than just fulfill the bare minimum ethical requirements and uphold a conscious mentally active attitude to be ethical overall.

Figure 12.1: Ethical Mindset
Focus areas (in no particular order):

- **To minimize impact on the physical and socio-cultural environment.** This means to minimise adverse impacts on the natural environment (for example felling of trees). This also means minimizing impacts on the social and cultural atmosphere such as taking into account religious customs and minimising change the community will have to adjust to.

- **To act within our level of skill.** This means whatever the role in the project is, doing it within your competence, experience and qualification level. Contrastingly it also means and knowing your personal and discipline based limitations.

- **Equal treatment of all involved.** This means the fair treatment of all involved in the project taking into account race, religion, social position, gender, sexuality, political view, age, disability and any other factor that can produce prejudice.

- **To promote a dynamic workplace.** This focus area places priority on growing individual experience and expertise, team building, encouragement, innovation, thinking outside the box and other factors that promote growth from an individual, team and corporate perspective.

- **To act with honour, integrity and professionalism.** This means promoting virtues such as honesty and truth that build company reputation in all activities and to conversely actively seek out and remove corruption.
• **To maximise happiness and fulfilment of all involved.** This focus area ensures the project/solution brings benefits to all involved. This includes factors such as the solution being of high quality, being sustainable and having a long life span, being available to all community members and more.

• **The safety and wellbeing of all involved.** This focus area places priority on the health, safety and minimisation of any risk for all involved in the project. This could mean ensuring safety procedures are obeyed in construction stages or that the solution won’t collapse and fall on villagers.

### 13.0 Sustainable Engineering Practices

A major aim of the project is to pioneer of ecologically sustainable development in terms of the triple bottom line (TBL) for engineers. This active awareness of the broader impact of our project is particularly important in a world that demands efficient and effective solutions to their problems yet is already exceeding the available resources to do this. Accordingly, the design solution is forward looking aiming to be environmentally sound and socio-culturally responsible.

#### 13.1 Environmental Assessment

Our ethical mindset seeks to minimise impact on the physical environment. Consequently the design places a large priority on meeting this standard. This can be summarised as doing more with less in terms of materials and energy.
A great advantage of the final design choice is the materials used. A large proportion is recycled, and/or renewable and/or locally sourced. These materials are summarised in table 13.1. The benefits of using recycled materials is that we are getting rid of local waste, giving it a new function in the design, and minimising the amount of waste created using new materials. This will help return the environment to its natural state in a place where “garbage litters the landscape” (EWB 2011). The second important category of our materials is that they are renewable and not completely depleted when used (Oxford University, 2005). This minimises human impact on the natural ecological processes of the planet. Finally the materials being locally sourced minimises foreign change to the environment and reduces energy costs used in transport.

<table>
<thead>
<tr>
<th>Material</th>
<th>Renewable</th>
<th>Recycled/Reused</th>
<th>Locally sourced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adobe</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Dirt</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Tyres</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Bottles</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Tin cans</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Bamboo</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Palmyra</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

In terms of energy, the group minimised energy usage firstly through implementing both directly local materials and local materials that are at furthest distance away, obtained from Chennai, the capital of Tamil Nadu. This minimises energy costs for transport. Secondly the only energy source used in operation of the design is gravitational potential energy as the water flows from the top to the bottom of the catchment and tank. This operation stage is the longest in the projects life cycle and producing no emissions in this stage is very advantageous environmentally. Thirdly, much of the construction stage involves low skill level human labour (i.e. digging dirt, plastering) which will ideally emit no greenhouse gases
at all. As is seen, our design aims at reducing energy consumption without diminishing the end product.

The project is however not without electrical energy use and consequent emissions. In the material acquisition and construction stages, tasks such as processing raw palmyra wood and processing aluminium rings for catchment structure will consume energy. Energy will be used transport to and from Chennai which is a 254km round trip. Based on values from a 2002 Australian Bureau of Statistics survey seen in figure 1 of appendix 16.4, the carbon emissions per return trip to Chennai by a rigid truck are 0.2 tonnes (Future Climate, 2007). Energy will also be used in the form of electrical power tools in the very small proportion of construction components that require skill such as sanding, joining and drilling.

13.2 Socio-Cultural Assessment

Within professional engineering circles such as Engineers Australia and the Institute of Professional Engineers New Zealand, the value of socially responsible engineering is clearly observable (Engineers Australia, 2010; IPENZ, 2011). Accordingly, the project places an equal priority on the wellbeing and interests of Devikulam and is bound to this by our ethical mindset. This includes EWB community consultation, integrating traditional Hindu beliefs and social requirements, and the inclusion of safety procedures.

Though a direct community consultation was not available in which we could gather first-hand information of how to integrate our design into the community this has partially been taken into account by EWB. EWB have worked together with Pitchandikulam forest volunteers to target community specific problems and provide detailed, local level, contextual
information relevant to each problem area (EWB, p.6). This allowed us to target areas of community dissatisfaction for example the water innovations report available on the EWB website revealed community dissatisfaction due to increasing salinity, faulty taps and non-functioning bores which led us to propose the solution of a rainwater collection system completely independent and unaffected by these problems (EWB, 2011). In essence, EWB was the medium through which we were allowed a second hand community consultation with the Devikulam community in circumstances where a direct community consultation was not viable.

Because of the Hindu ‘caste’ system, especially in rural India jobs are still associated with their respective caste. Out of respect for culture and despite how discriminatory it might appear from a western perspective, jobs will be categorized and issued according to the caste system. For example the lowest caste known as ‘the untouchables’ are considered the most impure and they are often designated unpleasant work such as the removal and cleaning of human waste as well as dirt which makes the upper castes ‘unclean’ (National Geographic, 2003). Since dirt and rubbish are directly involved in the construction of the storage tanks this is an example of task assignment to the ‘untouchables’ caste.

Tasks will also be done in caste groups and need to be highly regulated because there are also certain rules of association. For example if a Brahmin (the highest caste) is touched by an ‘untouchable’ (the lowest caste) they need to undergo an in depth ritual in which the ‘impurity’ is removed (Beyond Books, 2003). To minimise such associations, same castes will be grouped and designated appropriate tasks.
Safety is the final social implication which also needs to be considered. For this reason skilled labourers will be brought in for aspects of the construction and maintenance stages that require technical skill. Whilst this need is small, it needs to be done by those who are qualified to minimise the potential for harm. In the education stage, volunteers will be briefed on important safety procedures including how to correctly lift heavy loads, staying hydrated and protected from the sun, the correct use of construction tools, and basic first aid procedures. A qualified first aid officer will be on site for the entire construction process. Eye, hand and ear protection will be provided and enclosed shoes a prerequisite to work on site. Foreign workers and volunteers will be advised to get appropriate travel health advice in regards to vaccinations and hygiene measures.

14.0 Conclusion and Recommendations

The main objectives of the design solution are to firstly lessen the reliance that the Devikulam community places upon its current water supply system (bores) by providing a completely independent secondary source of water. The second main objective was to provide a potable source of water for the community due to the lack of such water quality. The group feels that the design fulfils these objectives to a large extent through a technically creative, simple yet effective and reliable rainwater catchment and storage system.

Not only does our design satisfy these goals but it does so in such a way that is firstly ethically sound in terms of impact on the environment as well as acknowledging a
responsibility to the culture and social requirements of Devikulam. Secondly, the design provides a high value to the community at a very low cost to all involved ultimately being exceptionally viable in terms of economics.

As a result of this, we highly endorse the design solution to the people of Devikulam and greatly anticipate the benefits it will bring to their community.

15.0 References


Engineers Australia. (2010). *Code of Ethics* [PDF]. Retrieved 17/04/11 from 

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Retrieved 25/03/11 from


http://india.gov.in/knowindia/india_at_a_glance.php


http://www.geographia.com/india/


www.hrw.org/reports/1999/india/

http://www.chargar.com/DATA_SHEETS/Thoroseal_MSDS.pdf


**Note**: The following references are for the materials listed in ‘Table 11.1: Material Costs’:


1300 Starpickets (Australia). (no date). *Black tar star pickets*. Retrieved April 30, 2011 from
www.1300starpickets.com.au/?stg=24


Google Documents (USA). (no date). *Truck rates per kilometre*. Retrieved May 12, 2011 from www.bheljhs.co.in/mm_b2b/works_contract/docs/award_letter_rci.pdf+trucking+india+price+per+km


16.0 Appendix

16.1 Design Calculations

Tyres for tank-
Tyre used- P215/60R16
215- Width of tyre in mm
60- 60% of the width of tyre = to sidewall height
16- Rim size, in inches

Diameter of tyre = 60% of 215 mm + 16 inches
60% of 215 mm = 129mm
16 inches = 406.4 mm

D = 535.4 mm

Circumference of centre line- Given diameter of tyre to be 0.5354 m, 30 tyres in a line
0.5354 × 30 = 16.062m (this should be equal to circumference of the centre line between the
tyres in a circle)

External diameter of tank- with circumference of centreline = 16.062 m

\[ D = \frac{C}{\pi} \]

Thus \( D = 16.062/\pi \)

= 5.11m

External hence Diameter of centreline + diameter of a tyre

= 5.648 m

Internal diameter of tank- with circumference of centreline =16.062m

\[ D = \frac{C}{\pi} \]

thus \( D = 16.062/\pi \)

= 5.11m

Internal hence Diameter of centreline – diameter of a tyre

= 4.575 m

Height of tank- will equal a stack of 12 tyres. Width of tyre = 215 mm

Thus 12 × 0.215 m = 2.58 m

Capacity of tank- Volume = \( \pi r^2h \) (radius to internal edge)

~V of tank= \( \pi \times 2.29^2 \times 2.58 = 42.4123 \text{ m}^3 \) or 42 412.3 L

Area covered by lid- Area= \( \pi r^2 \) (radius to external edge)

\[ A = 25.05m^2 \]

Performance Calculations

Water captured

The when an amount of rain is given in mm, it means it will fill any open uniform cylinder to
that given depth. Thus a 10 m and 100 m diameter cylinder will both fill to 1 mm in 1mm of
rain.

Area of capture- Diameter of Catchment- 10 m
\[ A = \pi r^2 \]
\[ A = 78.54 \text{ m}^2 \]

Assuming 1800 mm of rain:
Thus \( V = hA = 2.58 \times 78.54 \)
\[ V = 202.63 \text{ m}^3 \text{ or } 202,630 \text{L of water captured per annum.} \]

### 16.2 Economics calculations

#### Capital costs
Tyres: 360 tyres\( \times 11 \text{ kg per tyre} = 3960 \text{ kg} = 3.96 \text{ t} \) (To be certain we will assume 4 tonnes)
\[ 4 \text{ t} \times $100 \text{ per t} = $400 \]
Tyre freight: (Distance from Chennai to Devikulam is 126 km at a price of $0.45 per km)
\[ 126 \times 0.45 = $56.70 \]
Cost for 3 tanks: $1236 \times 3 = $3708

#### Operating Costs
Maintenance: $127 \div 2 = $63.50 \text{ per year for tarps and } $5 \text{ per year for plumbing-} = $68.50 \text{ per year or Rs.3282.2}

#### Value of Design
Water: \( 116 \text{ L} \times 365 = 42340 \text{ L per year} \)
\[ \text{Rs.10} \times 42340 = \text{Rs.423 400 per year} = $8 835 \text{ per year} \]
Upfront cost = $3 708 vs. revenue of water per year $8 835
\[ (\$3708\div \$8 835) \times 365 \text{ days} = 153 \text{ days (approx. 5 months)} \]
\[ (\$3 708\div \$40 000) \times 100 = 9.27\% \]
Net Value: present worth benefits \(-\) present worth costs
- Benefits: \( n = 50, B = $8835, r = 10\% \)
\[ PWs = B \left( 1 + \frac{1}{r} \right) \left( 1 - \frac{1}{(1 + r)^n} \right) \]
\[ = 8835 \left( 1 + \frac{1}{0.1} \right) \left( 1 - \frac{1}{(1+0.1)^{50}} \right) = $96 357 \]
- Costs: \( n = 50, B = $68.50, r = 10\% \)
\[ PWs = 68.50 \left( 1 + \frac{1}{0.1} \right) \left( 1 - \frac{1}{(1+0.1)^{50}} \right) = $4 455 \]
\[ NV = $96357 - $4455 = $91902 \]
16.3 Design Illustrations

Figure 16.3.1
Figure 16.3.2
Figure 16.3.6
16.4 Environmental Assessment

Figure 16.4.1: Australian Bureau of Statistics. (2002)