Biosand Water Filtration in Malawi

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Executive Summary

The purpose of this report is to outline the water problems faced by volunteers in Malawi, provide a detailed description of a biosand filter design, and discuss this filter's implementation in orphan care centers.

For this term's final project, our team chose to do a Greater Good project in collaboration with BLUELab. The student group BLUELab and the nonprofit organization Leap Frog Partners are working together to bring water filters to Malawi to provide clean water for volunteers at orphan care centers. In Fall 2007, teams ESPN-8 and Kings of the Hill outlined possible designs for filters. Our task was to pick one of these designs, build a prototype for it, and evaluate its effectiveness and feasibility.

Malawi has a very large orphan population due to the HIV/AIDS epidemic. To help alleviate this problem, there are orphan care centers around the country. Groups such as Leap Frog Partners send volunteers to work in these centers. An issue these volunteers face is that Malawi's water is contaminated by improper waste disposal and agricultural activities. Turbidity, iron, and coliform count do not meet satisfactory levels set by the World Health Organization. The local population has built up immunities to contaminants in the water, but the volunteers often get very sick from drinking it. Filters in orphan care centers would provide clean water for volunteers.

Before we built our filter prototype, we determined the criteria that it had to meet. The major criteria included water quality, amount of water produced, robustness, and ease of construction. Based on these criteria, we chose to build a biosand filter. A biosand filter consists of two layers of sand on top of a layer of gravel. Within the top sand layer resides a bacterial layer, called the schmutzdecke, that biologically cleans the water. As the water filters through all the layers, turbidity and harmful substances are removed from it.

We constructed our prototype from a 10-gallon Igloo cooler, PVC pipe, and plastic spigots. Afterwards, we made a detailed construction guide that can be used by the volunteers.

We conducted tests for nitrates, nitrites, ammonia, and pH on samples of water filtered by our prototype and also took qualitative observations of the water samples. Team Midwest Engineering tested our filtered water using ATP Bioluminescence. Test results indicated that our filter significantly removed bacteria, turbidity, and odors from the water.

Although our prototype improved the quality of water, testing over longer periods of time still needs to be done. Also, future teams should investigate materials, such as a better sealant for the pipes that would make the design more robust. Our prototype is not ready for implementation in Malawi, but with minor changes, our design can be used by the volunteers.

1 INTRODUCTION

This section describes the problem of obtaining potable drinking water for volunteers working in orphan care centers in Malawi, Africa. It includes a brief summary of our solution to providing clean water, the tasks involved in implementing this solution, and the purpose of this report.

Our project is to test the feasibility of implementing biosand filters to serve volunteers working in orphan care centers in Malawi. Specifically, this project focuses on providing enough drinking water for two volunteers at an orphan care center. Volunteers are not immune to different types of bacteria found in Malawian water and must be provided with a daily minimum amount of clean water.

Our solution is to build a biosand filter prototype for use in orphan care centers. Biosand filters use biological and physical methods to filter out bacteria and turbidity, or the cloudiness of water created by suspended particles, from water. This idea has been proposed by several teams in past sections of this class. As part of the implementation of our solution, our team assessed the feasibility of obtaining the materials for the filter in Malawi, as well as the ease of constructing the filter.

The purpose of this report is to discuss the water problems in Malawi, provide a detailed description of the biosand filter design and construction process, assess the viability of implementing this filter in an orphan care center, and present BLUElab and Leapfrog Partners with our findings.

2 BACKGROUND

This section provides a brief overview of orphan care centers and the water problems faced by volunteers in Malawi.

2.1 Malawi

Malawi is a landlocked country located in southeast Africa bordered by Mozambique, Tanzania, and Zambia (see Appendix A). Malawi was originally established as the British protectorate Nyasaland in 1891. It became an independent country 1964 and a multi-party government system was established in 1994. Under the current president, Mutharika, Malawi has seen some economic improvement, but political corruption, the spread of HIV/AIDS, population growth, and water contamination are major problems faced by the population (see Appendix B) (Malawi, 2008).

2.2 Orphan Care Centers

The government of Malawi has instituted orphan care centers as a way to sustain its growing orphan population. Typically in African communities, a child who loses his parents moves in with extended family members (Beard, 2005). The orphan care centers are meant to supplement the families that take in orphans by providing meals and education. Many non-profit organizations such as Leap Frog Partners help finance the construction of these centers and staff them with volunteers (Leap Frog Partners).

2.3 Problems with Water

The populations of many underdeveloped countries face difficulties finding water that is acceptable for drinking and cooking. Malaw is not exempt from this pressing issue. The country's water sources are contaminated by improper waste disposal, particularly from urban centers, and agricultural activities. Turbidity, iron, and coliform count do not meet satisfactory levels set by the World Health Organization (see Appendix C). As a result of the increasing levels of harmful substances plaguing Malawian water, waterborne diseases such as bacterial and protozoal diarrhea, hepatitis A, typhoid fever, cholera, and E. coli have become an even bigger concern for visitors (Water Profile of Malawi).

2.4 Volunteers

Volunteers, usually from western countries, go to Malawi to help in the orphan care centers. Unlike the natives of Malawi, volunteers usually have not built up immunities to the different types of bacteria found in Malawi's water sources. When these workers drink the local water, they often get sick. In order to create a safe environment for these volunteers who staff the orphan care centers, it is necessary to provide clean water.

2.5 Water Filtration Methods

Many methods of water filtration have been explored by teams in previous semesters of this Engineering 100 section. For example, teams Duderstadt, Kings of the Hill, and ESPN-8 all considered biosand filtration a viable option for cleaning water in different parts of the world. Team Duderstadt focused on providing clean water in Hagley Gap, Jamaica, while the other two teams worked on filtration systems for Malawi.

Along with biosand filters, teams Kings of the Hill and ESPN-8 came up with alternate solutions. Most notable of these are a clay filter and a purifying paste made from the seeds of the Moringa Oleifera tree. After comparing the advantages and disadvantages associated with each technique, our team decided that the biosand design, suggested in team ESPN-8's final report, would be the best option for the basis of our project (see Appendix D).

3 CRITERIA

This section outlines the criteria which should be met by our design.

3.1 Water Quality

The World Health Organization (WHO) has established standards for clean drinking water, and we plan to use these standards to determine whether water produced by a filter we make is sufficiently clean (see Appendix C). Our goal is to produce water which fulfills 100% of the standards, since we assume the WHO would establish the lowest acceptable standards needed for safe drinking water. Along with these specifications, our goal is to produce a filter which removes both microbial contaminants and turbidity.

3.2 Amount of Water Produced

On average, humans use about 20 liters of water per day for cooking, drinking, and for sanitation. For drinking, an average adult needs about two liters of water per day (Hadjer et al, 2005). In order to fulfill the minimum daily water requirement, our filter should produce at least four liters of water per day so that it can sustain two volunteers. We aim to produce at least 40 liters of water per day in order to meet the daily need for water by the volunteers.

3.3 Robustness

Since the filter will likely be in continuous use and operated by people of varying technical skill levels, the design should be robust enough to stand up to rough usage. In addition, the climate in Malawi features temperatures between 14° and 32° Celsius (Latimer Clarke Corporation, 2008), which means that the filter would have to endure varying temperatures. Also, it is possible that there are not many replacement parts available for the filter in Malawi, so the parts used to build it need to withstand many years of use.

3.4 Ease of Building

The filter will likely be built by the volunteers in Malawi based on a set of written instructions. Therefore, the parts and labor should be minimal, as the greatest likelihood of success comes from a simple design.

3.5 Parts Availability

The filter should be built out of parts which are cheap and easily accessible. Ideally, all parts needed for the construction of the filter would be available in Malawi, or easily transported there by the volunteers. However, shipping items over long distances can be extremely costly, and so our goal would be to have all parts available in Africa.

3.6 Cost

The budget for the filter is determined by the funds available to the western volunteers. Funds vary depending on the budgets set forth by Leap Frog Partners and BLUElab. Unfortunately, our team was unable to obtain specific figures for allotted budgets for the construction and maintenance of water filters, so our goal is to minimize cost.

3.7 Scalability

The initial goal of the filter is to provide enough clean water to sustain two volunteer teachers. However, there is a possibility that more than two teachers may be at an orphan care center at one time, or that one filter may provide water for several teachers in the surrounding area. To accommodate this, our filter should have the option of being duplicated or expanded to fit a larger water need.

4 BIOSAND FILTER PRINCIPLES

This section describes biosand filtration.

4.1 Biosand Filter

A biosand slow-sand gravity filter works by running dirty water through several layers of sand to remove contaminants (Seelaus, 1986).

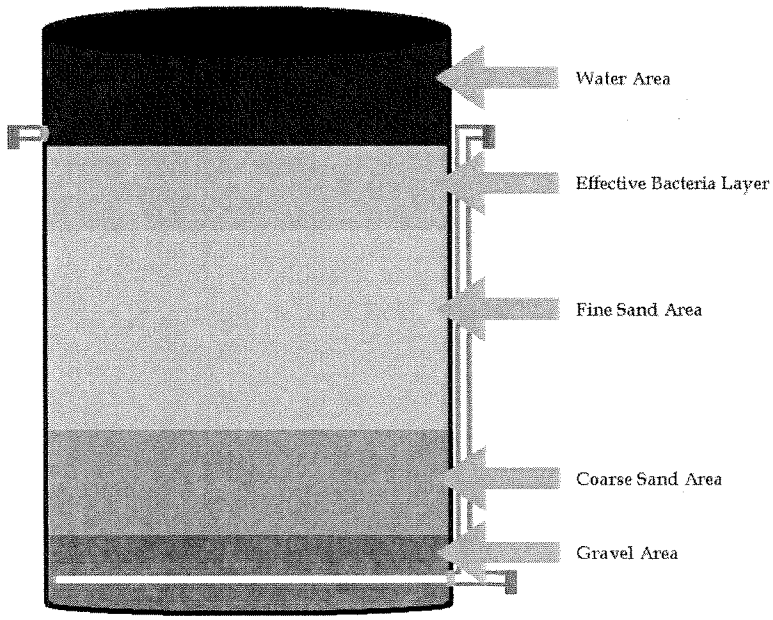

Figure 1: A typical Biosand Filter

Figure 1 shows a typical biosand filter. The space at the top of the filter is for water storage, below which are two layers of sand and a gravel layer. A PVC pipe runs through the bottom of the gravel layer and out of the filter. Water in the filter enters this pipe and exits through either spigot. The bottom spigot is to allow complete drainage of water from the filter (Seelaus, 1986). This can be of use when the filter needs to be moved, since it reduces weight, or when the filter needs to be cleaned. The top spigot is used to get clean water from the filter. This spigot is placed a small distance above the sand layer, so that when water is collected, gravity forces the water level to be above the sand layer (Seelaus, 1986). The top of the sand layer houses a beneficial bacteria layer.

4.1.1 Layers

As seen in Figure 1, a typical biosand filter has two layers of sand and one layer of gravel. In each respective sand layer, the granule size should be uniform (Di Bernardo et al, 1996).

Bacteria

The bacteria layer, or schmutzdecke, forms in the top half of the fine sand layer. The bacteria are cultured by running dirty water through the filter for about two weeks and allowing the top layer to stay undisturbed. The schmutzdecke cleans the water by consuming algae and bacteria and removing most harmful viruses. This layer also filters out heavy metals, such as lead, and poisons, such as arsenic (see Appendix E). The schmutzdecke entraps these contaminants in the top layer for easy removal when the filter is cleaned. This layer should stay wet at all times to ensure that the bacteria do not die (Muhammad, 2005).

Fine Sand

The fine sand layer makes up the majority of the sand in a biosand filter and is home to the schmutzdecke. The ratio of fine sand to coarse sand should be 4:1. Due to its small granule size, the layer packs together tightly and is useful for removing the majority of the turbidity from the water. It prevents large objects, such as leaves and sticks, from clogging the filter. To be most effective, granules of sand should be about 0.19 to 0.35 mm in diameter (Van der Hoek et al, 1996).

Coarse Sand

The coarse sand layer makes up the lower layer of sand in a biosand filter. It is thin in comparison to the fine sand layer by ratio of 1:4. Its main use is preventing the fine sand from traveling further down into the filter and clogging the filter's piping. The coarse sand removes some turbidity from the water as it passes through. To be effective, the granules of sand in this layer should be about 0.25 to 0.84 mm in diameter (Van der Hoek et al, 1996).

Mixed Sand

In the event that industrial-grade filtered sand is unavailable, mixed sand is a viable alternative for use in a biosand filter. The sand should be sifted for any loose materials, sticks, or rocks, and then added to the filter. Although mixed sand filters water relatively well, there are some trade-offs in quality. First, the flow rate of water in non-uniform sand is lower than that of uniform sand. Second, the schmutzdecke grows deeper in filters with uniform sand, resulting in more bacteria and virus removal. Finally, the retention of smaller particles is notably higher in filters with uniform sand compared to those without. Overall, the water produced by both types of filters has an acceptable level of turbidity. If mixed sand is used, it would take up the volume that the coarse sand and fine sand should have taken up combined (Di Bernardo et al, 1996).

Gravel

The gravel layer is the bottommost layer in a biosand filter and is deep enough to cover the drainage pipe by about one inch. The gravel's main purpose is preventing the coarse sand from traveling further down in the filter and clogging the filter's piping (Wegelin, 1987). The gravel also keeps the pipe off the bottom of the filter, meaning the water entering the pipe is cleaner because any water or particles that pass through the gravel layer accumulate below it. This increases the robustness of the pipe. If the pipe were to rest on the bottom of the filter, movement could cause it to break. The gravel layer acts as a buffer for the pipe. To be effective, the gravel in this layer should be very small rocks about 1 to 2 mm in diameter (Seelaus, 1986).

5 OUR PROTOTYPE

This section discuses the specific design and construction of our prototype.

5.1 Specifications

Most existing biosand filters are made out of concrete. However, the building process for these designs requires fragile molds that break after only a few uses. The current filters are expensive and heavy (Dow Baker, 2000). Our design uses a plastic barrel which allows for cheaper production, is lighter, and retains strength and robustness. The filter should be at least 1.5 meters in height to allow for ample space for water above the sand (Cleary, 2005). We determined that the filter should be at least 0.3 meters in diameter, since that would allow enough water to be stored in the filter for easy access at a later time. Larger filters are acceptable, but further research would have to be done to see how much weight the plastic walls of the filter could withstand without deformation. The piping outside of the filter should be as close to the side of the filter as possible to reduce the chance of damage to the filter or pipes. An upper drainage pipe, shown on the left side of the water area in Figure 2, should be installed directly across from the upper nozzle point of the water pipe. This drainage pipe is used for cleaning the schmutzdecke. The layer is cleaned using a process called "wet harrowing", which involves pouring water on the layer while slowly scraping the dirty sand out through the drainage pipe. This process speeds up the recovery time of the bacteria layer (Eighmy et al, 1992).

5.2 The Design

We built a prototype of a three layer biosand filter with two layers of sand and one layer of gravel. Figure 2 is a diagram of our filter.

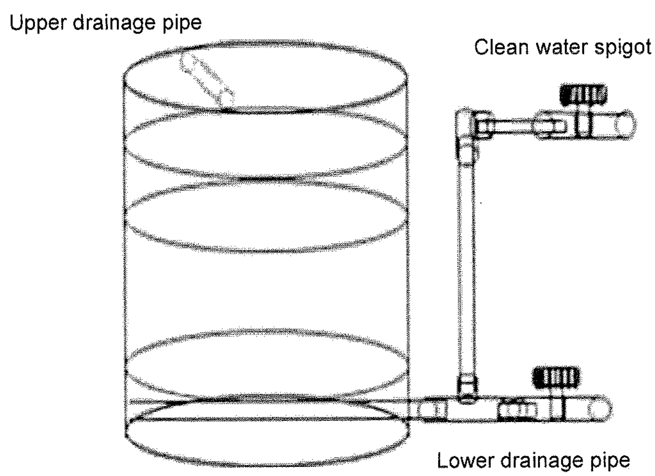

Figure 2: Diagram of the filter

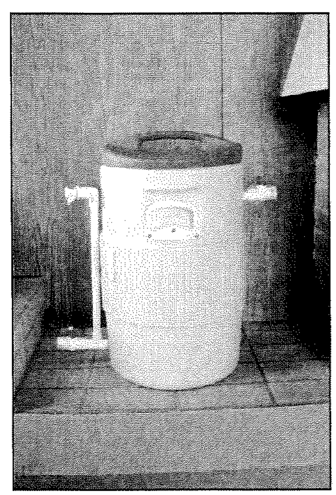

Figure 3: Photograph of the filter

5.2.1 Size

Specifications call for the filter to be 1.0 to 1.5 meters high and have a diameter of 0.3 meters. Our filter, however, is only 0.6 meters high and has a diameter of 0.4 meters. We determined that even though our prototype is smaller, it is more mobile and easier to construct than a large-scale model. We maintained the appropriate sand ratios so the quality of our filter should still meet our specifications.

5.2.2 Material and Tool Choices

For our prototype we chose robust and inexpensive materials which would likely be found in Malawi.

- The piping in our filter is made of 1/2-inch diameter PVC pipe and plastic T- and L-connectors. PVC pipe is robust, easy to work with, and is available in most basic hardware stores. We chose 1/2-inch diameter because it was large enough for our water flow and was not bulky.

- We chose 1/2-inch diameter plastic spigots for our nozzles. These spigots were very sturdy, fit perfectly on the PVC pipe, and were inexpensive.

- Our container is a 10-gallon Igloo® plastic water cooler. We chose this water cooler because it was an appropriate size and sturdy enough to withstand the force of sand and water. We considered larger containers, such as garbage cans and standard 50-gallon drums. These options did not seem appropriate, because a container with a capacity of more than 15 gallons would be extremely heavy and difficult for the volunteers to work with.

- We used all purpose sand, fine sand and gravel, which were purchased at Home Depot.

- For our adhesive we used PVC cement and primer. We also used caulk and PVC pipe cement to seal the joints of the PVC pipe.

- During construction we only used basic tools such as a saw and a drill.

5.2.3 Construction

Our construction process consisted of assembling the piping, integrating the piping into the cooler, and adding sand and gravel to the filter (see Appendix F for a construction guide, see Appendix G for pictures of the prototype).

5.3 Problems Encountered

This section outlines the problems we encountered.

5.3.1 Leaks

Our prototype had leaks around the bottom spigot. When our filter was full of water, enough water leaked out to fill a 1-gallon container in approximately 24 hours. This was likely because we only glued the drainage pipe on the outside surface, and therefore a good seal was not formed.

5.3.2 Simulating the Water

We had difficulties contacting BLUElab to get specifics about the water in Malawi. We decided to use water from the Huron River for our test water. Although this water is dirty, it is likely that it does not contain the same amounts and types of bacteria as the water in Malawi.

5.3.3 Growing the Schmutzdecke

Growing the schmutzdecke takes at least two weeks. We didn't have a full two weeks before we had to test the water, so we weren't able to test our filter at its maximum filtering capacity.

6 WATER TESTS

Two types of tests were conducted on our filtered water. We used an Aquarium Pharmaceuticals Freshwater Master Test Kit (see Appendix H) and Team Midwest Engineering tested our water with ATP Bioluminescence (see Appendix I). We also qualitatively analyzed our samples.

6.1 Freshwater Master Kit

Using the Freshwater Master Kit we tested for ammonia, nitrites, nitrates, and pH. Since Malawi's water has a high content of fecal matter and there is a considerable amount of pollution from farming, it is important that our prototype filters out ammonia, which is found in fecal matter, and nitrates and nitrites, which are often related to fertilizer. WHO has not established specific criteria for acceptable levels of ammonia in drinking water, but on average, water of acceptable drinking quality has no more than 0.2mg/L of ammonia (World Health Organization, 1996).

Initially, we intended to test five samples of water from the Huron River for before and after quantities of all of the substances testable by the test kit. However, after a few trials, we found that there is no ammonia present in the Huron River, even though there was a presence of nitrites. Water sample 4 shows that our filter was able to remove nitrites present in the water (see Table 1).

Water Sample	pH	Ammonia (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)
1. Water retrieved 3/30	7.6	0	5	0
2. Water retrieved 3/30 filtered once	7.4	0	5	0
3. Water retrieved 4/1	7.3	0	5	0
4. Water retrieved 4/8 filtered once	7.3	0	0	0

Table 1: Water test results for water samples

The lack of ammonia in the water posed a problem because it meant that an established nitrogen cycle exists in the Huron River. Over the course of a nitrogen cycle, ammonia present in the water is consumed by bacteria, which initially turn it into nitrites and subsequently into nitrates (Brown, Johnson, 1996). This means that any ammonia in the water would quickly be turned into nitrates, and we would likely be unable to detect any amount present. To work around this problem, we decided to alter our water sample.

To simulate authentic Malawian water conditions, we decided to add urine to water retrieved from the Huron River. Two of our team members donated urine samples amounting to a total of approximately 1 liter of urine, which we mixed into about 2 gallons of river water. Even though water in the Huron River already has bacteria which remove ammonia, we felt that if the water was tested within a short period of adding the ammonia (urine), the concentration of ammonia would not change significantly enough to affect the outcome of the tests.

Due to time constraints, we were only able to test one sample of water. Our filter normalized the pH of the water sample, and removed any nitrates present in the water, which followed the trends we saw in our initial tests (see Table 2). However, there was no change in amount of ammonia present in the water.

Water Sample	pH	Ammonia (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)
5. Water retrieved 4/13 with added urine	6.6	1.0	10	0
6. Water retrieved 4/13 with added urine filtered once	7.6	1.0	0	0

Table 2: Water test results for water samples with added urine

6.2 Qualitative Observations

We noted qualitative observations from every water sample during the course of testing. Overall, the filtered water looked and smelled cleaner than water put into it. Most notably, the water with added urine had a significant improvement in appearance and odor (see Table 3).

Water Sample	Visual Observations	Odor Observations
1	Murky green/tan color; Lots of floating sediment particles	Smells musty
2	Relatively clear, only small floating particles; Yellow hue	Musty smell is fainter, but still present
3	Small bits of twigs and leaves, murky sediment; Reddish/brown color	Smells musty
4	No floating particulate matter, very faint yellow hue	No perceptible odor
5	Strong yellow color, floating sediment particles	Strong smell of urine
6	Clear, colorless liquid	No perceptible odor

Table 3: Qualitative observations of water samples

6.3 ATP Bioluminescence

Team Midwest Engineering (MWE), with the help of Dr. Deininger, conducted ATP Bioluminescence testing on samples of water from our filter. ATP Bioluminescence qualitatively compares the amount of bacteria present in different samples of water. According to MWE, the unfiltered water we gave them measured at 921 rlu/mL (relative light units per milliliter), while our filtered water was 274 rlu/mL. When they tested Ann Arbor tap water it ranged from 76 to 201 rlu/mL. This shows that our filter considerably reduced the bacteria in the water to nearly the same level as tap water (see Appendix I).

6.4 Conclusions

Both the water testing done by MWE and our team indicate that the water that comes out of our filter is considerably cleaner than the water put in. Qualitative observations indicate that nearly all the turbidity present in the water is removed, as well as many odors. Water samples 4, 5, and 6 indicate that the filter is capable of removing nitrites. If we had more time, the schmutzdecke would likely have been better established and would also have removed ammonia. We came to this conclusion because as time passed, there was an increase in nitrite removal by the filter. Based on the water testing conducted by MWE, we can conclude that there is also a significant amount of bacteria reduction. Due to time constraints, we were unable to wait for the complete formation of a schmutzdecke, but we feel that once one is established, our filter may produce drinking-quality water.

7 IMPLEMENTATION IN MALAWI

This section discusses issues concerning the implementation of our design in Malawi.

7.1 Purchasing Parts from Hardware Stores

The parts for our prototype were bought from local hardware stores in Ann Arbor. Buying parts locally saves on shipping expenses, so the parts for water filters made in Malawi should be bought from hardware stores in Malawi. Malawi has five major hardware stores: two are in Lilongwe, two are in Blantyre, and one is in Limbe (see Appendix J for a detailed list, see Appendix K for a map of city locations). We were unable to contact any of these stores, so we are still unsure whether the parts needed for our filter are actually available for purchase. In the event that the parts and tools needed for building the filter cannot be found in any hardware stores in Malawi, there is a possibility that they can be bought in hardware stores in South Africa. South Africa is a much more developed country than Malawi and it is likely to have more supplies.

7.1.1 Shipping Costs

We were unable to determine whether all parts needed in the construction of our filter were available in Africa, so we investigated shipping the parts from the United States. We envisioned a scenario in which the container for the filter, the PVC piping and the spigots were shipped in a 10-pound package from Ann Arbor to Malawi in the summer of 2008, and got quotes from different shipping companies. We assumed that the method of shipping to be used would be air freight, since shipping the parts necessary by land could be too time intensive and would not reach the volunteers in a timely fashion. The least expensive option was to use UPS Consolidated Air Freight at the price of $179.42 (see Appendix L).

7.2 Sifting Sand and Gravel

The sand and gravel for the filter could potentially be obtained from the earth in Malawi. This saves on the total cost of the filter. However, the filter design requires two different grades of sand. In order to get two sizes of sand, it could be sifted by hand using two different sized sifting devices, such as two grades of wire mesh.

7.3 Mass Production

Our prototype is intended for use by two volunteers at an orphan care center. If filters are built and used successfully, mass production could be considered. This would make water filters accessible to multiple orphan care centers in Malawi. Additionally, if mass production is implemented, enough water filters could be produced to benefit the general population. While the natives have a built-up immunity to the water, it could be beneficial for them to drink filtered water.

8 CRITERIA EVALUATION

This section assesses how well our filter met the established criteria.

8.1 Water Quality

According to tests, our filter results in water which is less polluted than its initial condition. Testing was insufficient to determine absolute compliance to WHO standards, especially since our testing supplies and time were limited. However, from the data we were able to gather, we can conclude that if this filter in its current state was implemented in Malawi, the water quality would be significantly better compared to unfiltered water. It is inconclusive whether this betterment would be enough to make the water drinkable for those not used to Malawian water.

8.2 Amount of Water Produced

As we tested the water quality, we also tested how much water our filter can produce in a certain amount of time. We filled two 591 mL water bottles in 49 and 54 seconds, respectively. Extrapolating this data, we can assume that it would take about 87 seconds to produce one liter, and about 330 seconds, or five minutes, to produce 1 gallon of water. Mathematically, this would result in a daily water production rate of 288 gallons. However, this is an unrealistic estimate since it would require constant refilling of the filter. The current design of the filter is limited to producing approximately 1 gallon of water at a time because there is no large holding tank for unfiltered water. If holding tanks were added to the design, then the mathematical limit of water production would be between 250 to 300 gallons per day. We established our criteria of adequate water production to be 40 liters, or about 10 gallons, of water per day. Though this would require refilling the filter ten times over the course of a day, we feel that this is still sufficient to sustain two volunteers at an orphan care center.

8.3 Robustness

The robustness of our filter could still be improved upon. The main points of focus would be the seals between the piping and the container, as well as finding a proper way to keep the upper spigot secure, to keep it from turning and damaging the seal of the piping at the bottom of the filter.

8.4 Cost

The total production cost for our filter came out to be approximately $90 (see Appendix M). While this is not a large sum of money in the western world, this could make the filter inaccessible for the orphan care centers in Malawi. Since we used an insulated barrel for our water container, we likely wasted unnecessary amounts of money in purchasing it. We paid approximately $50 for our container. If we used a less expensive container, this would make our project more feasible for implementation because it is more affordable. We also investigated the costs of shipping, and determined that shipping the materials for one filter would bring the total cost of the project to about $300.

8.5 Parts Availability

We were unable to determine whether the parts for our filter are available in Malawi. However, we investigated the possibility of shipping parts from the United States to Malawi.

8.6 Ease of Building

As indicated in the construction guide, the process of building the filter is simple. The only power tool we used was a drill, and the design can be put together by two people. If need be, the filter can be built by one person.

8.7 Scalability

This is the first prototype of our filter. Once this filter is implemented, supporting systems such as water holding tanks can be designed around the filter. This is something that would be developed along with mass production of the filter.

9 CONCLUSION

Our task was to create a water filter to provide clean water for volunteers in orphan care centers in Malawi. We decided that team ESPN-8's proposed design of a biosand water filter would best fulfill our criteria. We designed and built a prototype to gauge the feasibility of the filter's implementation. We filled our prototype with water from the Huron River and tested the filtered water for nitrates, nitrates, ammonia, and pH levels. We also tested an altered river water sample for ammonia removal. Team Midwest Engineering ran an ATP Bioluminescence test to determine how much bacteria our filter removed. We found that our prototype removed nitrites, stabilized pH levels, and significantly reduced turbidity and odors. The bacterial count in our filtered water was reduced to a level near that of Ann Arbor's tap water.

The total cost of our project was $112.25 including the $22.99 water testing kit. We purchased the sand and gravel, and used an expensive container. However, this design could be modified to fit the budget of the volunteers by digging for the sand and gravel, and using a different container.

Our limited testing indicated that our filter has the ability to significantly improve the quality of water. We are confident that if the bacteria layer was given more time to grow, the effectiveness of our filter would increase. Our prototype also satisfied most of our criteria. While it has flaws, with minor adjustments, our design could be implemented in Malawi.

10 RECOMMENDATIONS

This section outlines our recommendations for future use of our design.

10.1 Sealants

In our design, we found that a leak developed in our drainage pipe. We attribute this to the use of an incorrect sealant. Future teams working on this project should investigate different types of sealants, seeing as PVC cement did not work effectively for our design.

10.2 Water Holding Tanks

We recommend that two water holding tanks be used with the filter. One tank should be used for clean, filtered water, and another tank used for dirty, unfiltered water. A large holding tank would cut down on trips for water. Dirty water could be kept in the tank and added to the filter as room frees up.

10.3 Diffusion Plate

When water is poured straight into the filter, there is a potential that sand will be stirred up, which could upset the schmutzdecke. This problem could be prevented through the development of a diffusion plate to be placed above the sand. A diffusion plate breaks up the stream of water, decreasing the force of water hitting the sand at one point.

10.4 Investigating Availability of Parts

Since we were unable to determine whether or not all the components of our filter could be purchased in Malawi, a future team working on this project should investigate this.

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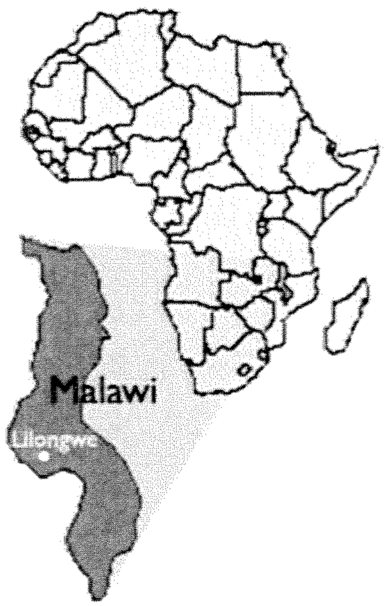
APPENDIX A: Maps of Malawi



(30-Hour Famine)

(Malawi, 2008)

APPENDIX B: Additional Information on Malawi

In southern Africa, the HIV/AIDS epidemic is spreading with frightening speed. It is estimated that by 2010 the number of children whose parents die from this disease will double to 20 million. If this calculation proves accurate, orphans would account for 12 percent of sub-Saharan Africa's child population (Beard, 2005).

Malawi has a population of approximately 13.6 million people. Approximately 46.1 percent of the population is under the age of 15. In 2005, the number of orphaned children was estimated to be over 1 million. Sixty percent of these orphans lose parents through AIDS. By the end of 2001, roughly 15 percent of the adult population was living with HIV (Beard, 2005).

APPPENDIX C: Water Quality Standards

	W.H.O	Ground water (dry)	Ground water (wet)	Surface water (dry)	Surface water (wet)
Turbidity	**5 mg/L**	12 mg/L	114 mg/L	4 mg/L	408 mg/L
Iron	**1 mg/L**	-	-	2.3 mg/L	4.03 mg/L
Coliform	**0 /mL**	190/100 mL	9500/100 mL	2900/100 mL	4600/100 mL

As indicated by this chart, the levels of select substances in Malawian water do not meet the standards set by the World Health Organization. Also, the fluctuations in the levels of the substances between Malawi's dry season and wet season can be seen.

(Palamuleni, 2002)

APPENDIX D: Alternate Filter Solutions

The chart below was taken from Team Kings of the Hill's Fall 2007 report.

	UV Filter	Rapid Sand Filter	Bio-Sand Filter	Clay Filter
Removes Bacteria	Yes	No	90%	99.88%
Removes Turbidity	Yes	No	Yes	Yes
Ease of Use	Medium	Easy	Medium	Easy
Material Availability	Available	Available	Available	Available
Maintenance	Low	Medium	High	Low
Rate of Filtration	Very Slow	High	Medium	Medium

This chart compares several different methods for cleaning water.

APPENDIX E: Heavy Metals in Water

Lead is a heavy metal that causes nerve damage with long-term exposure. It is a common threat to clean water in Malawi since most African countries still use leaded gasoline. Arsenic is a common element in the Earth?s crust. It is a natural poison to humans and is an extremely potent carcinogen. It is a threat in Malawi because well water is a main source of water in Africa (World Health Organization, 2006).

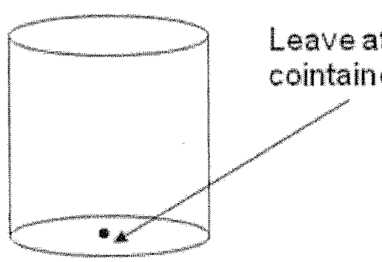
APPENDIX F: Construction Guide

Directions for Building a Biosand Water Filter

1. Parts List
   - ½" diameter PVC piping (about 10ft.)
   - plastic barrel-type container (preferably no more than 1 ½' in diameter and at least 2 ½' high)
   - lid or cover for container
   - PVC cement and primer
   - caulk
   - gravel (at least ½" particles, need enough to fill bottom 4" of container)
   - coarse sand (no more than 1/8" particles, used to fill about 1/3 of container)
   - fine sand (less than 1/16" particles, used to fill about 1/3 of container)
   - fine mesh netting (ex: mosquito netting, should be enough to cover top of container)
   - saw
   - drill with approx 1/8" bit and ½" bit
   - one ½" T- connector and one ½" L-connector for the PVC piping.
   - measuring tape

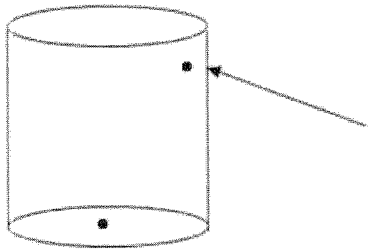
2. Drill holes in container
   - one ½" hole needs to be drilled at the bottom of the wall of the container
   - one ½" hole needs to be drilled at the top of the wall of the container
   - It is better to make these holes too small rather than too big!

<u>Bottom Hole</u>



Leave at least 1 ½" of space from the bottom of the cointainer

<u>Top Hole</u>

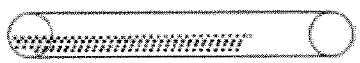


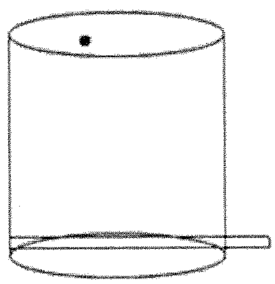
Top hole should be at least 2" from the top edge. Eventually, the sand will come up to this level. Make sure the bottom hole and top hole are not aligned vertically with each other.

3. Bottom Drainage Pipe

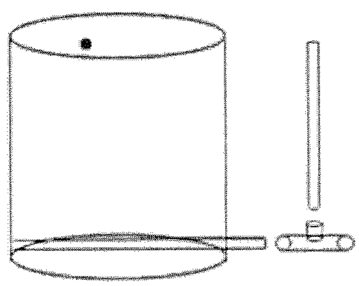
- A drainage pipe will be run through the bottom of the container.
- Test the size of the bottom hole by sliding the PVC pipe into the hole. The fit should be snug. If the pipe does not slide in the hole, use the drill to grind the edges of the hole, taking care not to make it too big.
- It is better to make your hole too small rather than too big. It is difficult to plug an excessively large hole.

<u>Making the drainage pipe</u>

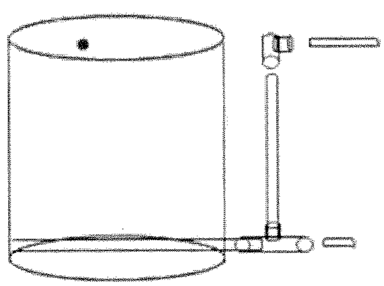




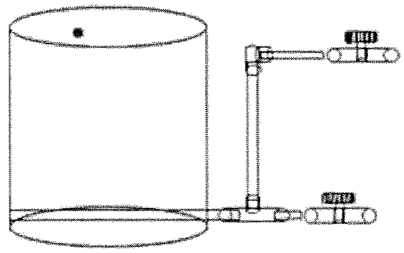
- cut a length of PVC pipe that is about 2" longer than the diameter of your container.
- using the smaller drill bit, drill holes on the bottom half of the pipe, spaced about ½" apart. Only drill holes from one end to approximately 1-2 inches less than the diameter of the container, so that water will not leak outside of the container.
- place the PVC pipe in the bottom hole, and put enough gravel on the bottom of the container to keep the pipe horizontal. Do not glue the pipe yet.



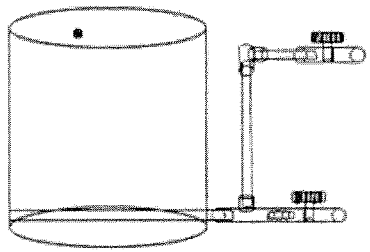
- cut another length of PVC pipe, to the length of the holes drilled in top of the container.
- connect this tube to the middle of the T-connector, and connect the other end to the drainage pipe.
- once a proper fit is ensured, disconnect the parts, apply primer, and glue the parts together. Do not glue the drainage pipe onto the container yet.



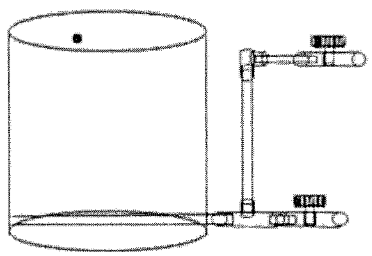
- cut one 3" and one 6" length of pipe
- connect the top tube and the 6" piece to a L-connector
- connect the 3" piece to the T-connector
- once a proper fit is ensured, disconnect the parts, apply primer, and glue the parts together. Do not glue the drainage pipe onto the container yet.



- connect a spigot at the end of the 3" pipe and the 6" pipe
- once a proper fit is ensured, disconnect the parts, apply primer, and glue the parts together. Do not glue the drainage pipe onto the container yet.



- attach pipe to side of container

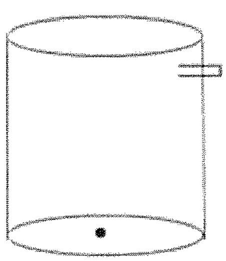


- if at this point the drainage pipe fixture tips forward, add gravel on top of the pipe to keep it in place.
- once the pipe is stable and remains in place, apply primer and glue the drainage pipe to the connector.
- when the glue has dried, apply caulk to the seal. This is a crucial seal and care should be taken to avoid leakage.

4. Top drainage hole

- a spigot needs to be attached to the top of the filter to aid in cleaning and maintenance of the filter

<u>Top Spigot</u>



For clarity, drainage pipe is not shown

- cut a 3" piece of PVC piping and test for its fit through the top hole. No more than ¾" of the tube should be inside the container.
- once a proper fit between the pipe and the hole is ensured, apply primer and glue the pipe onto the container.
- once the glue is dry, apply caulk to the seal.

APPENDIX G: Pictures of Filter Prototype

Figure 1: Our basic supplies

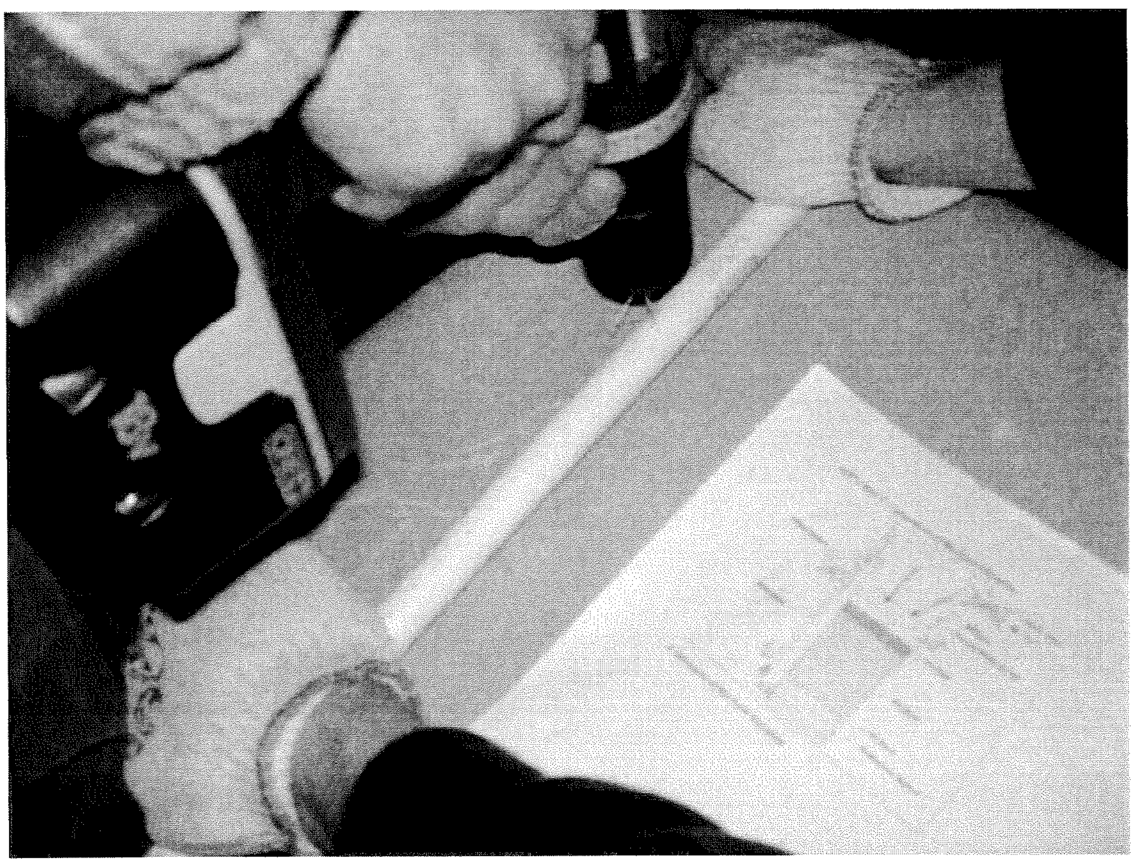


Figure 2: Drilling our bottom pipe

Figure 3: Our finished pipe

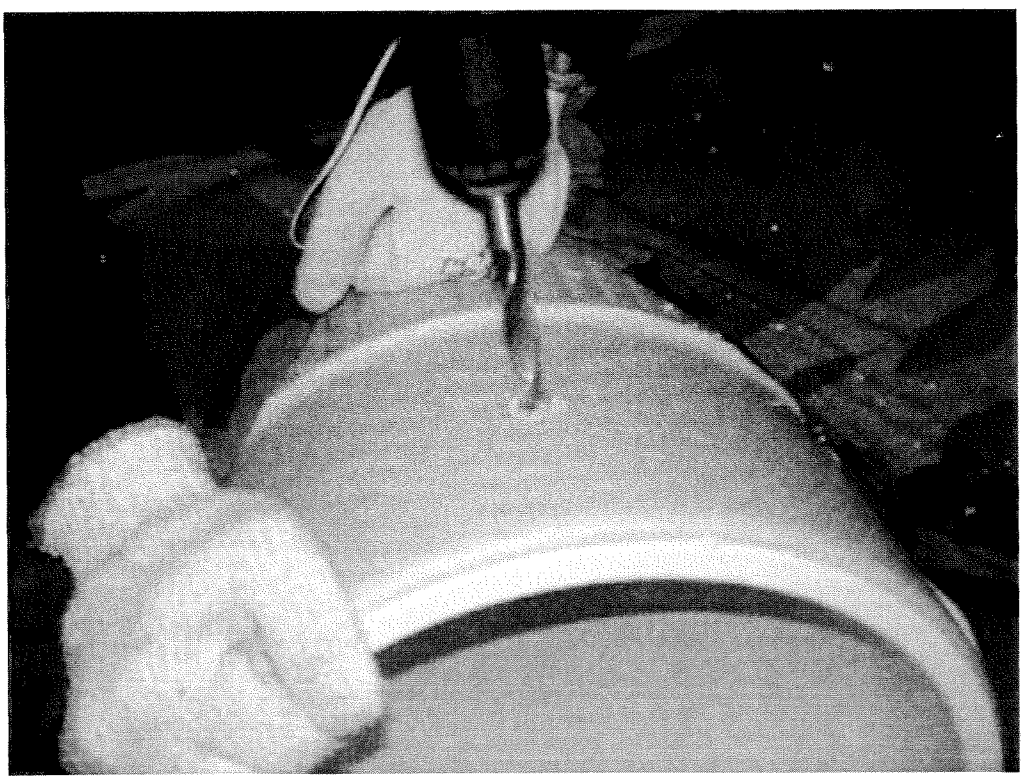


Figure 4: Drilling the top drainage hole

Figure 5: Our finished pipe prototype

Figure 6: Overview of spigots

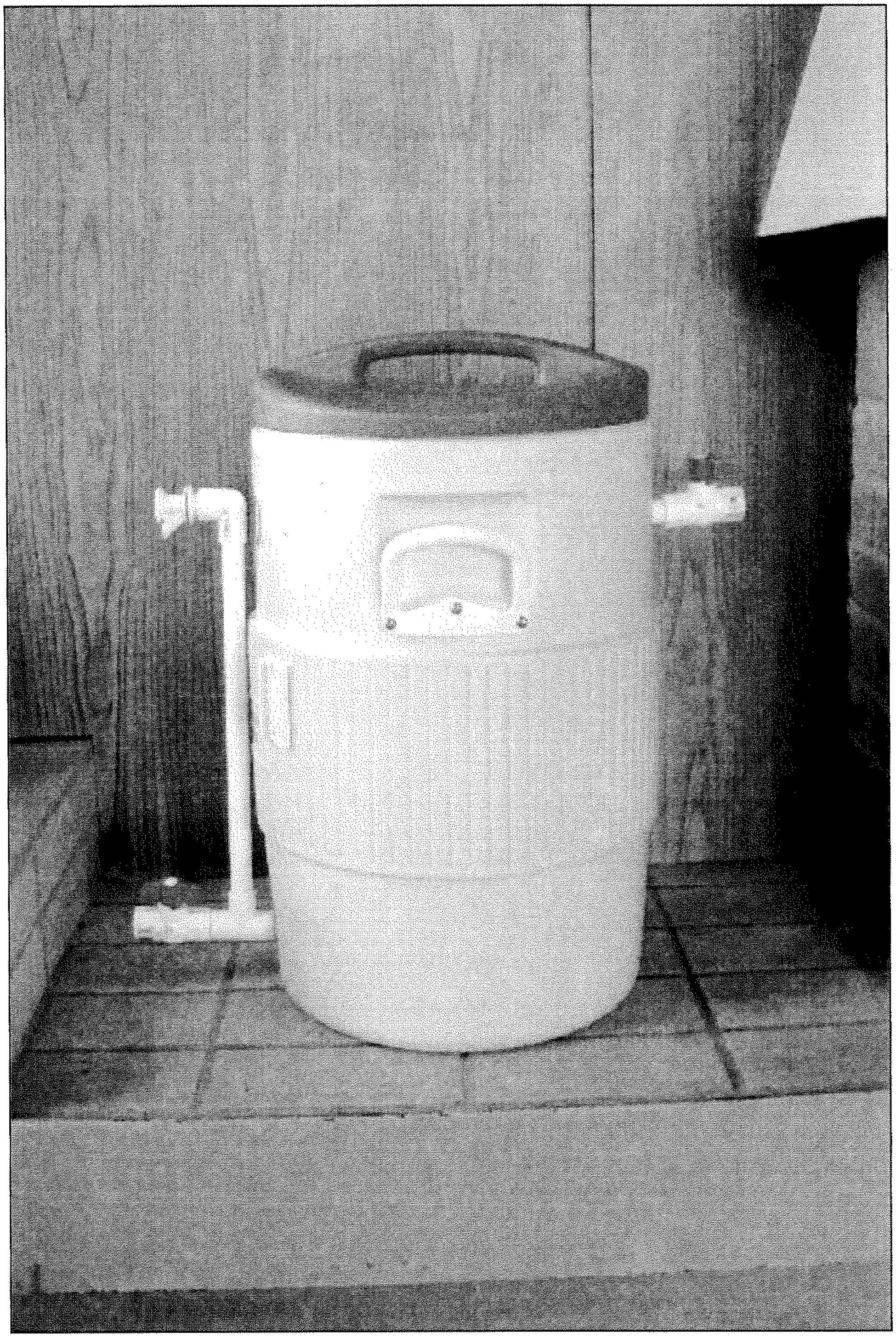
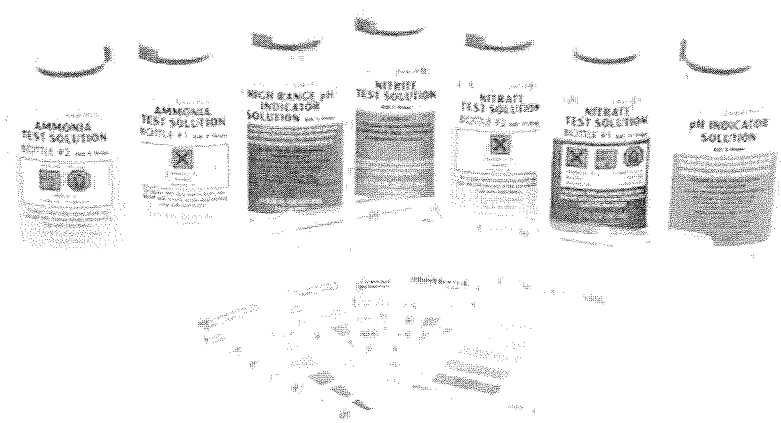


Figure 7: Our prototype

APPENDIX H: Water Testing Kit

The water test kit from Aquarium Pharmaceuticals includes four test tubes, and seven reagent bottles. Overall, it can test for low-end pH (freshwater), high-end pH (saltwater), ammonia concentration (0-7 mg/L), nitrite concentration (0-5 mg/L), and nitrate concentration (0-160 mg/L).



(Pet.Imageg.net)

APPENDIX I: Midwest Engineering's Water Testing Details

This section was provided to us by team Midwest Engineers. Please see their report for full analysis.

7.0 TESTING FOR BACTERIA USING ADENOSINE TRIPHOSPHATE BIOLUMINESCENCE

ATP Bioluminescence is a method of testing for the amount of bacteria in water, and will be elaborated upon in this section

7.1 Finding our Testing Method

We initially contacted the Environmental and Water Resources Engineering (EWRE) department and emailed and called various people. We finally got in contact with a man named Dr. Rolf Deininger. He is a retired professor from the University Of Michigan, School Of Public Health. Dr. Deininger, along with JiYoung Lee, developed this method of testing for bacteria with ATP bioluminescence. After various emails and phone calls, Dr. Deininger was very happy to help us obtain contaminated water to test and also supply us with a testing kit.

7.2 Background of testing method

ATP bioluminescence is a process that finds the bacterial populations in a sample amount of water within minutes and it can be performed anywhere. This method of testing is a great improvement over previous methods that required upwards of one hour, one liter of water, and has a high sensitivity of 100,000 cells. This new method is over 100 times more sensitive, requires a much smaller amount of water, and can be completed in minutes (Deininger, 2005).

7.3 Microluminometer and bacteria count

A microluminometer is a small, portable device that records the light emission from the ATP of living samples over a 10-second interval and integrates the light impulses. The microluminometer can detect amounts of bacteria as low as 0.2 picograms, corresponding to 200 bacterial cells and outputs the data accordingly. The result is output as relative light unit per milliliter (RLU/ml) which gives an accurate count of bacterial ATP in the sampled water. The amount of ATP is directly proportional to the number of bacteria therefore the number output is the amount of bacteria in the sample. (Deininger, 2005).

7.4 SRA, BRA, and Luciferin-Luciferase Application

A somatic cell releasing agent (SRA) is mixed into the sample of water and lyses all non-bacterial cells and releases their ATP. Air pressure is then used to remove the non-bacterial ATP so only bacteria remains in the Filtravette™, which is a combination of a cuvette and a filter with a pore size of 0.45 microns. The bacterial ATP is still inside the bacteria itself so the Filtravette™ is placed into the microluminometer and the bacterial cell-releasing agent (BRA) is added to lyse the bacterial cells. There is now only bacterial ATP left in the Filtravette™. 50 μL of luciferin-luciferase is then placed into the Filtravette™ and the drawer of the microluminometer, which holds the Filtravette™ is closed so the test can occur (Deininger, 2001).

7.4.1 Luciferin-luciferase

Luciferin is a solution that sensitizes, or induces the condition of hypersensitivity, when UV light in the range of 310–390 nm is applied. With histidine, an amino acid, or dithiothreitol, a redox reagent, as a substrate, a type II photo-oxidation occurs. Then an ATP-driven luciferin-luciferase reaction occurs (Steveninck, Boegheim, Dubbelman, 1986). Luciferase uses the ATP of a living sample to activate the luciferin, and the resulting product combines molecularly with oxygen. This now becomes an excited-state of the luciferin-luciferase and is called oxyluciferin. When oxyluciferin relaxes back to its ground state, it releases light, resulting in bioluminescence. Researching how fireflies emit light led to the discovery of this method, and that the luciferin luciferase was created, reacted, and then relaxed to give off energy in the form of light (Pepling, 2008).

7.5 Water Sample

To obtain our sample of contaminated water, Dr. Deininger set up an appointment for us to visit the Ann Arbor Waste Water Plant. There we learned about the various parts of the water treatment plant, how they remove sludge and objects from water, and how they disinfect their water. Afterwards, we were allowed to take samples of the water. We obtained our water from the secondary effluent, which is after the point where all the sludge has been removed, but the bacteria still mostly remains. We then took the water back to Mary Markley Hall where Dr. Deininger showed us the test for bacteria count with the microluminometer so that we could perform the test correctly.

7.6 Testing contaminated water

To test our water we first obtained our supplies. We used a pot, cups for samples, a timer, and the testing kit supplied by Dr. Deininger. We set up the experiment by first pouring the water into the pot and set the stovetop oven to high to start boiling the water. We took samples of the water at one-minute intervals to determine the bacteria count as the water heated. We took samples until the time reached ten minutes since the water had already boiled for five minutes. By the time when the test was finished, all bacteria should have been killed by heat and remaining water purified. We then tested each sample of water from the different time intervals with the bioluminescence process.

For the first five minutes of heating, we realized that the count of bacteria followed no pattern. From one test (around 2 minutes since heating began) we measured an amount of 3,650 bacteria per milliliter, much higher than the initial count of the raw water, yet the minute after that the water had 1,785 bacteria per milliliter, less than before. At the point where the water began to boil, around five minutes after heating began, the bacteria count decreased, from a maximum of 4,010 at five minutes, and finally stopped at 420 bacteria per milliliter, which is acceptable for drinking water. We determined this by testing the completely purified water from the water treatment plant and it had 200-300 bacteria per milliliter.

After these strange results we later tested a sample of water straight from the Huron river. The initial count we received for the amount of bacteria was 921 bacteria per milliliter. We ran the test and still had strange results. The bacteria count fluctuated from 380 to 1,430 over the first few minutes before it began to boil, but once again it settled down and the final bacteria count was 144, even better than the purified water from the waste water plant.

From this data we have determined that if the water is boiled in a solar oven that meets the specifications given by Mt. Hillox's design, the contaminated water in Malawi can be made safe for the volunteer teachers to drink. We also concluded that bioluminescence is a process that can be used in Malawi to help determine suitable water sources.

7.7 Errors and suggested improvements

There were a few errors we encountered when testing the water that we boiled. The first problem was making sure the container of contaminated water is well shaken before testing. Shaking the contaminated water ensures that the bacteria will not have settled in the water sample and will be distributed throughout the water. We realized this by getting faulty readings when taking the raw and clean samples. We also got some unreasonable numbers for the number of bacteria in the water during boiling because the bacteria had settled. For our second test where we had tested the water straight from the river, we shook it up but still ended up having weird results. Fortunately this time the deviation wasn't as high.

Another idea we had was that as the water heats up, the bacteria floats to the top, causing a higher concentration at the top right before they start to die. This is based off of the fact that living things tend to float up to the surface when they are dying or dead. Stirring the water while it is being boiled in the pot is also a necessity because convection causes the settled bacteria to slowly separate causing the bacteria levels to vary thus samples can vary. We learned this after our second test, and therefore for future testing, more accurate results will be obtained if the water is stirred before taking a sample of the water out.

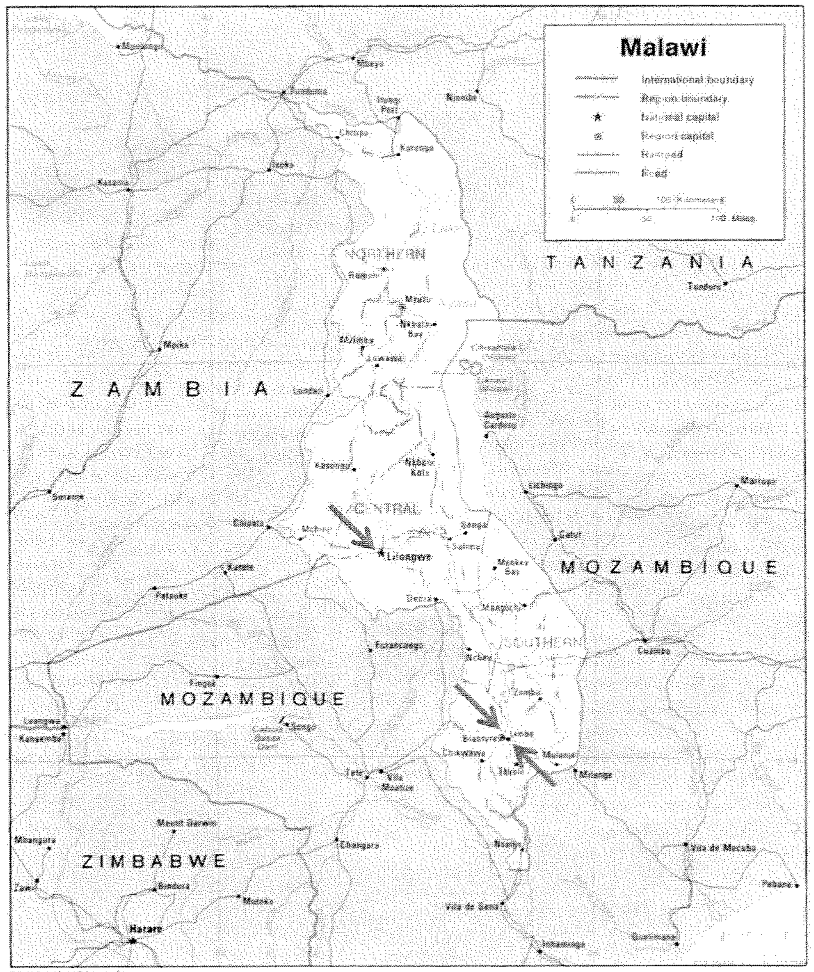
APPENDIX J: List of Hardware Stores in Malawi

Company		Description	Address	Contact
1	Highland Hardware And General Store		P.O Box 5303,,,Limbe	T: 01-645 912
2	Imd Trading House	Dealers in hardware, electrical products and accessories, building materials, motor accessories	P.O Box 289,Armitage Road,,Lilongwe	T: 01-754 656 F: 01-755 350 E: lmd@malawi.net
3	Metro	Dealers in hardware, electrical, agricultural, plumbing, sanitaryware, tyres, tubes& batteries	P.O Box 2275,,,Lilongwe	T: 01-724 847 F: 01-724 857
4	Riz-Tex Suppliers	Hardware, electrical, stationery	P.O Box 1436,,,Blantyre	T: 01-621 903 F: 01-623 139 E: riztex@globemw.net
5	Universal Trading	Suppliers of hardware, electrical and stationery items. Also agents for Forklift tyres	P.O Box 51102,,,Blantyre	T: 01-644 112 F: 01-645 251

(yellowpagesmw.com, 2008)

APPENDIX K: Locations of Cities with Hardware Stores

The map below shows locations of the cities in which there are hardware stores in Malawi. Arrows have been added to the map.



(Malawi.jpg, 2007)

APPENDIX L: Shipping Costs

Shipping from University of Michigan, Ann Arbor, MI 48109 to Lilongwe, Malawi
Assuming a customs value of 70 USD, weight of 10 lbs., dimensions of 18 x 16 x 24 in.

UPS:	UPS Worldwide Saver	$912.60
	UPS Air Freight Consolidated	$179.42
DHL:	DHL Worldwide Priority Express	$977.89
FedEx:	International Economy	$705.78

APPENDIX M: Cost Analysis

Item	**Price**
10' PVC Pipe	$1.52
1/2" Ball Valve	$1.93
3/4" Ball Valve	$2.94
2 50lbs bags all purpose sand	$5.74
3 50lbs bags all purpose gravel	$7.74
1 50lbs bag of commercial grade	$3.59
8oz bottle of PVC cement and primer	$5.96
Igloo 10 gallon cooler	$53.49
Aquarium Pharmaceuticals freshwater test kit	$22.99
TOTAL w/ tax	$112.25

APPENDIX N: Email to Professor Daida Requesting Funds

Date: Thu, 20 Mar 2008 21:38:40 -0400 [03/20/2008 09:38:40 PM EDT]
From: nillam@umich.
To: Jason Daida <daida@eecs.umich.edu>
Cc: Hulloa100@umich.
Subject: Updated parts list
Headers: Show All Headers
Professor Daida,

we now have the information for the container as well as a water testing kit. This is the updated parts list:

HOME DEPOT:
one 10ft long 1/2" pvc pipe for $1.52
one 1/2" ball valve for $1.93
one 3/4" ball valve for $2.94

two 50lb bags of all purpose gravel for 2x$2.87 = $5.74
three 50lb bags of all purpose sand for 3x$2.49 = $7.74
one 50lb bag of commercial grade fine sand for $3.59

one 8oz bottle of PVC cement and primer for $5.96

GFS:
one Igloo Container, 10 Gal, 3 ft. tall $53.49

PETSMART:
one Aquarium Pharmaceuticals freshwater master test kit $22.99

total: $105.9
with tax: $112.25

What is the next step? can we go and purchase these things or do we need to do something else first?

thank you,

-Nilla Majahalme
Team Hulloa

APPENDIX O: Email Communication with Midwest Engineering

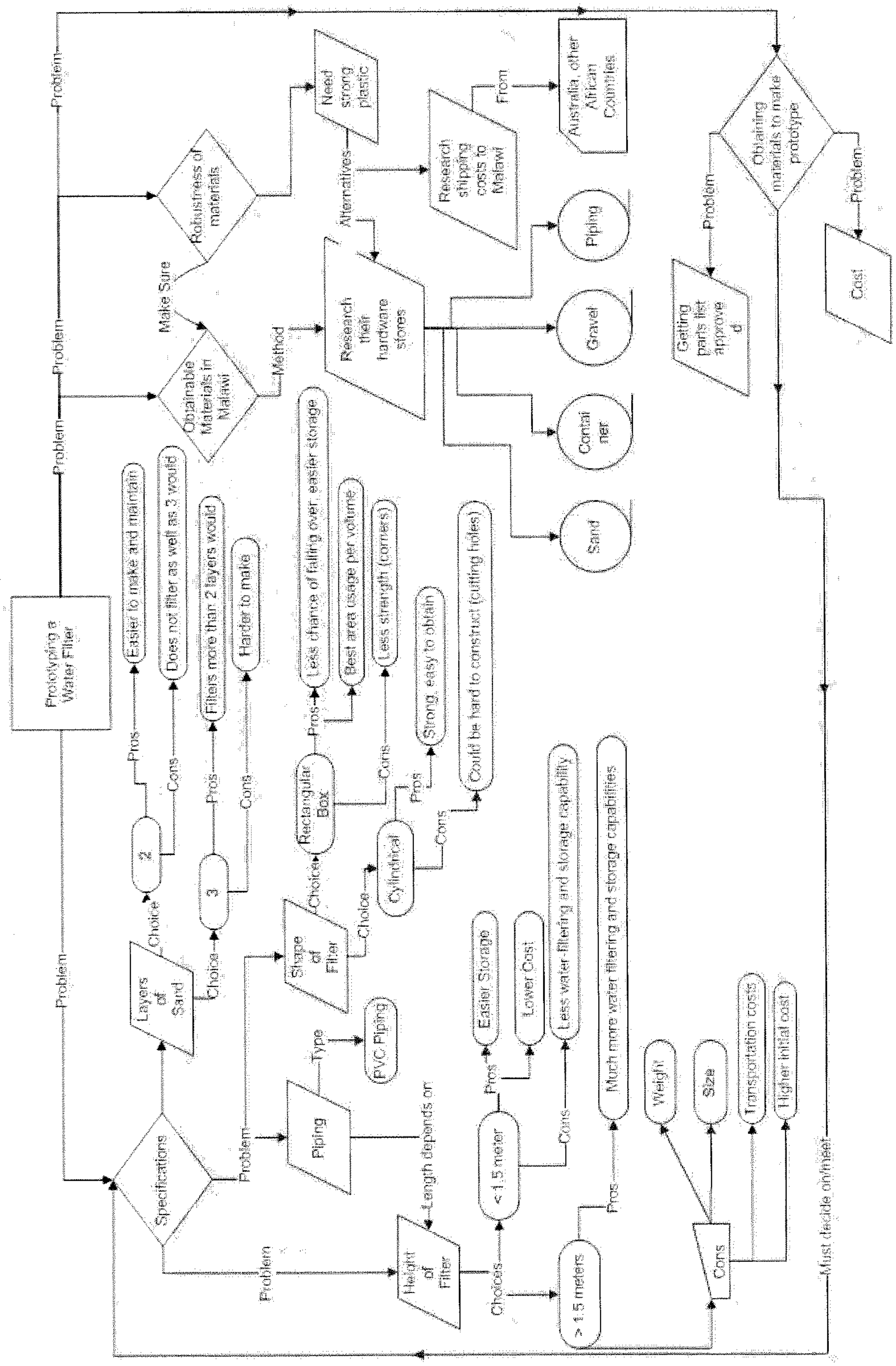
Date: Mon, 31 Mar 2008 12:40:38 -0400 [03/31/2008 12:40:38 PM EDT]
From: nillam@umich.edu
To: strenary@umich.edu, blceng@umich.edu, ajjessop@umich.edu, mreinker@umich.edu, aujean@umich.edu
Cc: Hulloa100@umich.edu
Subject: Team Hulloa's water filter
Headers: Show All Headers

Hi,
I'm just giving you a quick update on our filter.
You probably got a pretty good feel for our design during the symposium on Saturday, but we have a few updates. We added water from the river to test it on Sunday, and our caulking seal failed, so we are going to reglue it tonight and hope it works. So best case scenario would be that you can run turbidity tests on it starting Tuesday...
Also, do you have an update on the water situation?

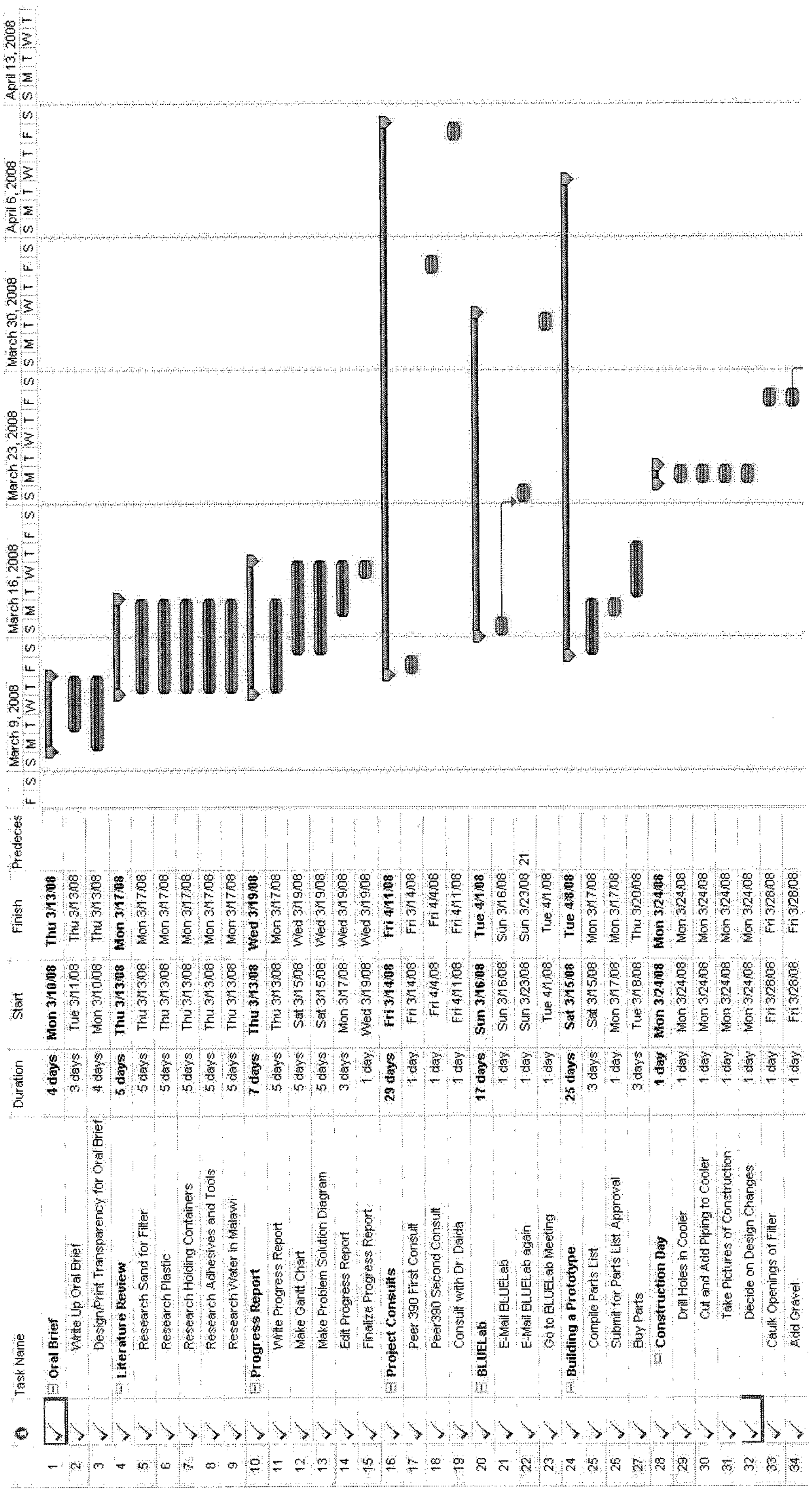
Let us know when you are interested in testing the filter and we will try to find a time that works.

-Nilla
Team Hulloa
Hulloa100@umich.edu

APPENDIX P: Problem-Solution Diagram



APPENDIX Q: Gantt Chart



35	✓	Add sand to filter	1 day	Sun 3/30/08	Sun 3/30/08	34
36	✓	Get water for filter	1 day	Sun 3/30/08	Sun 3/30/08	
37	✓	Seal Filter with Adhesive	1 day	Sun 3/30/08	Sun 3/30/08	
38	✓	Add Water to Filter	1 day	Sun 3/30/08	Sun 3/30/08	37
39	✓	Check Prototype for Flaws	1 day	Mon 3/31/08	Mon 3/31/08	35,38
40	✓	Make Decision on Leaky Filter	1 day	Mon 3/31/08	Mon 3/31/08	
41	✓	Attempt To Fix leaks in filter	1 day	Tue 4/1/08	Tue 4/1/08	40
42	✓	Look at Integrating a Diffusion Plate	1 day	Sat 4/5/08	Sat 4/5/08	
43	✓	Build a Diffusion Plate	1 day	Sun 4/6/08	Sun 4/6/08	
44	✓	Evaluate Diffusion Plate	1 day	Mon 4/7/08	Mon 4/7/08	
45	✓	Get extra containers for water	1 day	Tue 4/8/08	Tue 4/8/08	
46	✓	Get water for filter again	1 day	Tue 4/8/08	Tue 4/8/08	
47	✓	**Winter Symposium Preparation**	**7 days**	**Sun 3/23/08**	**Sat 3/29/08**	
48	✓	**Make PowerPoint for Symposium**	**6 days**	**Sun 3/23/08**	**Fri 3/28/08**	
49	✓	Sarah - Write Background	6 days	Sun 3/23/08	Fri 3/28/08	
50	✓	Nilla - Write Criteria	6 days	Sun 3/23/08	Fri 3/28/08	
51	✓	Adam - Write Design	6 days	Sun 3/23/08	Fri 3/28/08	
52	✓	Alex - Write Synthesis/Design	6 days	Sun 3/23/08	Fri 3/28/08	
53	✓	Tom - Write Implementation	6 days	Sun 3/23/08	Fri 3/28/08	
54	✓	Rehearse for Symposium	1 day	Fri 3/28/08	Fri 3/28/08	
55	✓	Hand in presentation	1 day	Fri 3/28/08	Fri 3/28/08	
56	✓	Winter Symposium	1 day	Sat 3/29/08	Sat 3/29/08	
57	✓	**Evaluating our Filter**	**5 days**	**Tue 4/8/08**	**Sat 4/12/08**	
58	✓	Midwest Engineer's Water Test	4 days	Tue 4/8/08	Fri 4/11/08	
59	✓	Water Testing with Testing Kit	1 day	Sat 4/12/08	Sat 4/12/08	
60		**Final Report**	**11 days**	**Sat 4/5/08**	**Tue 4/15/08**	
61	✓	Sarah - Write Background	8 days	Sat 4/5/08	Sat 4/12/08	
62	✓	Nilla - Write Criteria	8 days	Sat 4/5/08	Sat 4/12/08	
63	✓	Nilla - Make Construction Guide	8 days	Sat 4/5/08	Sat 4/12/08	
64	✓	Adam - Write Design	8 days	Sat 4/5/08	Sat 4/12/08	
65	✓	Adam - Make Pictures for Report	4 days	Wed 4/9/08	Sat 4/12/08	
66	✓	Alex - Write Synthesis/Design	8 days	Sat 4/5/08	Sat 4/12/08	
67	✓	Tom - Write Implementation	8 days	Sat 4/5/08	Sat 4/12/08	
68	✓	Brainstorm Conclusion	1 day	Fri 4/11/08	Fri 4/11/08	
69	✓	Brainstorm Recommendations	1 day	Fri 4/11/08	Fri 4/11/08	
70	✓	First Draft Final Project	3 days	Sat 4/5/08	Mon 4/7/08	
71	✓	Second Draft Final Project	3 days	Mon 4/7/08	Wed 4/9/08	
72	✓	Finish Gantt Chart	2 days	Sat 4/12/08	Sun 4/13/08	
73	✓	Compile Appendicies	9 days	Sat 4/5/08	Sun 4/13/08	
74	✓	Fix Citations	1 day	Sun 4/13/08	Sun 4/13/08	
75	✓	Final Draft Final Project	3 days	Fri 4/11/08	Sun 4/13/08	
76		Turn in Final Project	1 day	Tue 4/15/08	Tue 4/15/08