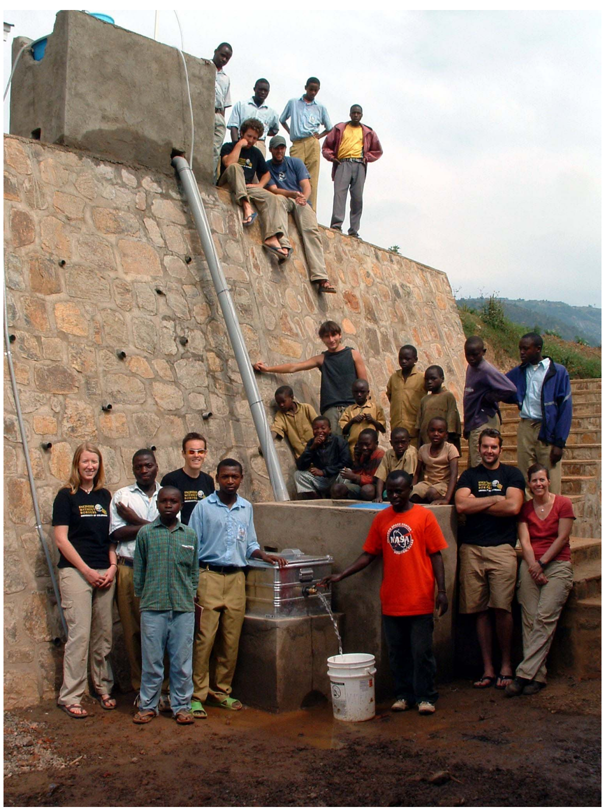
Mugonero and Muramba, Rwanda: June 2006

Addressing Public Health Challenges Through Education, Appropriate Water Collection and Treatment, and Biogas Generation Projects



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1.0 INTRODUCTION

1.1 Project Description

The Engineers Without Borders-USA team from the University of Colorado at Boulder and the NASA-Johnson Space Center returned from their most recent trip to Rwanda in June 2006.

After six team members attended the International Conference of Engineers in Yaounde, Cameroon and presented alongside EWB-Cameroon about their work in Rwanda and EWB-USA's work around the world, they headed to Kigali and were joined by other members.

The team consisted of Max Gold, Kate Beggs, Iain Elliott, Meg VanSciver, John Jannetto, Niko Kalinic and Evan Thomas from EWB-CU, plus Richard and Jo Byyny, Bob Kelly and Kurt Velguth from CU-Denver. We were joined in Rwanda by a team from EWB-JSC including Heather Paul, Dan Garguilo and Remi Canton. Our Rwandan partners included Peter Muligo and JP Habanabakize.

The team headed up to the Mugonero Hospital in Kibuye, Rwanda on June 13th. The EWB-JSC team of Heather, Dan and Remi installed a 10,000 liter rainwater catchment system on the main hospital building. The piped hospital water supply is prone to supply issues, and this new RWC system will assist the hospital to have a more reliable water supply.

Meanwhile, the EWB-CU team worked alongside the Kigali Science and Technology University (KIST) to install a family scale demonstration biogas reactor. The system takes animal waste and captures the methane produced to burn for cooking needs. The system can produce enough gas to boil up to ten liters of water per day, and the effluent waste is a safer fertilizer. Installed near the hospital canteen and kitchen, the system will assist one family while demonstrating the technology to a wide audience. Funding permitting, this project may lead to a large scale reactor for the benefit of the whole hospital using human waste.

Initial plans called for installing a public access water treatment system at the hospital. However, after additional observation of the habits of residents and additional water quality data and interviews, it was decided to install only the UV sanitation light in Mugonero, on the main hospital water supply line. Medical observations by Dr. Byyny suggested this as the most appropriate use of the UV light system. Because the solar panel power supply was designed to provide power for only eight hours per day, a new policy was developed wherein the hospital grid power would be used most of the time, and switched to the solar panel when the power went out. However, the hospital grid power proved to be unreliable, and a surge in the line burned out the UV light ballast on the day of departure for the team. The team discussed this with the hospital administrator, and are in the process of arranging to replace the ballast and ensure the avoidance of this problem in the future. Once operational, the UV light is expected to kill most of the bacteria in the water supply, which is used to dress wounds and other medical care needs.

The EWB-CU team then headed to Muramba, Gisenyi. In Muramba, the team installed an additional biogas system, and installed the complete water treatment system as planned. The Bring Your Own Water system consists of an input bucket on the top of a retaining wall, wherein residents pour turbid and bacteria contaminated water collected from nearby streams and taps. The water is passed through a 55 gallon UN standard drum tilted at 60 degrees and containing PVC tube settlers. A small portion of the water is automatically stored in another drum adjacent for later backwashing, and the rest of the water is passed down the retaining wall to another drum approximately 12 feet below. In the lower drum is six inches of gravel, 24 inches of sand, and another 6 inches of volcanic stone. The water is forced through the rapid sand filter, and then passed into a solar panel powered UV sanitation system. The system is operated by an electronic timer switch that simultaneously turns on the UV light and and electronic valve. The water that is then collected is significantly cleaner than before. Trials in Boulder inputting 1200 NTU and 10^6 bacterial colony-forming-units / 100 ml resulted in a total reduction in bacteria. The initial water quality in Muramba is much better than this, and the team is optimistic that there will likewise be a near total reduction in bacteria in the water.

The team will continue to monitor these projects and improve them over the next several years, and the EWB-CU and EWB-JSC chapters will continue to partner with these communities. During the 2006-2007 season, the EWB-CU team will attempt to address Rain Water Catchment and Higher efficiency stoves projects. EWB-JSC will address the contaminated water that the German NGO's pump is delivering to the school. Please see Section 8.2 of this report for more details.

Funding support for these projects came from UNESCO, the EPA, AmCom Insurance, the University of Colorado at Boulder, Rotary Clubs, EWB-USA and other private and grant donations.

1.2 Background of Project

This project has been in development since June 2003. Background documents are listed below.

"Assessing Engineering Solutions for Muramba, Rwanda," EWB-USA, Spring 2004.

"EWB-USA Muramba Project Health Metrics Survey Report," Frances Feeney, Spring 2004.

"EWB-USA Rwanda: May 2005 Design Report," EWB-USA, May 2005.

"EWB-USA Rwanda: January 2006 Design Report, 'Sustainability Through Stewardship'", February 2006.

"Developing Another World: Mugonero Hospital, Rwanda" EWB-JSC, http://www.ewb-jsc.org/mugonero.htm

"Rebuilding After the Time of the Running", Colorado Engineer Magazine http://cem.colorado.edu/archives/fl2004/rwanda.html

1.3 Professional/Student Chapters Involved

The travel team was composed of University of Colorado at Boulder engineering students Kate Beggs, Iain Elliot, Max Gold, John Jannetto, Niko Kalinic, Meg VanSciver, and Evan Thomas, along with volunteers from the EWB-Johnson Space Center Chapter Heather Paul, Dan Garguilo, and Remi Canton. University of Colorado at Denver volunteers included Chancellor Emeritus Richard Byyny, Jo Byyny, Kurt Velguth and Bob Kelly. Jean Pierre Habanabakize of Rwanda also joined the team. Many other volunteers at CU-Boulder and the Johnson Space Center contributed invaluably to this project.

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2.0 HEALTH ASSESSMENT

The Center for Global Health at the University of Colorado at Denver, represented by CU-Boulder Chancellor Emeritus Richard Byyny, MD, accompanied the Engineers Without Borders-USA team to Rwanda for this implementation trip. Chancellor Byyny provided valuable feedback to the team on the public health of both Mugonero and Muramba and the direction of the appropriate technology projects.

Observations are provided in bulleted format for ease of reading.

2.1 Overview of Community

- Severe poverty with subsistence income for the great majority.
- Health insurance is limited. The government is apparently not able to provide a universal government sponsored health insurance plan. A minority have an employer based or private health insurance. The military are covered by government health insurance. The government sponsors Health Maintenance pre-paid health coverage through cooperatives known as mutuelles. The person pays the modest annual premium each year and then subsidized by government funds covering illness, surgery, and drugs if they are available. They estimate that about 650,000 people of a population of 8.5 million people are in the mutuelles. Most are too poor to pay the annual fees. Without coverage they are required to pay for their care in cash and most have very limited ability.
- There are two major University and School of Medicine teaching hospitals. One in Butare, serving the southern part of the country, and one in Kigali. There are about 17 district hospitals and more health clinics. The teaching hospitals have about 500 beds with services for pediatrics, surgery, obstetrics and gynecology, internal medicine, intensive care, nutrition, radiology, HIV/AIDS, tuberculosis and others. There are almost no subspecialists nor subspecialty services. The laboratory facilities include a basic hematology lab, clinical chemistry, immunology lab, parasitology, microbiology, pharmacy, and radiology with basic x-rays available. Patients are hospitalized in open wards. Patient's families cook at an outdoor open fire for the patients and families often stay with the patient in the hospital during the stay. Some of the hospitals are Catholic or Adventist funded and supported. There is a private hospital, King Faisal Hospital, in Kigali and it has additional specialists and a CT scanner. It also has VIP rooms.
- There are about 240 physicians for 8.5 million people. The medical school and university closed during and after the genocide in 1994. The medical school reopened in 1997. It provides medical school education with a six-year post high school curriculum. The first two years are pre-clinical and the last four are clinical and basic science. They now have about 80 students in a class. High school certifying exam scores determine admission. Most graduates practice as general practitioners.
- Postgraduate medical education – There is a desperate need for specialists in medicine, surgery, anesthesia, obstetrics & gynecology, and pediatrics. These specialists are urgently needed as physicians and medical educators in the teaching hospitals. The government has funded and supported postgraduate, residency, and medical education in these specialties. Last year they funded 50 positions, but only enrolled 36 qualified residents for a four-year program. They have endorsed postgraduate specialty education and training in family

medicine with experiences in pediatrics, obstetrics& gynecology, surgery, orthopedics, caesarian section, trauma, infectious diseases. These specialty physicians would provide care in the district hospitals. They also need additional nurses and educated health professionals to staff health clinics and villages. They can work using algorithms to prevent, diagnose, and treat illnesses.

- Traditional healers – They have an extensive number of traditional healers and because of cost and location patients frequently visit these people before seeking western medical care. No one knows what they use in their treatments, but it usually results in delay for western care and the patient often has too advanced illness to recover.
- Health clinics and hospitals usually admit sick patients despite ability to pay. However, the dispensary often will not provide non-subsidized medication without cash payment.
- Nutrition – Obesity is rare. Severe malnutrition is seen and the teaching hospitals have nutrition services for malnourished children. The diet is mostly beans, corn, sorghum, pineapple, bananas, and potatoes. These are mostly available through subsistence farming.
- Chronic bronchitis – This was an almost universal illness secondary to open fire heating and cooking with wood. Most do not smoke cigarettes.
- Anemia – This was an almost universal illness probably secondary to gastrointestinal parasites with associated dietary and pregnancy related iron deficiency.
- Malaria – Appears to be the most common infectious disease affecting large numbers of children and adults. They believe it is not quinine resistant and is, therefore, treated with oral or intravenous quinine. Diagnosis is made from the clinical story and with malaria blood smears if available. The problem is that many live remotely from any health care facility and they must purchase the drugs if they are not in a mutuelle.
- Diarrhea – For most this is a chronic life long condition starting in childhood. The etiology is complex, but is often due to parasites. Acute diarrheal illnesses are frequent because of contaminated water and may be due to enteropathic ecoli, giardia, amoeba, and others. Teaching hospitals and some district hospitals have laboratories for confirming these illnesses and they have effective medications for treatment. However, the great majority is not treated.
- HIV/AIDS – The population seems informed about HIV infection and the relationship with sexual behavior and transmission. It is estimated that about 6% are infected. The government provides free condoms and they are used, but with uncertain compliance. The information is transmitted by portable radios by government radio stations. Most of the population has access to radio programs. They also have HIV/AIDS education posters in communal facilities. The District Hospitals and some Health Clinics can screen for HIV. If positive, a blood sample is sent to one of the teaching hospitals for ELISA test confirmation and usually for CD4 counts. Most patients with the diagnosis are treated with a WHO 3 drug protocol and drugs are available supported by the Global Fund, WHO, and the government. Drugs are also available to prevent or treat opportunistic infections, e.g. tuberculosis and pneumocystis. However, complicated patients with secondary infections and sequelae from AIDS die.
- Tuberculosis – Tuberculosis is a common disease associated with the chronic bronchitis and HIV/AIDS. X-ray is not commonly available except in the district and teaching hospitals. The diagnosis in the remote locations is based on algorithms. Three drug therapy is available, but it is unclear is it is short treatment observed treatment or not.

- Prenatal care and obstetrics – Pregnancy is very common. Prenatal care is rare and vitamins and nutrition are marginal. With a high pregnancy rate, the rate of complicated pregnancy is high with a great need for caesarian section delivery without the facilities or obstetricians.
- Trauma and wound infections – Minor to major trauma is common and transport is limited. Wound infections are very common and fractures with non-union and disability are frequent.
- Chronic diseases – Type II Diabetes mellitus is not uncommon and treatments are available with oral drugs or insulin. However, they do not have refrigeration and that limits treatment. Testing of blood glucose is also limited. They do have hypertension, pregnancy induced and essential hypertension. Drugs are available for treatment in some health clinics as 3 drug regimens.
- Common diseases – Most common childhood diseases are prevalent. They claim that about 80% of children are immunized, but in the orphanages they were uncertain who was immunized and what vaccines were used.
- Cancer – This is an area of uncertainty. They do diagnose hematologic malignancy, since available hematology laboratories can often do it. The chronic bronchitis frequency makes speculation of lung cancer likely. Coronary heart disease is common if they survive to an older age.

2.2 Potential Impact of Project on Community's Health

Providing clean water, cleaner air, power sources, education, health care, infrastructure, and economic development can prevent most of the diseases. The greatest needs are in engineering solutions, agriculture, economic development, education, and infrastructure development.

Engineers Without Borders – USA has been providing support for remote, poor communities for several years. Their projects have had a substantial impact that is easily observed and documented in these communities.

- Clean Water – In the communities of Mugonero and Muramba EWB-USA has installed rainwater catchment systems with storage tanks for easy community access. They installed rainwater catchment and storage for a Catholic girls school in Muramba. They installed additional rainwater catchment for the District Hospital in Muganero this June. The water this time of year comes to the communities, hospital, and clinic from remote sources of unknown purity and cleanliness. The water this time of year is not turbid as documented by the EWB-USA team. They installed a solar powered ultraviolet water purification system for the hospital and health clinic. This should prevent hospital acquired water borne diseases and wound infections. This should significantly improve medical outcomes for the patients. We performed bacteriologic and parasitic tests on the before and after water samples during the solar powered ultraviolet water purification installation. In the future we will take containers with water preservatives and improved refrigeration for further bacteriologic and parasitic evaluation.
- Power sources – Previously EWB-USA had provided solar powered backup systems for Mugonero Hospital that enable surgery with uninterrupted power and additional illumination for caring for obstetrics and other patients. They had installed solar powered electrical system for the Muramba Health Clinic that enables the health care workers to utilize microscopy for hematology and malaria diagnosis. Record keeping has improved

dramatically with illumination. EWB-USA installed solar powered electricity for the Catholic girls school. This has enhanced the academic environment and supported students studying and learning after day light with improved educational outcomes including graduation.

- Biogas Generators – The team installed demonstration biogas generators at both Mugonero Hospital and the Muramba Health clinic. These were manufactured by the Kigali Institute for Science and Technology (KIST). They are basically made of a lower metal barrel with tubular connections to an upper metal barrel tank. The lower barrel has an intake tube and the upper tube has a valve to release gas. Bioproducts, especially human or animal feces, is delivered into the intake and transported to the lower tank where it undergoes bacterial fermentation producing methane gas that rises to the upper tank and then is available as fuel for heating, cooking or operating a turbine for power generation. The byproduct is relatively odorless, noninfectious, manure for fertilization of agricultural uses. A major benefit was the education and training of students in a technical school in Muramba, who participated in the installations and will be technical support for the systems. This type of fuel generation could remarkably decrease the air pollution and prevent the debilitating effects of wood burning smoke. It also can provide power to provide electricity to the hospitals, clinics, and schools.

3.0 WATER QUALITY RESULTS

The results from the June 2006 water quality tests in Mugonero can be seen below:

Date	Site	UV?	pH	Temp	Conductivity	TDS	Turbidity	Coliform 1:1		Coliform 1:10	
								Total Coliform	E. coli	Total Coliform	E. coli
				Celsius	*microS/cm*	*mg/L*	*FAU*	*CFU*	*CFU*	*CFU*	*CFU*
15-Jun	Kitchen Tap	N	5.30	22.8	36.1	17.8	0	1	0	0	0
16-Jun	Nurse's Station	N	5.90	21.6	37.2	18.5	0	1	0	0	0
20-Jun	Nurse's Station	Y					2	1	0	0	0
16-Jun	Patient Room	N	5.72	21.8	35.5	17.6	0	5	0	0	0
20-Jun	Patient Room	Y					4	0	0	1	0
16-Jun	Surgery	N	5.93	21.0	38.6	19.6	0	2	0	0	0
20-Jun	Surgery	Y					0	0	0	0	0
16-Jun	Maternity	N	6.02	20.6	43.8	22.4	0	2	0	0	0
20-Jun	Maternity	Y					0	1	0	2	0

The general water quality data (temperature, conductivity, TDS, turbidity) as seen above is within EPA regulations and does not directly indicate the need for concern. The pH values are all below the recommended range of 6.5 – 8.5, though not low enough to cause major concern. This should be monitored to assure that corrosion and metal dissolution is not occurring. A possible reason for the low pH would be the nature of the source water which is a combination of surface and groundwater. (Groundwater typically has lower pH than surface water).

From the data above there is some evidence that the UV reactor is effective at removing total coliform, though the data is not completely conclusive. The overall water quality at the hospital before UV treatment was quite good, with little coliform bacterial contamination, which may contribute to the insignificant changes in CFU counts pre and post UV treatment. In 3 out of 4 undiluted water samples, there was a decrease in total coliform CFU counts. As no E. coli was found in any of the water samples, we cannot make a statement about the effectiveness of the UV on E. coli specifically.

From earlier tests, we can feel confident that the UV is able to perform significant removal with similar turbidities. As UV is also known to be effective in destroying pathogens such as giardia and cryptosporidium (Linden, et al. 2002), we can feel confident that any pathogens not found using the Petrifilm tests would most likely have been made inactive by the UV reactor.

Water quality results for the June data falls inline with the data seen in January. While the water quality appears to be good and may not immediately appear to require extensive treatment, we believe that with UV radiation, the water, used for patients in the hospital, will still be significantly improved. Turbidity should be continuously monitored to assure that the UV reactor is able to be as effective as possible.

During interviews with hospital staff we received some conflicting information about the water system. There was mention that the water supply is not always consistent due to problems with the distribution. The water is then shut off to repair the lines, and when it is turned back on the water is often turbid such that the hospital staff let the water run until clear before using it.

The results from Muramba can be seen below:

Date	Site	UV?	pH	Temp	Conductivity	TDS	Turbidity	Nitrates
				Celsius	*microS/cm*	*mg/L*	*FAU*	*mg/L NO3-N*
21-Jun	Clinic Source - Pipe in hill	N	6.00	21.05	98.70	50.80	0.00	4.40
23-Jun	Maternity Tap	N	5.97	22.60	52.00	25.60	0.00	3.30
26-Jun	Esecom Tap	N	5.24	23.30	50.10	24.00	0.00	4.70

			E. Coli 1:1		E. Coli 1:10		E. Coli 1:100	
Date	Site	UV?	Total Coliform	E. coli	Total Coliform	E. coli	Total Coliform	E. coli
			CFU	*CFU*	*CFU*	*CFU*	*CFU*	*CFU*
21-Jun	Clinic Source - Pipe in hill	N	1	0	0	0	0	0
23-Jun	Maternity Tap	N	1	0	4	0	1	0
26-Jun	Esecom Tap	N	6	0	3	0	0	0

Legend for dilutions. (Samples diluted with DI water)

1:1
1:10
1:100

These results show water from a representative sample of taps located nearest to the BYOW system. It is most likely from sources such as these that water will be collected to be poured through the treatment system. Many of these taps had previously been turned off, but were turned on in part due to the extra water being provided by the new pipeline built with the

University of Wisconsin EWB team. It is unclear if these taps will remain on, and questioning did not result in a certain response. Keeping this in mind, surface water quality is much lower and values can be seen in the January 2006 report. All basic parameters for water tested in June are within normal ranges. Again, no E. coli colony forming units were seen, and very little general coliform colony forming units were counted.

Improvements have been made to the Muramba system which we could not completely quantify. During our January visit to Muramba, no taps were turned on in the area, and the water tested at the clinic showed very high counts of both E. coli and general colilform. We will need to continue to investigate the operational practices of the water system as improvements are made.

The BYOW system was installed at the clinic in order to best serve both patients and their families, with special consideration to newborn babies and their mothers.

The data below relates to the BYOW system and shows both pre and post treatment data:

Date	Site	BYOW?	pH	Temp	Conductivity	TDS	Turbidity	Nitrates
				Celsius	*microS/cm*	*mg/L*	*FAU*	*mg/L NO3-N*
21-Jun	Clinic Tap (Admin)	N	6.14	21.80	47.2	23.90	0	3.70
23-Jun	Clinic Tap (Admin)	N	6.15	22.25	51.5	25.50	2	5.00
26-Jun	Muramba Town Tap (up from clinic)	N	5.91	22.60	47.0	23.20	1	3.60
27-Jun	Post UV Clinic Tap (Admin)	Y	6.27	20.45	55.0	28.60	20	3.00
27-Jun	Post UV Test #2 w/o pumice	Y	6.29	19.95	55.0	27.90	2	3.20
1-Jul	Post UV Test #3 w/ pumice	Y	-	-	-	--	3	--

			E. Coli 1:1		E. Coli 1:10		E. Coli 1:100	
Date	Site	UV?	Total Coliform	E. coli	Total Coliform	E. coli	Total Coliform	E. coli
21-Jun	Clinic Tap (Admin)	N	0	0	0.00	0.00	0	0
23-Jun	Clinic Tap (Admin)	N	3	0	4	0	0	0
26-Jun	Muramba Town Tap (up from clinic)	N	6	0	7	0	1	0
27-Jun	Post UV Clinic Tap (Admin)	Y	0	0	0	0	0	0
27-Jun	Post UV Test #2 w/o pumice	Y	1	0	0	0	0	0
1-Jul	Post UV Test #3 w/ pumice	Y	2	0	3	0	0	0

Legend for dilutions. (Samples diluted with DI water)

1:1
1:10
1:100

During the early tests of the BYOW system, we found that, as the sand was not clean, the system was outputting water with a higher turbidity that was input. This can be seen in the first post BYOW test results. After a day of washing sand and adding pumice to the filter, we were able to output water with similar turbidity as the input water.

Again, the bacterial results are slightly inconclusive due to the low counts seen in the pre-treatment water. As the water sits in a settling tank before going through the system, it was difficult to test individual water sources, so all of the post treatment waters are from the clinic administration building tap which was being used to fill the settling tank. In every case, the total coliform counts post-treatment are less than those pre-treatment, indicating that the system is working as intended. We will need to monitor the system and retest continually during different conditions.

References

Linden Karl, Shin Gwy-Am, Faubert Gaetan, Cairns William, Sobsey Mark. *UV Disinfection of Giardia lamblia Cysts in Water*. Environmental Science & Technology, 2002.

4.0 EDUCATION INITATIVES

At the Mugonero Orphanage, several things are being done with education. The concept of the Tippy Tap was introduced on the June trip. One was constructed at the orphanage, and materials for seven units were left behind. The goal was for the idea to be shown, and the work to be customized and carried out by the workers and orphans.

Health education is taught in school to all the children. Many children were observed to be washing their clothes and bodies at all hours during our visits there. There is plenty of soap provided to the children, so it is believed that an easier source of water will help stimulate better hygiene practices.

AIDS is a large problem at the orphanage, with several of the orphans coming from families with both parents deceased from the disease. At the time of our visit, it was unknown how many children actually had AIDS or not. Plans for testing all the children for HIV/AIDS are being formulated by the Orphanage director.

In Muramba, the team is investigating the use of test kits that would allow vocational students and/or The World Changers group to test the effluent water from the BYOW system. This would allow us to have some idea of the filters efficiency as well as help to allow the students to gain experience with testing materials.

This concept falls in-line with the larger goals of the educational efforts of the team; to help the community members feel ownership over the projects through improving their understanding of the project details. During the last trip, several small informal workshops were help in order to teach vocational students and clinic staff about each of the systems at the clinic: solar lighting, biogas, and the BYOW system. Students were involved in each step of the BYOW assembly and were encouraged to ask questions in order to further their understanding. Placards and manuals were provided with each system, as well as additional educational placards for the rainwater catchment system at the Muramba College.

A number of books – some technical, some not were provided through donated books from the Boulder Bookstore, EWB and Professor Bernard Amadei. We left a copy of Appropriate Technology and the Field Guide to Appropriate Technology as well as several handicraft books with Sister Donata and Anne Marie in order to organize a library of engineering resources. The aim of the non-technical books is to help allow the students practice reading English.

We met with the World Changers, a group formed by Muramba College students during the January 2006 visit of EWB-USA, at the Murmba College and discussed possible projects in the future for the group to focus on. We introduced the idea of the Tippy Tap handwashing station to the girls, which they worked on after we left. Unfortunately the team received word that the soaps from the constructed Tippy Taps had been stolen by some of the girls, as many of the girls cannot afford soap for themselves. We are working to find an appropriate solution to this problem that will allow the girls to have access to handwashing stations of some sort. The World Changers have been using shows with skits to make money for future projects. They have lofty goals and are very driven to achieve them.

5.0 MUGONERO RAINWATER CATCHMENT

5.1 Component description

Overview

The rainwater catchment system works by collecting rainwater off of the corrugated metal roof of Mugonero's hospital (main building) using gutters, and directing the run-off to a small 200 liter foul flush tank. This tank collects the first rain of a storm, which is most contaminated with roof material. Once this tank fills up, the column of water in the down pipe feeding the foul flush provides a contamination barrier and directs the rest of the water to the sealed 10,000 liter storage tank. The main tank has an overflow pipe to release extra water, should it be at capacity, thus relieving tank pressure and avoiding a backflow in the pipe system.

The main tank is isolated from contamination, and under some circumstances may be cleaner water to drink than the existing water supply system. However, the Mugonero Hospital water quality is higher than in other communities EWB-USA has tested, and rainwater catchment systems have not been conclusively demonstrated by EWB-USA to provide more potable water than pipelines. Instead, the RWC system in Mugonero provides an additional source of water when the pipeline is known to be contaminated or is not producing enough flow during the dry seasons.

The foul flush tank has a small drain hole to slowly empty the tank after a rainfall in order to be re-used as a filtration system during the next rain shower. The foul flush tank is anchored on its side allowing the top lid to be opened for maintenance (debris removal).

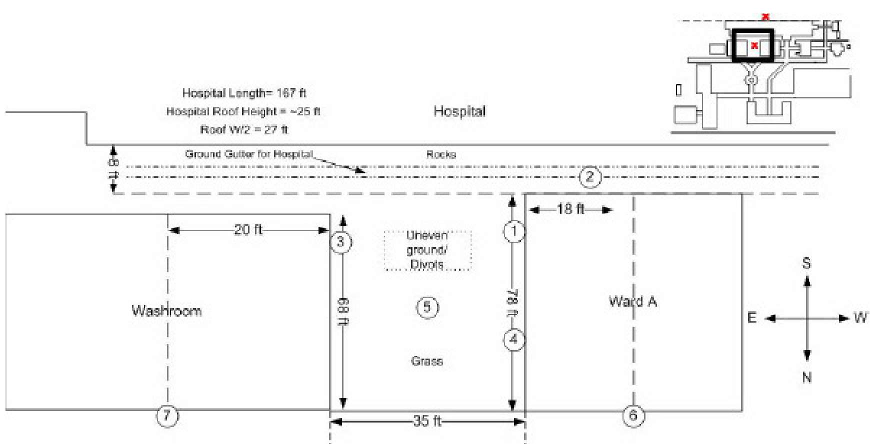
Final RWC Assembly

JSC Chapter preparation

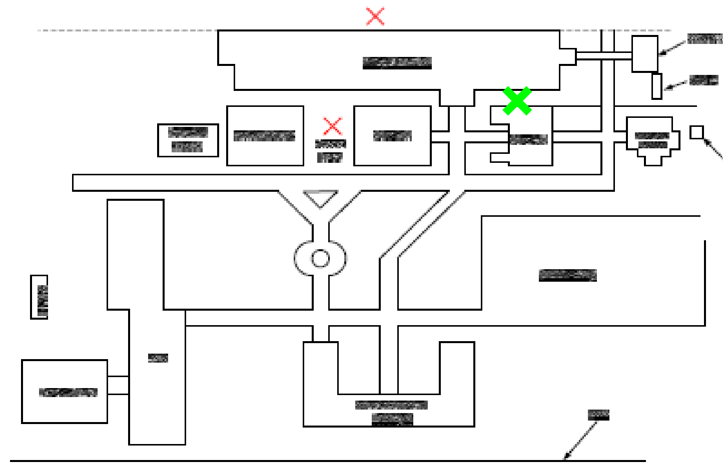
This implementation trip consisted of three engineers from the Johnson Space Center Chapter (EWB-JSC). EWB-JSC chose to develop a rainwater catchment system for the hospital after the May 2005 assessment trip to Mugonero. The professional member team worked together on the different elements of the design (including catchment tank prototype development), in addition to fundraising for the implementation trip. Frequent meetings were held to design and plan the project between May 2005 and May 2006 varying from a monthly, biweekly and weekly basis as the trip approached.

Installation details

The tank was initially supposed to be installed in an open, grassy area between Ward A and the Washroom (see below). This central location would have a means to ensure adequate slope from either ends of the roof to the gutter downspout. However, the hospital administration maintenance staff redirected the team to have the tank installed on the north end of the hospital (see below). This new location would allow easier access for women doing cooking and cleaning near the outdoor cook area. The new location provided two problems: an absence of a level area for placing the tank, and the gutter would now have to run the entire roof length sloped in the same direction. Calculations showed this would require a drop of 1mm for every meter of gutter to fit on the roof fascia.



Initial Location for the Main Collection Tank



Map of Mugonero Complex with Possible Tank Locations from Assessment Trip (Red), and Final Location (Green)

It was determined appropriate to install a fascia bracket every meter to minimize the load on the gutters when filled with water. Due to the very small slope calculated, a chalk line was used to guide the fascia bracket installation. The bracket location and pattern was then marked to facilitate drilling the bracket anchor holes.

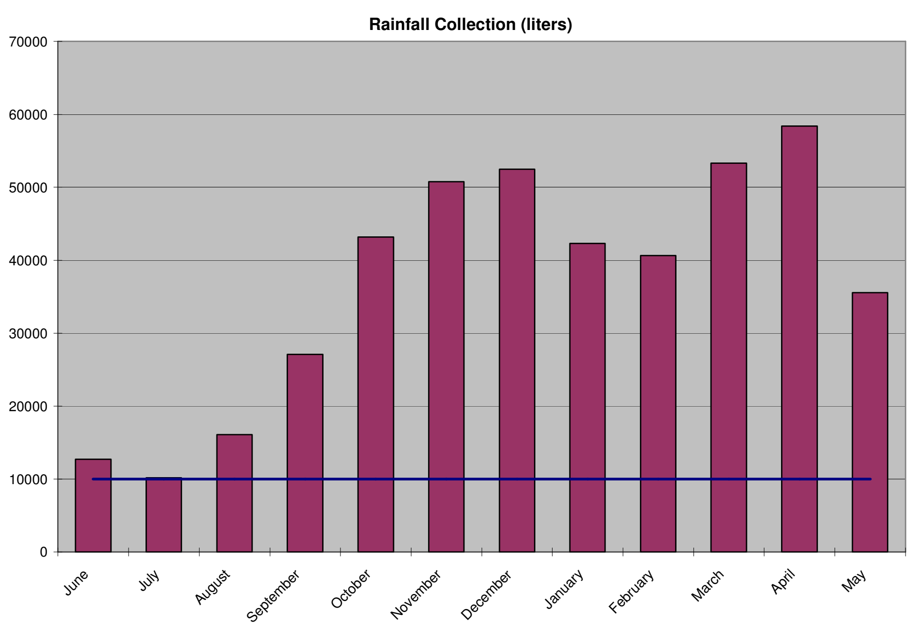
The hospital roof is made of corrugated metal that extends approximately 5 cm past the roof fascia. This provided an optimum overhang for mounting the fascia brackets directly to the metal roof fascia (see photos below).

Fascia Bracket Installation

Collection calculations:

After an assessment in January 2006, the team decided to install the rainwater catchment system on the main hospital building roof as it provides the largest collection surface and would position the distribution system right were the water is used. In addition, the moderate slope of the roof would reduce the risk of water flow over-shooting the gutters during heavy rainstorms. Seeing as the total projected area of the hospital roof was a considerable 9808 sq. ft., and the back side of the hospital roof sat a full two stories off the ground, it was determined that only the front half of the roof would be guttered. As shown below, this would provide sufficient collection for the 10,000 liter storage capacity.

In order to establish a rough estimate of rainwater collection potential, the projected roof area was multiplied by the average monthly rainfall. Assuming losses due to evaporation, leaks, and overshoot were no more than 20%, the monthly collection would be as follows below.



Rainfall Collection Potential

As accurate demand data was not available, it was assumed that all water collected would be used by the community. Therefore, even though storage capacity is limited to 10,000 liters, the system would still be able to provide close 60,000 liters of water during the wettest month of April. Based on this assumption, the system would provide approximately 440,000 liters of usable water annually. Based on the World Health Organization (WHO) standard of 25 liters/day for drinking, sanitation, bathing, and cooking, this system would sustain approximately 48 people on an annual basis—more, when you consider the existing water supply system that the RWC system will be supplementing.

5.2 Materials and Logistics

Prefabricated Tank System

A rainwater collection system with prefabricated gutters and plastic tanks was designed and installed at the Mugonero hospital main building during this implementation trip. In addition to the reasons cited above, the main hospital building has the advantage of being in a highly visible location, is easily accessible, and is in a geographically flat area.

The decision to use prefabricated materials was primarily based on the size of the system, and the limited timeframe available to complete construction and installation. To ensure reproducibility, all materials were bought at local hardware stores in Kigali and brought to Mugonero with flatbed trucks and local drivers.

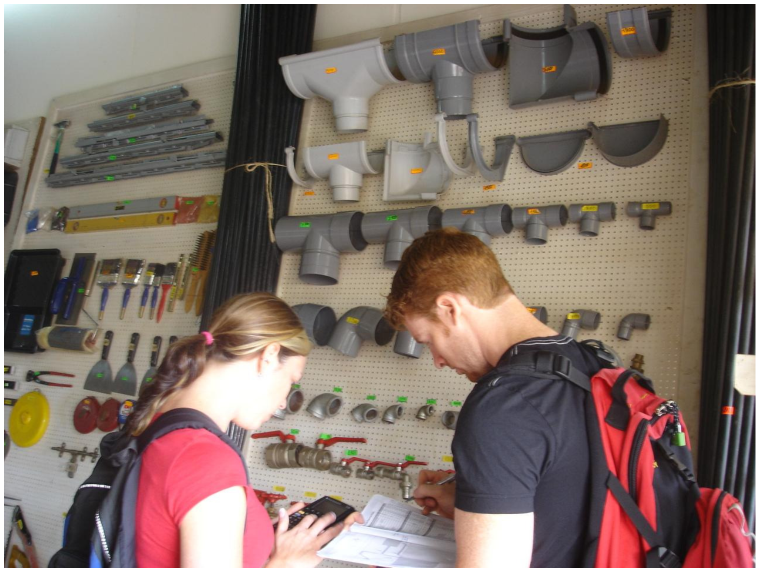
The components of the system are separated into three main categories: gutters, foul flush tank, and collection tank. Total materials cost of the system was approximately $2400.

Gutters

The gutters selected were 11 cm diameter, PVC, prefabricated gutters. Gutter joints, end caps, corner pieces, downspout, fascia brackets, and the necessary mounting hardware were additionally purchased. All pieces were built be the same manufacturer and designed to be part of the same system, thus making assembly fairly straight forward and reproducible. The gutter joints, downspout and elbows were sealed with silicone all weather sealant.

Gutters	Qty	Price/unit	Total
fascia bracket	80	$2.68	$214.40
gutter sections (4m)	14	$22.32	$312.48
gutter elbows (inside/outside)	4	$14.69	$58.76
gutter joints	20	$3.39	$67.80
gutter downspout	1	$16.07	$16.07
end caps	2	$3.21	$6.42
2" metal screws (144/box)	2	$3.57	$7.14
all weather sealant	2	$4.46	$8.92
		Subtotal:	**$691.99**

Gutter Material Actual Pricing



Hardware Shopping in Kigali

Figure 8: Gutter Installation

<u>Foul Flush and PVC Piping</u>

As water is collected from the roof and flows to the gutter downspout, the collected rainwater enters the filtration section of the system, commonly known as the "foul flush". During periods without rainfall, dust, debris, and animal waste may accumulate on the roof. The concept of the foul flush is to let the force of the rainfall hitting the roof clean the surface before collection begins. This initial rainfall is diverted to the foul flush tank. Sediment and debris settles to the bottom of the foul flush tank, and once it fills the clean water is naturally diverted to the main collection tank. The clean water is separated from the dirty sediment by approximately 10 ft column of water. A small hole drilled in the base of the foul flush tank allows the water to slowly drain out over time.

Foul Flush

11 cm and 5 cm diameter PVC piping was purchased to do the majority of the plumbing work. A 200 liter tank was used for the foul flush that had a sealable lid to access the tank for maintenance.

PVC Piping and Foul Flush	Qty	Price/unit	Total
50mm PVC pipe sections (6m)	2	$7.50	$15.00
50mm PVC 90 degree elbow	2	$2.14	$4.28
50mm PVC female coupling	4	$1.43	$5.72
50mm x 110mm PVC adapter	1	$5.89	$5.89
110mm PVC pipe sections (6m)	2	$16.07	$32.14
110mm PVC 90 degree elbow	5	$4.46	$22.30
110mm PVC 45 degree elbow	2	$4.64	$9.28
110mm PVC tee	1	$6.25	$6.25
110mm PVC female coupling	6	$3.39	$20.34
110mm PVC masonary bracket	2	$5.61	$11.22
PVC cement	1	$6.90	$6.90
200 liter foul flush tank	1	$35.71	$35.71
		Subtotal:	**$175.03**

Foul Flush and PVC Piping Actual Pricing

To facilitate ease of maintenance, the foul flush tank was set on its side. This allows maintenance personnel to open the lid, reach in, and remove debris. However, this configuration did prove troublesome in terms of securing the tank. The solution was to use metal pipe straps to anchor the tank into the building masonry.

Securing Foul Flush

Collection tank

The collection tank was made from polyethylene and capable of holding 10,000 L (manufactured by Afri-Tank, 2.44 m diameter x 2.50 m height). Given the height of the roof were the tank was to be installed, a significant amount of earth needed to be excavated to provide adequate clearance for the tank, and the ground leveled to provide a stable resting surface.

Main collection tank

The tank spigot was installed 1 ft above the tank base to allow a bucket or jerry can to fit underneath. This ensured water would be extracted from the tank at the optimum location (any remaining sediment would settle to the bottom of the tank). A pit was dug at the spigot and lined with bricks. The hospital maintenance staff was to complete the masonry work at a later date.

Figure 16: Tank Spigot

<u>Lessons learned</u>

- Installing the foul flush sideways is convenient for maintenance (lid on the side), but it deforms the tank circumference when filled with water: due to the weight of the water, the tank flatten, which adds loads on the brackets securing the tank against the wall
- The fascia board from the hospital roof was expected to be made of wood, but it turned out to be metallic. It seems to be the common construction configuration in Mugonero.
- As a result, the drill bits need to be for metal frame. Given how isolated Mugonero is, it is crucial to have several spare drill bits in case one gets snapped.
- The slope of the hospital roof is not very big, but big enough to make it inconvenient to stand on. Some work needs to be done from the roof (like snapping the gutters in the brackets), so it would be a good idea to be better secured.
- The ladders were a bit of an issue, because only one (metal) was initially available. Two other ones (wood) were used by the nearby maternity aisle construction. The foreman (Philippe) made arrangements to have one wood ladder made for us, but it took an extra day. The wood ladders are very heavy, and require at least 2 persons to be moved. Also keep in mind that the ladders can't be put against the roof when installing the gutters.
- In Kigali, three hardware stores were used for material shopping: Muhirwa, Magasin le Trio, and Sonatubes. Muhirwa turned out to be the best for PVC, pipes, gutters and connectors. We were helped by Célestin, who was speaking almost exclusively French. The 10,000L tank was bought at Magasin le Trio, whose manager was Alphonse, bilingual in French and English. Both Célestin and Alphonse turned out to be very helpful. We didn't have to negotiate the prices, they were very reasonable and properly labeled. We had to pay before picking things up, and they had everything prepared on time for pick-up. Note: be careful about their cultural sensibility, by avoiding being too skeptical of their honesty and ability to prepare all the purchased material on time.
- We had bought 2 cordless power drills in Houston, with 4 good pre-charged batteries. We were able to recharge them in the community, which had to be carefully planned.
- The PVC pipe and fittings did not share the same wall thickness. There, most did not have a tight slip fit. Consequently, we were forced to heat the ends of the pipe in a fire

pit to deform the pipe to make the connections. It's definitely worth making these fit checks BEFORE making your purchase.

- Bulkhead fittings for making tank connections were purchased in Houston and brought with the team as their availability was unknown. This was confirmed in Kigali, were very few were found, and not the size we needed. However, for the same reasons noted with the pipe and fittings not mating properly, this was found to be the case with the bulkhead fittings as well. We were able to make due for the spigot (brought this with us) and the supply and overflow lines (don't see pressure), but we couldn't install a tank drain line because it would hold pressure. This will need to be added on a future trip.
- Due to the combined absence of Dr. Mark and Dr. Kamali (conference out of town), we suffered a lack of direction from the hospital management. Examples: the requirement on the tank location changed on us on the 2nd day, and the availability of the ladders was resolved on Day 3. This issue has been addressed since.

Recommendations:

- Involve more the hospital management to emphasize the importance of maintenance (even better: have somebody assigned to a weekly check-up and cleaning)
- Try to find the opportunity to demonstrate to the community the importance of spreading the rainwater collection concept to the many people in the area as a means of collecting water for their daily needs (maybe this would include a presentation after a mass, with the team presenting a lesson on dirty versus clean water, and potential ways to collect rainwater.

5.3 Plan for Village Participation and Sustainability

The Mugonero Community was involved in virtually every step of this project. They identified the need and the EWB-JSC team responded to it with the rainwater catchment systems. The hospital foreman (Philippe) and the plumber (Augustine) were involved in discussions about the tank location, tools/hardware supply and various logistics. It was established that the systems would be properly used and maintained. However, the absence of hospital director Dr. Kamali and Dr. Mark for professional reasons meant a lack of direction from the hospital management. This is being addressed for future trips.

6.0 BIOGAS GENERATORS

6.1 Component Description

In January 2006, EWB-CU met with KIST (Kigali Institute of Science and Technology) to discuss a partnership with EWB-CU, KIST and the communities involving the possible implementation of large scale biogas reactors. These reactors would be of the same order as the systems KIST has famously installed in Rwandan prisons.

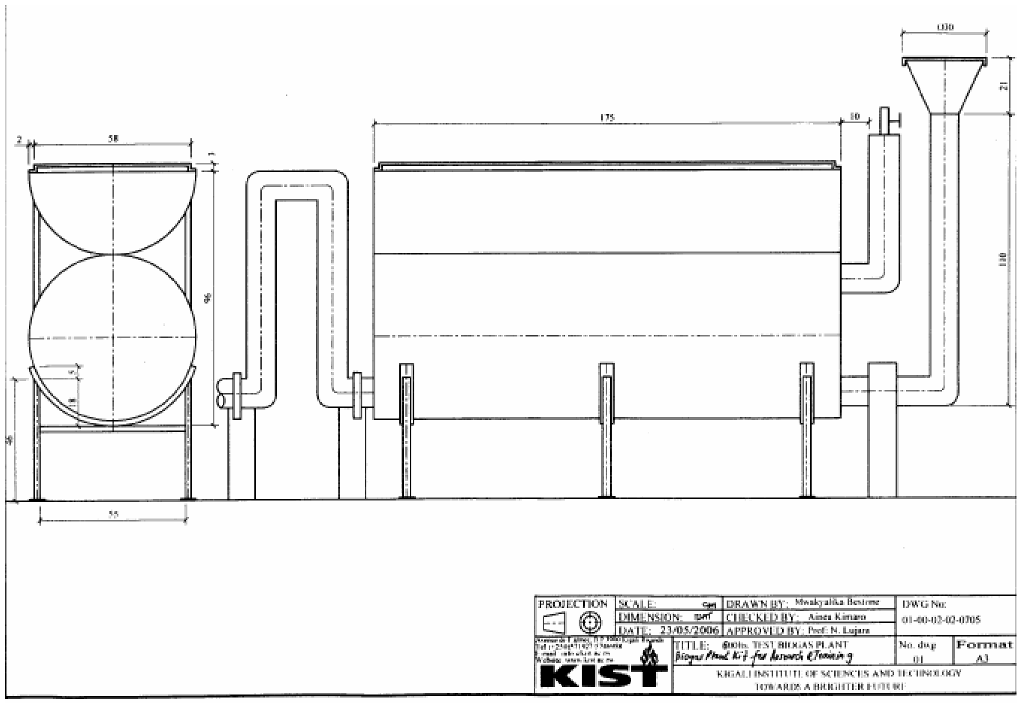
Following continuing discussion after the January trip, it was decided that EWB-CU and KIST would implement two small scale, demonstration size reactors in Mugonero and Muramba. The reactors would be funded by EWB-CU, designed and built by KIST, and operated by the communities. EWB-CU and KIST also signed a non-disclosure agreement, allowing KIST to provide EWB-CU the designs of two large scale reactors.

The 600 liter demonstration size reactor is designed to provide 200-600 litres of biogas per day, approximately enough to boil 10 liters of water. The reactors built by KIST consist of two 55 gallon drums, PVC and metal pipes, and fitted sheet metal, and some other small pieces such as brackets and gas valves.

Demonstration scale biogas reactor in Mugonero

The reactor can operate solely on cow dung, or together with a mix of other organic matter, such as pig or chicken manure and kitchen leavings. The cow dung is mixed with water at a ratio of 1:1; or until the mixture has attained a paste-like consistency. For most efficient use, the reactor operates as a continuos flow system. After initial filling the plant is to be fed roughly 60 litres per day, or 120 litres twice a week. In Mugonero and Muramba KIST engineers instructed the plant caretakers to burn the biogas to completion everyday, and then to refill the reactor.

The EWB-CU team also were taken on a tour of a prison and it's biogas system by Engineer Ainea Kimaro.



Small-scale reactor drawing

6.2 Materials and Logistics

The reactors were purchased from KIST and trucked up to communities. Cement for the masonry housing and foundation was also purchased in Kigali. The team travelled to the communities accompanied by the young engineer Eli Twagilimana and a plumber. They were also supplied by KIST to supervise the installation and filling of the reactor, and educate individuals in the communities.

In the communities installation work consisted of locating a satisfactory site and organising the acquisition of brick, mortar, sand and gravel. Masons were hired to construct the foundation, housing and drainage systems. All construction costs were funded by EWB-CU. The communities were required to organize the acquisition of manure and assist in the filling of the reactor.

6.3 Plan for Village Participation and Sustainability

As the communities could not afford to pay for the reactors themselves, it was decided that the communities fill and run the reactors as a way of ensuring community partnership.

In Mugonero, Philippe, the hospital caretaker, organised people to collect the manure and hired a labourer to continue to fill the reactor. As the reactor is located at the back of the canteen, Philippe decided that it would be best if the nurses used the gas to boil water for themselves and some patients. Eli and the plumber educated Philippe and other members of the community on how to run the reactor throughout the installation process.

In Muramba a similar approach was taken. Joselyn (the head nurse) arranged for labourers to obtain manure and help fill the reactor, while clinic maintenance stall were educated on how to run the reactors. The nurses at the clinic will use the biogas.

In both communities there were many curious onlookers during the construction and especially the filling process. Eli and the plumber thoroughly answered the many questions asked about the biogas. Though larger systems have not yet been implemented, the project was still successful in introducing a previously unknown renewable technology to rural Rwanda.

7.0 "BRING YOUR OWN WATER" TREATMENT SYSTEM

7.1 Background

An assessment in January 2006 indicated that the Muramba Clinic was in need of a water treatment solution. At the time, water was being transported to the clinic in jerry cans and buckets from a river located in an adjacent valley. The water was being transported by clinic staff and the families of clinic patients. Testing revealed that this water was of low quality with significant turbidity as well as bacterial contamination by fecal coliforms (see January 2006 EWB-USA Rwanda Design Report).

To improve the quality of the drinking water consumed at the clinic, the team decided to install a near point of use water treatment system that could treat water on a bucket by bucket basis. This type of system was chosen because it is compatible with a variety water sources. This compatibility is because nearly all drinking water consumed in rural Rwanda is transported to its point of consumption in a jerry can or bucket. Whether the water comes from a muddy river, a rainwater collector, or a public tap, it invariably ends up in a container. By installing a container level treatment solution at the Muramba clinic, the project ensures that all patients have access to treated water, regardless of the original source.

7.2 Water Treatment Requirements

The primary objective of this work was to address microbial contamination in the water near the Muramba Clinic. The basic requirements suggested a system with a simple yet robust design that could provide approximately 8,000 liters of drinking water per day while minimizing capital and maintenance costs in order to maximize sustainability.

The requirements for the water treatment system at the Muramba Clinic are detailed below.

Table 7-1: Water Treatment System Requirements

Parameter	Requirement	Considerations
Bacterial Contamination	Reduce contamination (specific level not defined, as water quality varies and any improvement is presumed to benefit community, but target is the elimination of all coliform bacteria)	May be affected by seasonal variations in source water quality
Time	System must provide treated water in less than five minutes after influent water is added	Most people already spend time fetching water and do not want to spend extra time waiting for treatment. Long treatment times could deter people from using the system.
Influent Water	System should work for both continuous and intermittent use, with varying water quality	Water treatment will be required by families at different times of the day, and at varying volumes and quality throughout the day and year.
Cost	System must have a per liter maintenance cost affordable to the responsible party (family or community facility)	Rwandan families have on average less than ten dollars cash per year for purchasing anything such as clothing or medicine
Materials	Utilize locally available materials as much reasonably feasible	'local' may be defined as include community level and country level, including imported goods depending on how reasonably the parts can be obtained; May use materials in implemented system of higher quality than those available in Rwanda as long as materials with comparable functions can be obtained
Quantity	Treat approximately 8,000 liters per day (about 800 peoples' supply)	Varies depending on population and season
Maintainability	System maintenance must be easily performed by local trainees	May involve training local maintenance personnel with some infrastructure experience
Reproducibility	System design should be able to be reproduced by local communities trained in the design	May be on a household or community scale, depending on complexity and nature of design
Sustainability	System must operate successfully for at least five years after implementation without continued support from EWB-USA	Initial implementations may involve follow-up by EWB-USA before design and education weaknesses are resolved

7.3 Water Treatment Trade Study

There are a few technologies that are capable of disinfecting water in developing communities such as Muramba. These include chlorination, slow and rapid sand filtration, ceramic candle filtration, Filtrons, boiling the water and UV irradiation.

A thorough trade study was conducted to identify appropriate water treatment approaches to address these water treatment goals. The results of the trade study are summarized below, including identified benefits and drawbacks for application in Muramba.

Boiling

Boiling water for approximately one to three minutes will kill or inactivate microorganisms that cause most water-borne diseases. Boiling does not remove dissolved or particulate chemicals in water. Evaporation during boiling may increase the concentration of potentially harmful chemicals already present. Boiling is a low-tech option to sanitize drinking water. Given enough fuel, it is relatively easy to implement in households.

Boiling requires relatively large amounts of fuel, which is in short supply in Rwanda. Government restrictions are currently in place against cutting down trees for firewood, making the actual implementation of this option a hardship for many people. Additionally, many families do not have the proper materials needed to efficiently boil water, such as quality pots with lids. Boiled water requires time to cool to be consumed. Most families in Rwanda are subsistence farmers and do not have time to wait for water to cool, making this option ineffective in daily use. The introduction of pots with lids and more effective cookstoves could make water boiling an effective

Coffee Ground Filtration

Coffee ground filters employ recyclable materials that common in many parts of the world to effectively filter water for potable use. The filter consists of terracotta clay, if native to the area, and other simple organic materials such as rice husks and coffee grounds. The clay is passed through a sieve made of insect screen and mixed with a volumetrically equal proportion of coffee grounds or other organic material, ensuring a continuous distribution of organic material. Water is added to create a clay mixture that will maintain its shape when manipulated. Using this mixture and an existing container, such as a bucket, a pot is formed with a one centimeter thick wall. The newly formed pot is dried and then fired using cow dung and straw.

As the pot is fired, the organic material burns away, creating a porous wall. The pore size created by this process will allow water to pass through but will filter pathogenic microbes. The type of organic material used will affect the effectiveness and filtration rate of the pot. Coffee provides the most effective removal rate, but filters water at about a liter per hour. Additionally, coffee grounds contain silica particles that are not burned away during the firing process, thus increasing the structural integrity of the pot. Rice hulls are another common source of organic material in the developing world and can be used to produce a pot that filters one liter in eight minutes with a lower removal rate.

The coffee filter approach requires a high time commitment from dedicated individuals to produce a product that with have cost associated with its distribution.

Rapid Sand Filter

Rapid sand filtration removes microbes and particulates from water as it travels via gravity through a layer of sand at a rate of 2 to 5 meters per hour and can remove up to 90 percent of the turbidity of raw river water. Rapid sand filters may be composed of a variety of materials, including activated carbon, gravel, or sand, or a combination of materials. To ensure proper filter performance, the filter should be monitored for effluent water quality and backwashed to clean the filter of debris as needed. This process may require power-operated pumps and flow control of the filter outlet, although sustainable options are available. Rapid sand filters must generally be followed by disinfection such as chlorination or UV application to ensure proper disinfection for potable water. High turbidity water may require pretreatment. The system may generate large quantities of filter backwash water and sludge that may require treatment before environmental discharge. Rapid sand filters require approximately twenty percent less filtration area than a slow sand filter, due to significantly higher filtration velocities; however, pretreatment requirements for slow sand filters are usually less than for rapid sand filters.

A rapid sand filter requires regular backwashing to remove suspended particulate matter deposited in the filter bed by influent water. The period between backwashes depends on the quality of the water input to the filter. The filter bed may need to be repacked periodically. Operation and maintenance requires trained personnel. Construction costs for a rapid sand filter are determined by the costs and availability of building materials, land, and transportation rather than labor costs. Operation and maintenance costs may be significantly influenced by the systems energy requirements and local energy costs.

Rapid sand filtration is suitable for surface water sources and in areas where land is not easily available. The technology is effective in removing suspended solids and requires a smaller filtration area than a slow sand filter.

Slow Sand Filter

Slow sand filtration is similar to rapid sand filtration with a few key differences. Firstly, the flow rates for slow sand filters are 20-50 times slower than for rapid sand filters. A slow sand filter can be more effective than a rapid sand filter at removing microbial contamination due to the formation of a biological layer on top of the sand called a Schmutzdecke. The microbes in this layer consume much of the influent organic matter and microbial particles in the influent water. The slow sand filter provides superior water quality to a rapid sand filter and can provide potable water to the user without need for a secondary treatment. A typical slow sand filter requires five times as much filter area as a rapid sand filter for a given flow rate.

The maintenance of the filter bed consists of scraping off the Schmutzdeke manually, not through a backwashing process. This process may take several days, with the filter completely off-line. The scraping only takes a few hours to do though it may take some days to regrow the Schmutzdeke. This often leads to a requirement for two filters in parallel to avoid losing treatment capacity. Additionally, slow sand filters often require pretreatment to reduce the turbidity of the influent water. However, this requirement is usually less than the pretreatment requirements for a rapid sand filter.

"Surface Water Treatment for Communities in Developing Countries" (Shulz and Okun, 1984) contains a thorough comparison of slow and rapid sand filters.

Solar Cookers

Solar cookers, often used for collecting and focusing the sun's energy for food preparation, can also be used for water disinfection. A typical solar cooker for disinfection includes large flat panels covered by glass. Water runs over a dark surface beneath the glass in a thin film and is disinfected by the UV radiation and heat produced.

This style of solar cookers requires a large area to produce enough water for a family, and disinfects water slowly, on the order of several hours per liter.

SODIS

A derivation of solar cookers for disinfection is called SODIS, or "Solar Disinfection", which exposes water to direct sunlight to denature pathogens and treat water. SODIS is best utilized to treat small water quantities for individuals and families in areas where sunny days are prominent. Water is collected, poured into transparent plastic bottles, and exposed to direct sunlight for at least six hours. This process is made more effective by placing the bottles on a tin roof, which exposes the water to additional UV radiation and increased the temperature of the water. A water temperature above 50 degrees Celsius magnifies the disinfection process, decreasing the required exposure time by a factor of three.

Several factors can limit the effectiveness of SODIS. On days with a maximum of 50 percent cloud cover, the container should have 6 hours of continuous sun exposure to ensure the deactivation of pathogens. On days with 100-percent cloud cover, 2 days of exposure is required to provide the same amount of water treatment. SODIS in not effective and should not be used during continuous rainfall. SODIS is most effective in between latitudes 15 degrees N/S and 35 degrees N/S and fairly effective in regions between the equator and 15 degrees N/S. SODIS does not improve the chemical quality of water. For SODIS to be effective, water turbidity should not exceed 30 NTUs and plastic PET bottles free of scratches should be used. These bottles maximize exposure of the water to UV radiation but are not necessarily easily available in developing communities. Glass bottles can be used, but are not as effective. Bottles that are old or contain many scratches reduce UV transmittance and should be replaced. Depending no many factors, bottles may last up to a year. Maintaining a fresh supply of PET bottles may not be sustainable unless an inexpensive and accessible source is available.

Using SODIS, water must be exposed to the sun for a minimal time interval in order to ensure disinfection. Thus, if water is removed from the sun before the SODIS process is complete, the user may mistakenly assume it to be disinfected. A wax temperature indicator can help determine that the water has reached a minimum temperature, but does not guarantee appropriate exposure time. Additionally, exposing the plastic bottles to sunlight evokes a photochemical reaction that creates photoproducts. However, research shows that these photoproducts are created outside of the bottle and do not contaminate the water.

According to research, SODIS destroys pathogenic bacteria, viruses and protozoa. This includes the inactivation of the several pathogenic bacteria such as Escherichia coli (E.coli), Vibrio cholerae, Streptococcus faecalis, Pseudomonas aerugenosa, Shigella flexneri, Salmonella typhii, Salmonella enteriditis, and Salmonella paratyph; viruses such as bacteriophage f2, rotavirus, and encephalomyocarditis virus; yeast and molds such as Aspergillus niger, Aspergillus flavus, Candida, and Geotrichum; and protozoa such as Giardia spp., and Cryptosporidium spp.

Laboratory experiments showed an efficient reduction of the fecal coliforms through SODIS also with initial concentration of 10,000 organisms per 100ml up to more than one million organisms per 100ml, which is much higher than normally encountered in river and ponds. However, the conditions during the experiments may be different from practical situations where the process might not be applied in a strictly controlled way, materials are not optimal, and handling of the treated water is often inadequate. Important for an efficient inactivation of fecal coliforms is sufficient exposure of the contaminated water to the sun (500 W/m2 during at least 5 hours) in an appropriate container and clear water (water turbidity should be less than 30 NTU).

Filtron

The Filtron is a porous clay filter shaped like a pot and lined with colloidal silver, a substance with anti-microbial properties, designed by Potters for Peach to generate potable water. A mixture of clay, sawdust, and water is formed and then fired in a brick kiln. The pot acts as to filter large water-borne particles from the water and colloidal silver inactivates pathogens that may pass through the filter. The Research shows that a properly constructed Filtron can remove 98 to 100 percent of E Coli. Education on the proper construction and use are central to ensuring such removal rates in the field. The filter has a 30 cm diameter, is 24 cm high, and holds 7.1 liters of water. It sits inside a receptacle, consisting of either 20-liter plastic buckets or ceramic pots, and include a plastic spigot at the bottom. The filter and receptacle are covered with a plastic or ceramic lid. A Filtron costs $5 to $10 per household with a short lifespan of 1 to 5 years and a low flow rate of 1-2 liters per hour.

In 2002, a research team from the University of Colorado at Boulder surveyed 33 homes in seven communities at a village in Mangua, Nicaragua, where Filtrons had been introduced to the public. The research team observed the community's Filtron usage habits and the water quality produced by the filters in the field. Seventy-three percent of the households surveyed were using the filter at the time of the unannounced visit. Usage rates within each community ranged from 33 to 100 percent. Higher usage rates were observed in communities where representatives of the sponsoring NGO or community leaders conducted follow-up visits in comparison to usage rates of communities where no follow-up visits occurred.

While Filtrons have had success in several South American countries, when the EWB-USA team investigated applying the technology in Rwanda, it was determined that the replacement cost of each unit per family was economically infeasible.

Electrical Ultraviolet Disinfection

Ultraviolet light in the UV-C spectrum between 200-300 nm is known to disrupt biological activity and has bactericidal effects. While sunlight naturally includes this range, the effectiveness of UV disinfection can be dramatically increased by artificially generating the targeted wavelengths. The conventional target wavelength is at about 254 nm.

The disinfection occurs because high energy UV light passes through cell walls, cytoplasm and nuclear membranes. The DNA absorbs the photons in the UV lights and is altered. The altered DNA causes inactivation of the micro-organisms by prohibiting replication of the micro-organism.

When compared to boiling water over a biomass cook stove with an average of 12% efficiency, UV disinfection can be 20,000 times more energy efficient (Gadil, 1998). Other advantages include the high volume of water that can be treated both continuously and intermediately by a UV light bulb, the fail-safe nature of the system (no overdose possible), and low maintenance costs. A typical light bulb can run continuously for a year, treating 20 liters per minute of water.

Disadvantages include the requirement of low turbidity water (usually recommended to be less than 1 NTU) to be effective, the lack of availability of UV light bulbs in most developing communities, the possible contamination of the environment or water supply by the mercury content in the bulbs, and the added training necessary to ensure proper operation of these systems.

Chemical Disinfection

Chemicals, particularly chlorine, are the most common form of water disinfection in the world. These chemicals are often cheap and available in developing communities. If used properly, chemical disinfection can be highly effective in producing any volume of potable water.

The speciation of chlorine is dependent on other aspects of the water chemistry, including the pH, temperature, turbidity, and dissolved organic carbon content. Determining the minimum effective dose for a water system can be complicated. It's misuse can lead to illness or death. Resupply costs and unfavorable changes to the taste of water are other significant disadvantages.

The results of the trade study are summarized in the table below.

Table 7-2: Trade Study Results

Technology	Advantages	Disadvantages
Boiling	Common in the developing world	Firewood is expensive, time consuming, and not readily available
Coffee Filters	Can use local materials	Cost, slow filtration rate
Rapid Sand Filter	Can treat varying volumes and quality of water, uses simple technology and local materials	Does not offer total disinfection
Slow Sand Filter	Can provide disinfection	Requires continuous supply of high volume, high pressure water, large infrastructure (EDIT this)
Solar Cooker	Utilizes sunlight for disinfection	Requires large area, high cost
SODIS	Recycles bottles, easily understood and implemented by families	Bottles can be expensive, slow disinfection rate
Filtron	Uses locally available materials, can be a marketable skill	Replacement cost is outside the means of most Rwandan families, slow filtration rate
Electrical UV	High filtration rate, low maintenance costs	Light bulbs not generally available in developing communities, requires added training to ensure safety, requires low input turbidity
Chemical	Chemicals available in most countries, very effective when used properly	Can be misused, taste is not appreciated by most communities

The conclusion of the study was that family sized disinfection systems were impractical because of the replacement and maintenance costs were all outside the means of a typical family. Therefore, the team decided to work with the Muramba Clinic who would be responsible for absorbing the maintenance costs of the system while providing access to the residents living nearby. For this type of community scale system, UV disinfection was determined to be the optimal solution for rapidly disinfecting a containers' worth of water brought to the Muramba clinic. While UV irradiation is capable of treating a bucket of water rapidly with minimum maintenance, UV has some distinct drawbacks. The main drawbacks that had to be addressed in the system design were the requirement for low turbidity input water and the requirement for a source of replacement bulbs.

7.4 System Description

The “Bring Your Own Water” treatment system combines several water treatment approaches. The first stage consists of a “Plastic Drum Sand Filter”. The PDSF consists of a tube settling tank placed on top of a hill, into which residents pour jugs of water.

Next to this settling tank is a backwash tank that automatically takes a percentage of the water input and stores it for later backwash of the sand filter. The water then travels down the hill, providing pressure, and into the sand filter drum. The sand filter has 6 inches of gravel and 15 inches of graded sand, topped by 6 inches of pumice stone. The water is pushed through this sand, removing particulates and bacteria. Because the system pressurization is provided by the added bucket, the amount of treated water provided is no greater than the inputted volume. Additionally, the water is provided within minutes, because the sand filter is already pressurized.

The water then flows into a solar powered UV reactor. The UV light deactivates much of the remaining bacteria in the water.

One major drawback of UV is the fact that it requires some high-tech components like a power source and a supply of specialized light bulbs. The problem of a power source was solved by integrating the system with a photovoltaic power system. After implementing a solar powered lighting system at the Muramba Clinic in January 2006, the EWB-USA team is confident that clinic personnel will be able to properly operate and maintain the nearly identical PV power system for the UV unit. The second challenge of finding replacement bulbs for the UV disinfection unit was solved by working with a water system supply store in Kigali that can import the bulbs at a reasonable cost for Muramba. Because the Muramba Clinic regularly re-supplies medicine and materials from Kigali, this was a minor added burden.

The second drawback of UV treatment is that UV radiation does not work very effectively when treating turbid water. Because the water around the clinic can be quite turbid depending on the season, any implementation of UV disinfection would require some pretreatment to reduce the turbidity of the water.

To meet this pretreatment requirement for UV disinfection, the BYOW system employs an inclined tube settler and a rapid sand filter prior to the final UV disinfection stage. The inclined tube settler was included as a way to reduce the burden on the sand filter by removing much of the particulate matter in the incoming water before it enters filter. The combination of a tube settler and a rapid sand filter was chosen because it is capable of reducing turbidity at a volumetric flow rate which matches that of the UV disinfection system, about 20 liters per minute maximum.

While traditional rapid sand filters require frequent maintenance, BYOW innovations significantly reduce the maintenance required. The rapid sand filter in this system is significantly oversized relative to the net flow rate of water through the system. This intentional imbalance in sizing drastically reduces the maintenance interval of the filter by more than an order of magnitude. This reduction in maintenance requirements allows the rapid sand filter to be maintained by a single person who attends to the filter once every one or two months.

The regular maintenance of the rapid sand filter, known as backwashing, requires that a large volume of water be rapidly discharged through the filter in the opposite direction of normal operation to remove contaminants that have accumulated in the filter media. To achieve this effect without a pump, the system must be installed on a large elevation differential. With the system input section positioned at least 15 feet higher than the sand filter component. The hydrostatic head generated by this elevation differential is harnessed to power the filter backwash process. An added benefit of this elevation difference is that filtration takes place under significant pressure, thus increasing the speed of treatment to approximately 10 liters per minute.

An interesting note regarding this elevation differential across the system is that the energy required for backwashing the filter is provided by the user. In other words, this instance of sand filtration is actually human-powered. The cumulative result of all the aforementioned features is a system that can treat a five gallon bucket (about 20 liters) of water in about two minutes using solar and human power alone.

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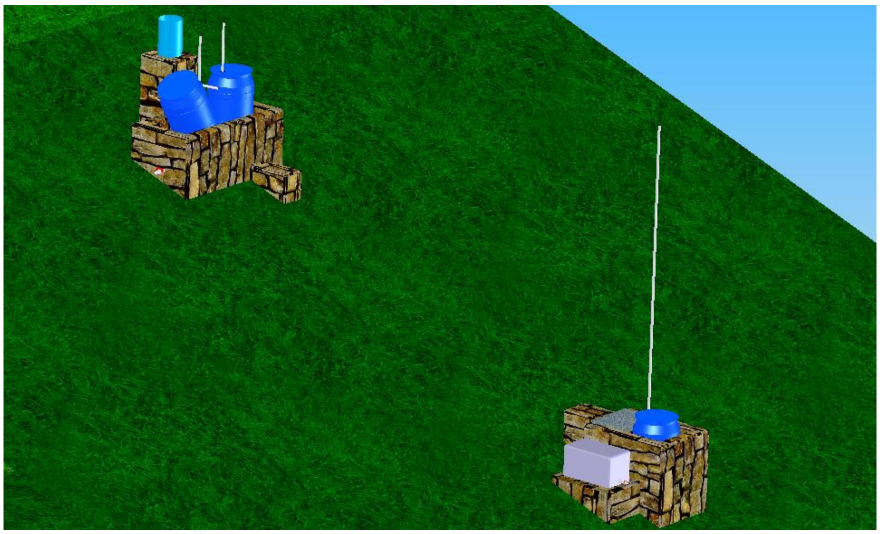

Figure 7-1: CAD drawing of the BYOW treatment system installed on a hillside. The upper portion is where a user deposits their water and the lower portion is where it is retrieved post treatment.

The original plan dictated that the team would find a steep hill on which to install the BYOW system. However, upon arrival, a large retaining wall that was perfectly suited to the BYOW system was used instead. The approximately 18 foot high retaining wall was located in an ideal location on the clinic grounds, well within the patrol of the clinic security guards. In addition to being in a particularly safe and convenient location, the retaining wall also featured a built-in stair case that would serve as an ideal path for users between the input and output sections.

Figure 7-2: The BYOW treatment system installed on a retaining wall at the Muramba Clinic

The BYOW treatment system uses three different treatment processes to bring water of very low quality near-up to standards approaching those seen in the industrialized world. The first two of these three processes are low tech while the third and final UV treatment stage is considerably higher technology. Because of the unique challenges of implementing water treatment in developing communities there is always a chance that some of the system components may fail. Because of the high tech nature of UV component and its associated PV power system, it is the most likely point of failure in the system. While we do not anticipate any failure, a failure of the UV component would not entirely disable the system. Because there are three distinct treatment processes, the system will still significantly increase the quality of the input water without operating the UV subsystem.

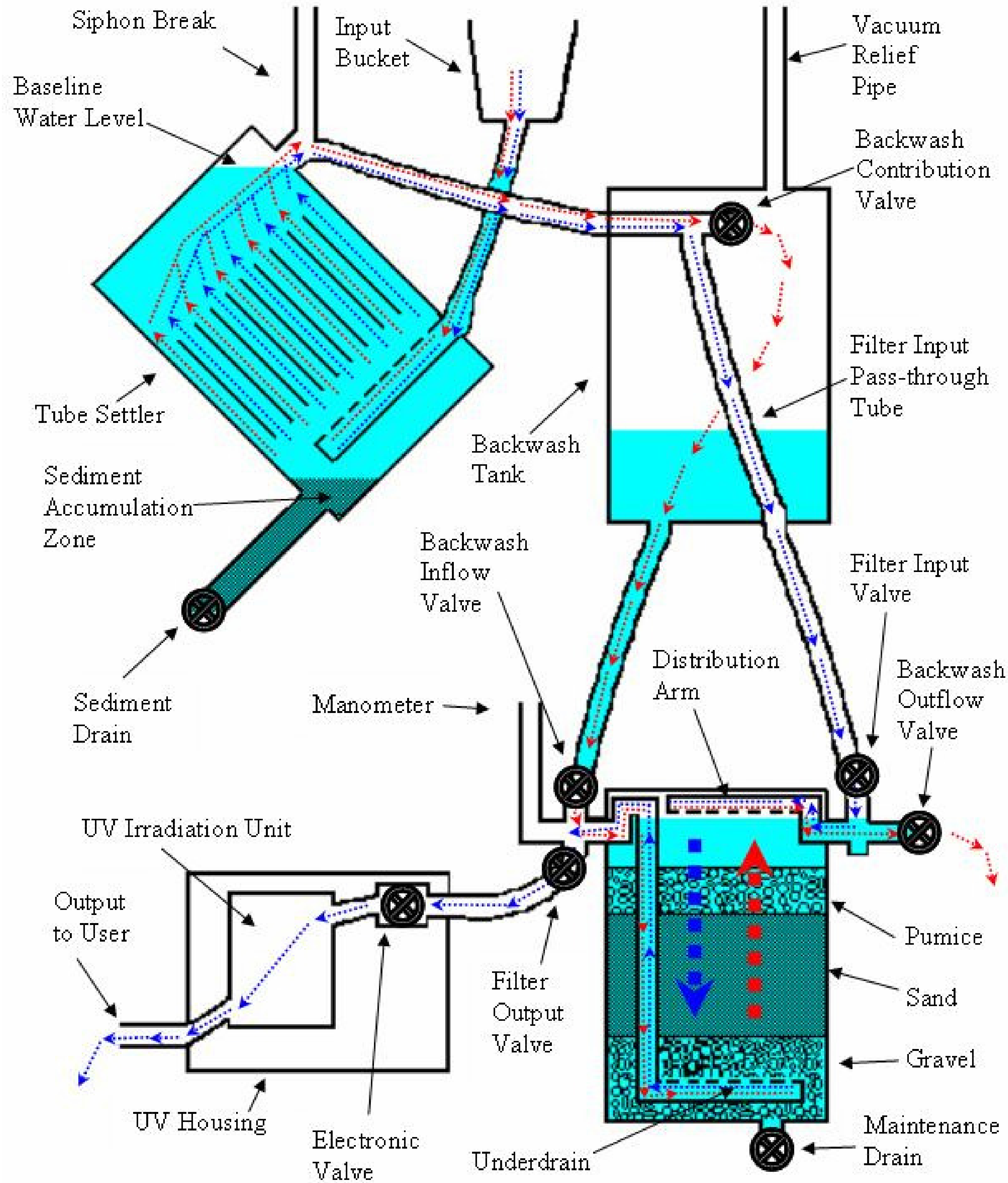

Figure 7-3: A schematic of the system detailing the main components and the flow path of both the filtration water (blue) and backwash water (red). The backwash is partially filled and the system is in the "uncharged" state.

7.4.1 System Components

The following is a description of the major components of the BYOW system listed in the order of the component's general position in the flow path. The component descriptions correspond to the schematic in Figure 7-3.

Upper masonry housing

The upper masonry housing contains the tube settler and the backwash tank; it also features a pedestal for the input bucket. This housing supports the tube settler at a 60° angle off the horizontal and also protects the workings of the upper half of the treatment system. The upper housing is constructed of bricks with a ¼" parge coat of concrete to increase its durability.

A noteworthy feature of the upper housing is that it allows for complete disassembly of the treatment system; none of the system components are permanently fixed to the housing. This feature simplifies maintenance of the system. There is a small staircase built into the upper housing which permits smaller users to access the input bucket.

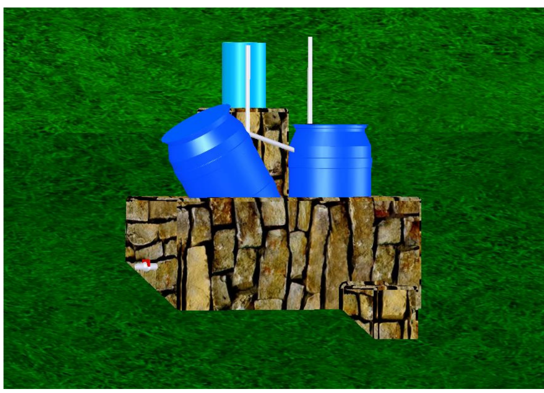

Figure 7-4 (left): Cad drawing of the upper masonry housing. The vertical tubes in both pictures are the backwash tank vacuum relief and the settler siphon break respectively.

Figure 7-5 (right): Photograph of the upper masonry housing from above. The input bucket with its integral concrete funnel can bee seen in the bottom of the picture. The drum on the left is the backwash tank and the drum on the right is the tube settler.

Input bucket

This is where the user introduces their water to the system. The bucket has a smooth concrete funnel poured into the bottom (Figure 7-5) to ensure that all of the user's water gets into the system and that water doesn't stagnate in the bottom of the bucket. The smooth concrete finish was created by using a mix that was heavy on water and cement.

Inclined tube settler

The tube settler is the first treatment step in the system. The water flows upward through a set of 1" tubes that are inclined 60° from the horizontal. As the water travels through the tubes, sediment settles downward vertically through the inclined columns of water. The array of tubes serves to minimize the distance a given piece of sediment has to travel before reaching a surface. Once a particle contacts a surface, it will adhere to other particles on the surface and form a small floc (clump). These accumulations eventually become heavy enough to slide downward through tubes and settle at the bottom of the tank. Without the tube array, the average settling particle would have to travel a distance greater than the radius of the drum before contacting the side and the settler would be less effective. Conversely, with the array in place, the average particle only has to travel a distance equal the diameter of a single tube. The water enters the settler from the lower portion of the drum via a "T" shaped distribution arm that is connected to the input bucket via the input bulkhead. The distribution "T" is perforated with ¼" holes at 1" intervals. These holes are directed upward to prevent the incoming water from disturbing the sediment that accumulates in the bottom of the drum. The tube bank is suspended above the distribution "T" by a set of four legs that position the tube bank in the center of the drum.

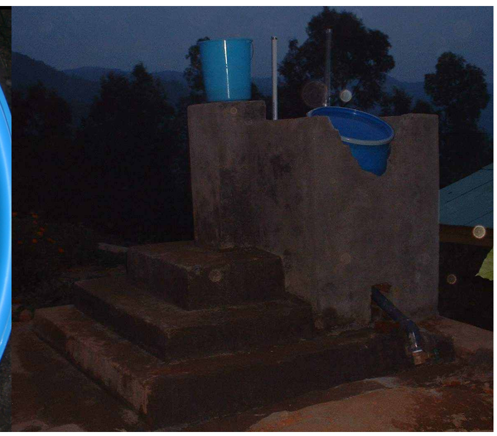

Figure 7-6 (left): The parts of the tube settler in a disassembled state. The tube bank is the upside down relative to its intended position in the drum. The four tubes that extend above the bank are the support legs that keep the tube bank elevated within the drum. The distribution "T" is clearly visible in the center of the picture. The annular black objects are the bulkheads that are used to make water tight fittings through the drum walls.

Figure 7-7 (right): Picture of the upper housing that illustrates the location and orientation of the sediment drain. The drain is the grey pipe in the lower right corner protruding diagonally downward from the housing.

Sediment drain

The sediment drain allows the sediment that accumulates in the tube settler to be drained. The entire length of the sediment drain pipe serves as a storage area for sediment, thus extending the cleanout interval of the tube settler. The sediment drain is operated by actuating a gate valve. The gate valve is oriented so that the flow direction is vertical to reduce the chance that sediment will interfere with the operation of the valve.

Settler siphon break

This vertical tube prevents the water in the tube settler from being siphoned out of the system. It also serves as the highpoint for the rest of the system. Any air that accumulates in the system downstream of this point will eventually emerge here. Without a mechanism for air relief, air bubbles would accumulate in the highpoint, restricting the flow rate. The siphon break extends above the maximum water level to ensure that no water is lost when the system is charged with water. The top of this pipe features a screen to prevent the entrance of mosquitoes. This feature is visible in Figures 7-4 and 7-5.

Backwash tank

This tank stores water for use during the backwash process. When needed, the backwash water is discharged to the bottom of the sand filter through a bulkhead in the bottom of the tank. The backwash tank is filled via a valve that branches off from the pass-through tube. Section 7.4.3 explains, the operation of the backwash mechanism in detail. While *all* the water that enters the system technically passes through the backwash tank, the vast majority of it passes directly through the tank via the filter input pass-through tube and on to the sand filter. Thus, along with its primary function, the backwash tank acts as a conduit for the pass-through tube.

Filter input pass-through tube

This tube transmits the tube settler output to the sand filter in the lower housing. Water that takes this route never contacts the water that is stored in the backwash tank. There is a branch in the tube that terminates in a valve. This valve diverts some of the water to the backwash tank proper.

Backwash contribution valve

This valve allows the operators to switch the system from tap water backwash mode to user contribution backwash mode. When this valve is closed, the system is in tap water backwash mode, when open, the system is in contribution mode. When in contribution mode, this valve diverts a fraction of the user's water from the "filter input pass-through tube" to the backwash tank. The size of the valve aperture dictates the size of the contribution to the backwash supply. The details of the use of this valve are explained in Section 7.7.

Backwash vacuum break

This pipe allows air to enter the backwash tank as the water is discharged to the filter during the backwash operation. Without this feature, the backwash tank would implode when drained. Like the settler siphon break, the backwash vacuum break pipe extends above the maximum water level of the system so that water is not lost through the opening. The top of the pipe is screened.

Conduit

The conduit is made from 4" thin-wall PVC. It encloses both the backwash and treatment hoses. The conduit serves to protect the hoses from the elements and local children. The conduit also supports the manometer tube, which is fixed to the outside of the conduit. The conduit is the long grey pipe in Figure 7-2.

Treatment Hose

This ½" inner diameter vinyl hose carries the water that is to be filtered from the upper portion of the system to the sand filter. It is enclosed in the conduit. The treatment hose's relatively small diameter serves to maximize the pressure on the sand filter while a bucket of water is processed. The small size of this tube minimizes the amount of water that is contained within, thereby maximizing the length of time that the filter is under full pressure.

When the system is charged with a bucket of water, the water flows through the system and backs up in this tube. This forms a static water column that extends from the water level in the input bucket down to the sand filter. When a user opens the output valve to collect their water, the hydrostatic pressure developed by this column decreases as the water exits the system. While water level is above the settling tank output, this decrease in pressure is gradual due to the relatively large ratio of water surface area to flow rate. Once the water level in the settling tank returns to the baseline level, the pressure column consists solely of the water in the treatment hose. From this point on, the pressure falls off drastically due to the relatively small ratio of water surface area to flow rate. Minimizing the volume of water contained in the treatment hose, maximizes the fraction of the user's charge that is rapidly filtered due to the pressure developed by the water column.

To further illustrate this mechanism, it helps to imagine an exaggerated hypothetical case where the treatment hose is very large. For simplicity, let's assume that it is the same diameter as the input bucket. If this were the case, a full bucket poured into the system would only increase the level of the water column a distance equal to the height of the bucket. In this extreme case, *none* of the water is filtered at high pressure and the output flow rate is drastically reduced.

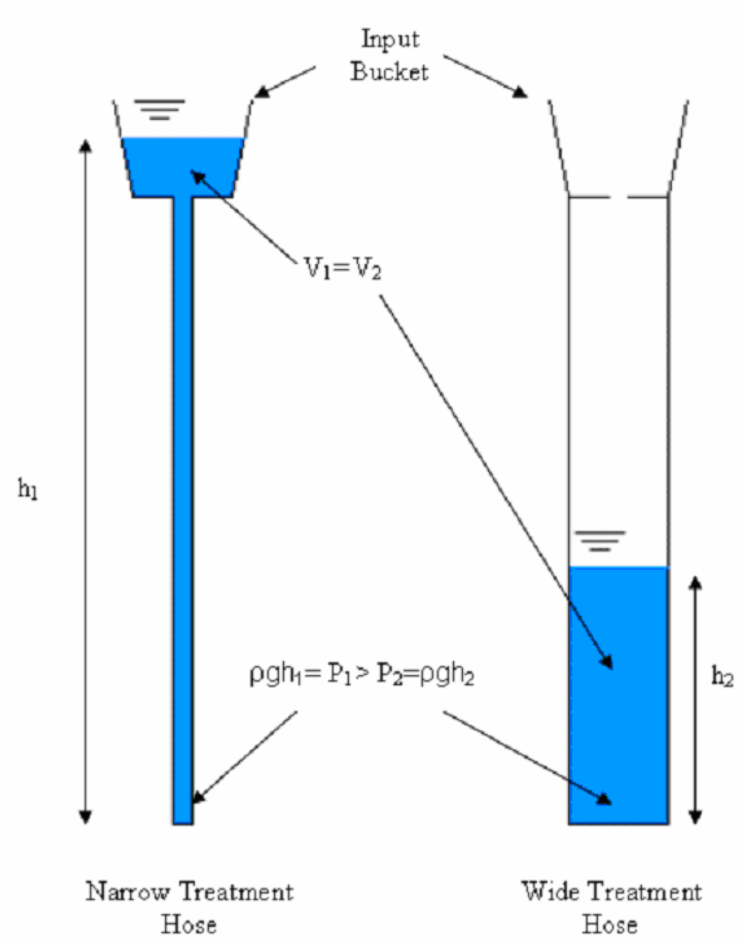

Figure 7-8: Exaggerated schematic illustrating the benefits of a narrow treatment hose. The equal water volumes, V_1 and V_2, represent a user's water. A thinner treatment hose allows for a higher average filtration pressure by minimizing the amount of water that is filtered at low pressure at the end of a filtration run.

Backwash hose

This 1" inner diameter vinyl hose has carries the backwash water from the bottom of the backwash tank to the filter underdrain. As with the treatment hose, it is also enclosed in the conduit. The backwash hose's relatively large diameter serves to maximize the flow rate of the backwash water to increase the efficiency of the backwash process.

Lower masonry housing

The lower housing contains the filter body and acts as a pedestal for the UV disinfection box. As with the upper housing, the lower housing was constructed of bricks and then coated with a ¼" concrete parge coat for durability. With the exception of the UV disinfection box, all parts of the system are easily removed from the housing for maintenance purposes. The single exception is the UV box which is mortared to the pedestal to reduce the likelihood of it being stolen. The rear portion of the lower housing serves as a valve box; it contains all the valves needed to operate the system.

Figures 7-9, 7-10: CAD model and photograph of the lower housing. The silver container is the UV disinfection box resting on its pedestal. The sand filter is the blue drum enclosed in the masonry. The valve box is located behind the filter drum.

Valve box

The valve box contains the valves needed to operate and maintain the system. It is normally covered by a reinforced concrete slab to keep passers by from tampering with it. The valves in the valve box can be divided into two groups: the input valves, which are connected to the galvanized “T” on the input bulkhead (left) and the output valves which are connected to the galvanized “T” on the output bulkhead (right).

Figure 7-11: The inside of the valve box. The left bulkhead connects to the distribution arm above the media bed. The right bulkhead connects to the underdrain beneath the media bed. The lines, from left to right, are: backwash water discharge valve, unused, filter input (from user input), backwash input (from backwash tank), filter output (to UV unit), and the manometer.

Plastic drum sand filter (PDSF)

The PSDF is a small filter body that can accommodate a variety of media types. Built from a plastic Standard 55 gallon drum, the PDSF is watertight and is designed to operate under pressure to increase the speed at which the water is filtered. In this implementation, the PDSF operates at a maximum pressure of 14 feet of water (6 psi, 41 kPa). The PDSF contains the filter media and the plumbing needed to direct the water through that media for both normal operation and backwash operation. All plumbing that penetrates the wall of the PDSF drum does so via plastic bulkhead fittings with rubber gaskets. These bulkheads prevent leaks from the pressure vessel. What follows is a list of the major components of the PDSF.

Distribution Arm

Unfiltered water enters the top of the filter through the distribution arm and is broadcast across the top of the media bed. It constructed of 1" PVC pipe in the shape of a cross. The arms of the cross are perforated with ¼" holes spaced at 1" intervals along the bottoms of each of the arms. Three of the four arms of the cross are terminated with PVC plugs while the forth arm is connected through a bulkhead in the PDSF wall to the valve box. The line from the distribution arm to the bulkhead features a PVC union that allows the distribution arm to swing upward and out of the way to facilitate access to the media. This line is plumbed to position the distribution arm as high as possible in the filter body without obstructing closure of the drum lid.

Figure 7-12 (left): Top view of the PDSF. Both the distribution arm and the filter output pipe are visible in this view.

Figure 7-13 (right): Side view of the PDSF at the EWB-CU prototype site in Boulder Colorado. In this view the distribution arm is swung out of the way to provide maintenance access.

Filter media

The filter media rests in the central portion of the PDSF, between the distribution arm and the underdrain. The media is supported by a 6" layer of gravel which prevents the media from entering the underdrain. The primary media used in this implementation is sand with an effective size (D_{10}) of ~0.6mm. This is the typical size for sand in a rapid sand filter. This sand forms a layer 15" deep. Above the sand is a 6" layer of pumice gravel which acts to pre-filter the water so as to lighten the filtration load on the sand and increase the length of the filter backwash interval. Due to its low density, the pumice gravel will remain on top of the sand despite its larger size.

Underdrain

The filtered water passes through the media bed and is collected by the underdrain. The underdrain is similar in construction to the distribution arm, a perforated cross of PVC with three of the cross arms plugged and the fourth connecting the underdrain to the next step in the process. As with the distribution cross, the arms are perforated with ¼" holes at 1" intervals. Unlike the distribution cross however, the underdrain has its holes on the top of the cross arms rather than the bottom. The holes are located on the top of the underdrain to minimize head loss.

Filter output pipe

From the underdrain, filtered water travels upward through the filter output pipe and out of the filter drum to the filter output valves via a bulkhead fitting. The filter output pipe is plumbed so that it rises to the top of the filter body before making a 180° bend and running 6" downward to the filter output bulkhead. This inverted "U" path taken by the filter output pipe serves to define the minimum water in the filter; the principles of fluid mechanics dictate that, once the water level drops below the "U" formation, no more water can exit the filter. This feature facilitates a number of desirable operational characteristics that are explained in the operations section of this report. Additionally, there is a PVC union in the middle of the output pipe to facilitate the removal of the lower portion of the pipe and the underdrain assembly for maintenance purposes.

Maintenance drain

The maintenance drain allows the filter body to be completely emptied of water if the need arises. Like the sediment drain on the settling tank, this drain features a gate valve in a vertical orientation to reduce the possibility of particulates interfering with the operation of the valve. The outlet for the maintenance drain features a perforated plug to prevent the loss of media through the maintenance drain. The maintenance drain can be detached from the filter drum if there is a need to remove the filter drum from the lower housing.

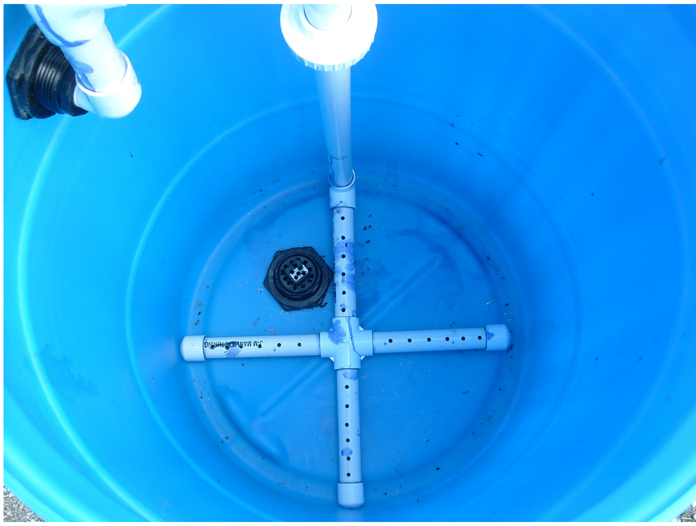


Figure 7-14 (left): A view of the underdrain and the outlet for the maintenance drain (black). Also visible in this figure is the union on the filter output pipe that allows the underdrain assembly to be removed.

Figure 7-15 (right): Rwandan EWB-CU team member, Jean-Pierre Habanabakize, and Mr. Innocent of the vocational school faculty stand by as a test run is performed. The white pipe directly below Mr. Habanabakize is the maintenance drain.

Manometer

Connected to the filter output valve assembly is a thin clear tube that extends upward along the conduit. The tube continues upward beyond the top of the upper housing where it is fixed to vertical piece of rebar extending above the maximum water level of the entire system. This tube serves as a manometer that indicates the water pressure at the output of the filter. When the system is discharging water, the difference between the water level in the manometer and the input bucket indicates the head loss induced by the filter. This reading can be used to determine the degree to which the media is clogged as well as to diagnose problems with the system. There is a fishing bobber trapped in the manometer tube to make identifying the water level in the manometer less difficult.

Ultraviolet System

The Ultraviolet disinfection system utilizes a commercial-off-the-shelf disinfection unit and ballast, the R-Can Environmental Sterilight S5Q-PA 20 liter per minute unit. The system is stored in a waterproof, locked Zarges aluminum box. The necessary electrical and plumbing connections are also enclosed in the box. The system is operated by actuating the electrical timer switch shown on the top of the box in Figure 7-15. This switch turns on the UV system ballast, proving power to the light, while also actuating an electrical solenoid valve to allow the water flow to from the system.

The UV light bulb is enclosed in a protective quartz sleeve that is transparent to UV radiation while protecting the bulb from the water. The components of the commercial UV system are shown in figure 7-16. The water passes through the aluminum tube visible on the right side of Figure 7-17, around the enclosed bulb.

Power is provided to the UV light bulb ballast and solenoid valve via the external power interface visible in the upper left hand corner of Figure 7-17. Power is provided by a waterproof cord transmitting AC power from the solar panel power supply located in an adjacent building. The power cable is protected by a conduit and buried beneath a concrete walkway.

While the manufacturer of the commercial UV unit do not recommend intermittent use of the system because it decreases bulb lifetime, the fact that the BYOW system will be used for much less than 24 hours per day led to the decision to trade off the decreased lifetime against the decreased use. It is predicted that the trade-off is in favor of the BYOW configuration. Additionally, the effect of a recommended warm-up time of the UV unit is being investigated for further BYOW iterations, and possible changes to BYOW operating procedures.

Figure 7-15: UV system box

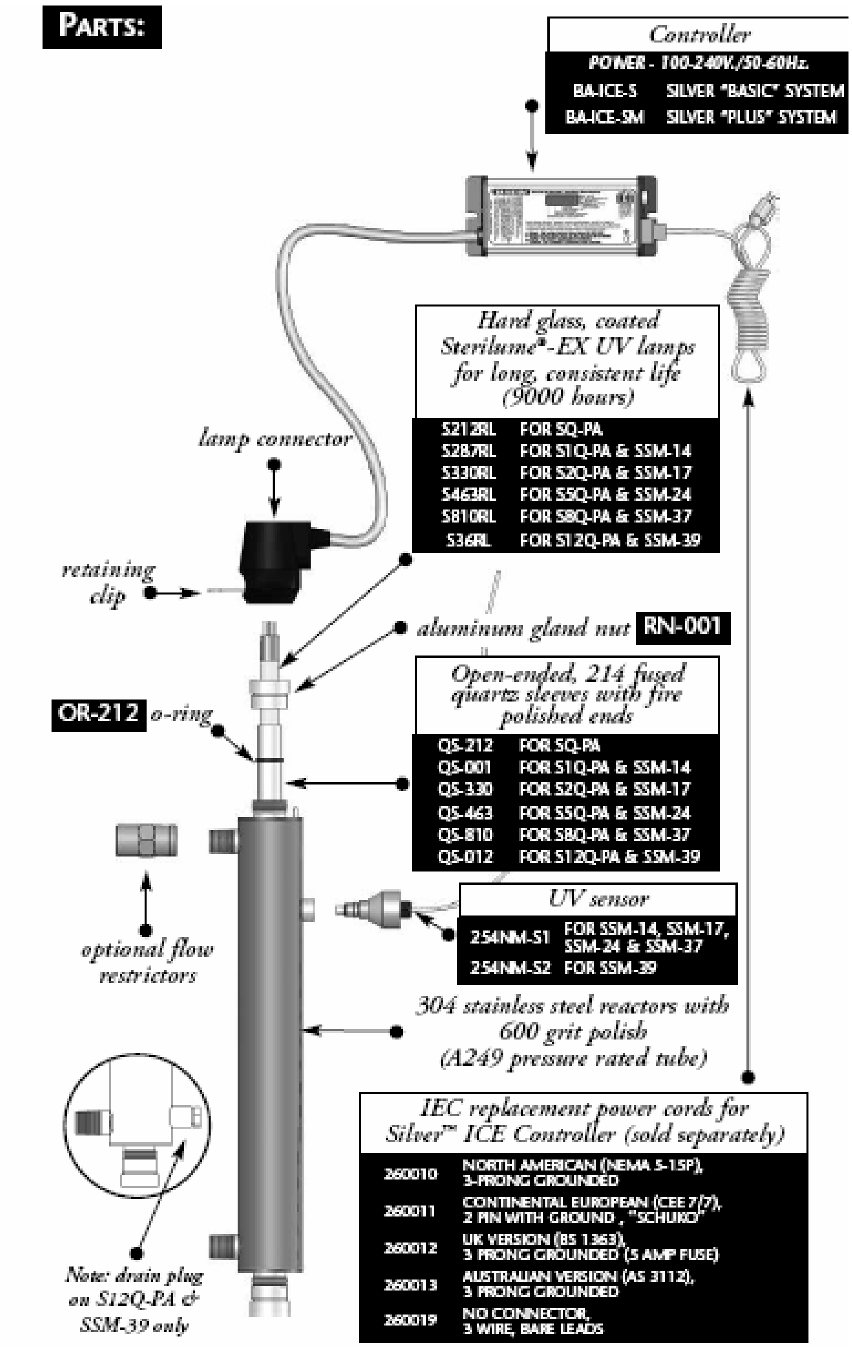

Figure 7-16: Commercial UV unit component description (R-Can Environmental, 2005)

Water valves

Figure 7-17 shows the internal plumbing and electrical connections of the UV box. The green valve visible at the top of the picture is a standard Asco solenoid valve. The purpose of the valve is to allow a one-stop operation of the system. Turning on the electric timer switch simultaneously allows water flow and turns on the UV light. However, should the valve fail, it can be easily removed and water flow provided by a standard hand valve visible in Figure 7-17.

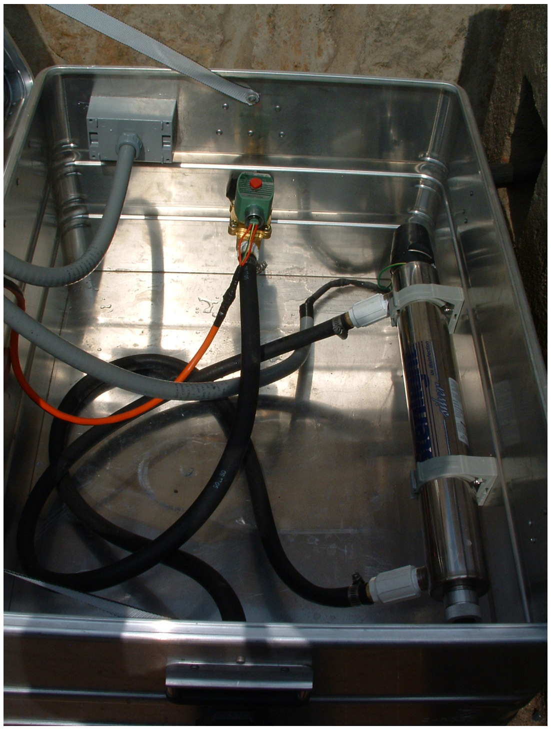

Figure 7-17: Inside of UV system box

Figure 7-18 shows the inside of the box including the weatherproof UV ballast box, shown bolted to the top of the aluminum enclosure box. This ballast regulates the power to the UV unit, and times the total operating time of the UV unit. Should the UV bulb fail or wear out, the ballast will alert users and maintenance personnel with a sustained beeping sound. The box is locked so that only trained personnel may access the UV unit, to minimize the chances of someone being exposed to dangerous UV radiation.

Figure 7-18: Inside of box showing UV ballast control

Photovoltaic power supply

The UV system is powered by a 102 watt solar panel power supply. The total draw of the system is approximately 41 watts. Therefore, the system was sized to provide power to the system for about 7 hours per day, or about 8,400 liters per day.

Table 7-3: Load Summary

Quantity	Load	Watts	Hours Used Per Day	(W hrs/day)
1	UV light and components	41	7	287
Total:				287 W Hrs / day

The system will incur loses from temperature, battery, wiring, DC to AC inverter, and charge controller. Loses due to the charge controller are factored into the wiring efficiency.

The losses due to temperature were obtained from determining the average temperature and peak sun hours in Muramba. The NASA website (*http://eosweb.larc.nasa.gov/sse/*) provides this information.

Table 7-4: Temperature and peak sun hours

Average temp. during 10am to 3pm	24° C
Average peak sun hours	4.76 hrs

Assuming loss of 0.5% per degree C over 25° C, and panels operate at 25 degrees above ambient temperature in Rwanda.

Table 7-5: Operating temperatures

Operating temp. of panels	24° C + 25° C = 49° C
Degrees above ideal temp. of 25° C	49°C – 25° C = 24° C
Lose due to temperature	24° C x .005 = .12

Therefore, the panel alone will be 88% efficient, corresponding to a temperature multiplier of 0.88. Assuming a battery efficiency of 85%, and a wiring and charge controller efficiency of 97%, and a inverter efficiency of 90%, the overall panel factor .88 x .85 x .97 x .90 = .65, therefore the system will have a total efficiency of 65%.

Since the system is about 65% efficient, the watts peak for the array calculation is shown below.

Table 7-6: Panel sizing

Compensated load	297 Whrs/day / .65 = 441.5 Whrs/day
Watts peak for array	441.5 Whrs/day / 4.76 hrs/day = 92.76 W

Therefore, a single 102 watt solar panel will provide the necessary power.

Next, the battery requirements were determined. With the requirements that it is desirable to have at least three days of autonomy (should there be total cloud cover), and that the depth of discharge on the batteries should not exceed 50%, the adjusted total Watt-hours per day is shown below.

Table 7-7: Adjusted total Whrs/day including battery, wiring and inverter losses

Adjusted total Whrs/day	287 Whrs/day / (.85 x .97 x .90) =387 Whrs/day

This is the total amount of Whrs/day that the battery needs to be able to supply to the load to compensate for the losses. Since the depth of discharge is 50%, and there are three days of autonomy, the battery bank will be six times larger than the adjusted total, or 2321 Whrs. The system is 12 VDC, so the battery bank in amp-hours is therefore 2321 / 12 or 193 amp-hours. Therefore, a single 200 amp-hour truck battery was sufficient.

The charge controller was then sized for the required amperage of approximately 3.4 amps. To meet NEC 2005 code, a charge controller that is capable of handling 1.56 times the maximum current was used. An oversized charge controller capable of handing 30 amps was used.

An inverter that is capable of a continuous output of 360W was used to make the system more robust. Inverters that output less than 100W are typically not as durable or permanent as those with higher outputs. The inverter used is designed for marine applications and is conformal coated. Even though the inverter will be housed in its own enclosure it is always important to protect electronic equipment from moisture damage.

The wiring was sized assuming a 2% voltage drop, and a typical short circuit current for the panels of 7 amps. The wire sizing summary is shown below.

Table 7-8: Wire sizing

	Distance	Gage
Panels to charge controller	30 ft	10awg
Charge controller to batts.	10ft	6awg
Charge controller to inverter	6ft	8awg

This system was designed and constructed in the United States and shipped to Rwanda along with the rest of the equipment. The battery was purchased in Kigali, and stored in a cool, ventilated room. The charge controller and inverter were installed in clear-topped Fi-box enclosures.

The solar panel was mounted with a panel frame contracted in Kigali, and the panel was aimed about two degrees north.

7.4.2 Normal Operation

Water treatment with the BYOW system begins when a user pours a container's worth of water into the input bucket on the upper portion of the system. The act of adding water to input bucket effectively "charges" system, providing the hydraulic energy needed to drive the water through the treatment processes. The user then carries their empty container down to the output side of the system at the bottom of the wall. The user places their bucket under the output faucet and activates the electronic timer switch. This switch simultaneously activates the UV disinfection unit and opens the electric solenoid valve, allowing the water to proceed through the treatment system into the user's container. The water will continue flow until the user receives a quantity of treated water equal to that which they poured into the system (or slightly less depending on system configuration), a process which takes about two minutes for a typical 20 liter jerry can of water.


Figures 7-19, 7-20: A local woman pours her water into the system input bucket for treatment and then collects it at the system output by operating the electric valve switch.

Because of the size of the system and the large amount of water that is stored in the three treatment processes at any given time, the user does not receive the same water that they poured into the input bucket. Rather, the user's added "charge" of water serves to displace an equal volume of water through each of the treatment processes. Thus, the user receives water that was poured into the system by previous users.

By design, it is not possible to take more water out of the system than a user puts in. Water will only come out of the faucet if the system has been "charged" by an addition of water from the user. When a volume of water is added to the system, an equal volume is displaced out of the tube settler. This volume of water forms a hydrostatic column above the sand filter and is held in place by the closed output valve. When the valve is opened, the potential energy in the water column forces the water down through the sand filter and UV unit to the user's container.

7.5 Materials and Logistics

The BYOW system was fully prototyped, tested, and the field unit constructed in the United States before departure. The system was then shipped to Rwanda and received by the team upon arrival. The purpose of this was to reduce the likelihood of design failure due to design, materials or construction, as this was the first field unit to be tested. However, all materials used to construct the system were either available in Rwanda or importable with minimal effort. The team worked with the Rwandan government to import the equipment duty-free, and contracted for a flatbed truck to bring the equipment into the community.

The materials required to construct the BYOW treatment system are discussed individually below.

Drums

Three plastic 55 gallon drums with removable lids were procured from the University of Colorado Environmental Services Division. These were purchased in the US and shipped to Rwanda so that the necessary modifications and plumbing didn't have to be performed during our limited time on site. Similar drums can be obtained in Rwanda for future implementations.

Plumbing Supplies

A wide array of basic PVC and Galvanized Iron plumbing fixtures were used in the construction of the BYOW system. They ranged in size from 3/8" to 2" and included valves, junctions, adapters, pipes and bulkhead fittings. These were all shipped to Rwanda, in many cases already plumbed into their assembled position on the drums. This pre-assembly was done to reduce the time needed to install the system.

All of these fittings are available in Rwanda; however, acquiring them in a timely fashion given Kigali's patchwork of plumbing suppliers is quite difficult. The team learned this first hand when an airline baggage handling malfunction caused ~15% of our plumbing supplies to vanish. The team believes that a first attempt at assembling the BYOW system using only locally procured parts would likely take an extra week of finding supplies and adjusting the design to accommodate the differences between local pipe fittings and the NPT fittings that are used in the US.

For example, most of the threaded fittings and pipe that were encountered were in Imperial units. This includes parts found in stores and fittings on buildings that were installed decades ago. This does not seem to apply to larger (>3") PVC fitting.

While threaded fittings were generally compatible, the same is not the case for slip fittings. This seems to be a result of different wall thicknesses that are used in the pipes. The PVC pipe that we encountered does not conform to the US "schedule" system.

The threaded PVC that we encountered was of a high quality. The metal fittings, on the other hand, were of rather low quality. Metal fittings should be inspected before purchase for major defects. This is especially true for unions and other more complicated fittings.

Masonry and Concrete Supplies

The BYOW system required bricks, mortar, and concrete supplies for the construction of the system housing. All these items and the expertise to use them are widely available in Rwanda. The construction of the system required approximately 5500 bricks and 15 bags of cement.

Filter Media (gravel, sand and pumice)

Ungraded gravel is widely available in Rwanda. This gravel was easily washed and graded to suit the needs of the filter. However, graded sand was not found. Instead, “river sand” was used and graded it with sieves. Cleaning and grading this sand is an incredibly time consuming process. Future implementations of the BYOW system should use specialty sand if possible. There may be a company in Kigali that can provide clean, graded sand and this is being further investigated.

Volcanic Pumice is widely in Rwanda as it is located in a volcanic region. Pumice for this implementation was provided by Mr. Aniea Kimaro of the Kigali Institute of Science and Technology.

UV system

The UV system requires the Sterilight UV light, housing and ballast. The system is stored with the necessary plumbing in a weatherproof, aluminum box. Other materials include an electric timing switch, electronic solenoid valve, and manual valves. All of these materials are readily available in Rwanda, although of admittedly lower quality. The UV light bulb itself, the only component likely to need replacement that is not easily available, can be imported by a store in Kigali.

Solar panel power system

The top-level required components for the solar panel system are shown below.

Table 7-9: Components summary

Component	Type, (quantity)
Solar Panels	102W (2)
Batteries	220amphr (1)
Wire	6awg, 8awg, 10awg
Inverter	360W
Charge Controller	30amp (1)

7.6 Construction

Foundation and System Housing

The first step in installing the BYOW system was to excavate 3" of soil and level the ground where the foundations were to be poured. 4" reinforced concrete slabs were poured at the upper and lower construction sites.

Figure 7-21: Foundation and housing construction

The housing was then constructed of bricks by a team of masons hired from the local community. The completed housings were covered with a concrete parge coat to enhance their durability. During this time a 3" thick cover for the valve box was constructed from reinforced concrete poured in a wooden form.

A 4" PVC conduit was run form the upper housing to the lower housing in order to enclose the hoses that carry water between the upper and lower treatment processes.

PV Power system installation

The PV power system installation primary consisted of installing the solar panel on the clinic roof, running the panel wires to the charge controller located inside the building, mounting the charge controller and inverter, and running the AC wires through a waterproof conduit to the UV unit, outside.

Assembly

The three component drums were assembled, tested for leaks and placed within the housings. The sand filter input hose and the backwash hose were installed in the conduit and attached to their respective locations on the drums and the valve box. Likewise, the backwash storage tank and the settling tank were connected to each other and the input bucket. The metal box containing the UV unit was mortared to its pedestal and connected to the output from the filter drum. With all the water bearing components plumbed together, the two vacuum break pipes were covered with screen to prevent the entrance of mosquitoes.

Filter Media Preparation

The gravel was first sifted to remove dust and debris. The gravel was then washed by hand in a small basin until the wash water was no longer visibly turbid. This gravel was loaded into the bottom of the filter body to a depth of 6" thus covering the underdrain.

The ungraded sand was sifted using 2 mm and 0.5 mm mesh. The sand that fell outside this range was then discarded. The graded sand was washed by hand and loaded into the filter body above the gravel to a depth of 15".

The large pumice stones were crushed with a sledge hammer into pieces 1-2" in diameter. This pumice gravel was then washed by hand and loaded into the filter on top of the sand to a depth of 6"

Final Preparations

With the system completely assembled and the media finally cleaned and in place, the filter was backwashed repeatedly until majority of the residual silt in the media was removed. It took about 10 backwashes of the media to reduce the turbidity of the output water from 40-44 FAU (comparable to NTU for most purposes) to 0-3 FAU With the residual silt removed from the media, the system was ready for normal operation.

7.7 Maintenance Procedures

As with all EWB-USA projects, community maintenance of the system is critical to its long term success. To this end, clinic personnel and vocational school staff were educated on the design, construction, operation, and maintenance of the system. The EWB-USA team spent time throughout the construction process discussing the construction and design of the system and answering the questions of the people responsible for maintenance. Mr. Innocent, an instructor at the Kolping Vocational School, was placed in charge of the routine maintenance of the system. The clinic director, Joselyne, assigned the clinic's maintenance director with the duty of looking after the day to day operation of the system. Both Innocent and the clinic maintenance director were walked through the maintenance procedures. These walkthroughs included supervised maintenance practice where Innocent and the maintenance director were requested to perform the maintenance procedures without any external assistance. This was repeated multiple times to ensure that proper understanding was achieved

The individual maintenance procedures are detailed below. Note that what follows is a preliminary maintenance routine and that it may be altered as the team and community gain experience on the system's performance.

Backwash (1-2 times per month)

After a few weeks of normal operation, the sand filter will become clogged with contaminants that it has removed from the water. As water travels downward through the media bed during normal operation, contaminants are removed by physical, chemical and possibly biological processes. These contaminants accumulate in the voids between the media granules and eventually clog the filter, preventing it from passing water at an acceptable rate. At this point, the media needs to be washed to remove the accumulation of contaminants and allow the filter to pass water again. This washing action is achieved by discharging a large amount of water upward through the media in a process known as backwashing. The flow path of the backwash process is displayed in the system schematic in Figure 7.3.

The Backwash process involves running 55 gallons of water from the backwash tank through the bottom of the filter media. By passing a large volume of water through the media in the opposite direction of normal filtration, the backwash process removes debris that have accumulated in the filter thus readying the system for the next round of filtration. As the backwash water travels upward through the filter body, the person responsible for maintenance must stir the upper layer of the media with a rod to help dislodge the filtrand that may adhere to the media. This stirring operation is known as "harrowing" and helps to ensure that the backwash water cleans the media in its entirety. Harrowing must take place for the entire time it takes to drain the backwash tank, which is about two minutes. The entire backwashing process should take no more than 10 minutes. This includes the time needed to remove the lid from the filter, operate the valves to reverse the flow direction, discharge the backwash water through the media (while harrowing) and finally replacing the lid of the filter body and resetting the valves to their normal position.

The backwash process consists of maintenance personnel performing the following actions with a full backwash tank:

-The filter input valve is closed to disconnect the filter from the settling tank

-The filter output valve is closed to prevent water form entering the UV unit

-The lid of the filter is removed to give access to the media and to allow the backwash water to exit the filter.

-The backwash valve is opened allowing the backwash tank to discharge its contents from the underdrain and up through the media.

-The media is manually agitated with a rod while the backwash water tank drains through the open lid, carrying away the accumulated contaminants. This takes about 2 minutes

-The filter lid is replaced and all valves are reset to their original position.

When tap water is available at the clinic, the system operators were advised to refill the backwash tank directly after the backwash process using a hose to the tap. This is to ensure that the operators are not left with an empty backwash tank in the event that the water is cut off at the clinic shortly before a backwash is due. By following this policy, the operators can be sure there will always be enough water to perform one more wash with tap water before switching to user contribution mode in the event of a disruption in the water supply. During the installation, the taps at the clinic were working so the contribution valve was left closed.

When running water is not available at the clinic, the system must be switched to contribution mode. Maintenance personnel were trained in the use of the contribution valve and instructed to open this valve in the event that water stops flowing at the clinic. Opening the valve effectively switches the filter from tap water backwash mode to user contribution backwash mode. The procedure for setting the correct contribution valve aperture for monthly backwash is as follows:

-Determine the monthly throughput in liters and divide 280 by this number. This is the required fraction that must be taken from each load of input water

-Remove the cover of the backwash tank and open the contribution valve slightly, approximately 15 degrees from the closed position.

-Place a container beneath the contribution valve to capture the water that pours from this orifice when water is added to the system
-Fill a large (~20 L) bucket of known volume with water and pour it in to the input bucket as per the normal operation procedure.

-Carry the empty bucket to the system output and retrieve the treated water. It is important that time interval between adding the water to the input and retrieving it at the output be the same as that seen during normal usage.

-Measure the amount of water that came out of the contribution valve in to the container.

-Divide this figure by the volume of water passed through the system to determine the contribution fraction. If this is higher than the required fraction calculated in the first step, decrease the valve aperture and repeat the process. Likewise, if the contribution fraction is lower than the required fraction, increase the aperture slightly and repeat the process.

-Once the contribution valve is set to provide the required fraction, replace the cover on the backwash tank and resume normal operation.

Contribution Mode

The BYOW system was designed to operate in an area where there is no running water as was the case at the clinic during our initial assessment. To accommodate backwashing when tap water is not available, the system was designed to withhold a small fraction of the user's water in the backwash drum for the next backwash. The size of this "contribution" is determined by the aperture size of the contribution valve located inside the backwash tank, (See Figure 7-3).

In contribution mode, a fraction of the user's input water is diverted from the treatment stream and stored in the backwash tank. When the system is operated for a period of a few weeks, enough water will have been diverted from the input water to have completely filled the backwash tank. At this point, the system can be backwashed if need be. While the system is in contribution mode and the backwash tank is already full, users get 100% of their water treated and returned.

Settling tank cleaning (1-4 times per year)

By design, the settling tank can store a few gallons of settled material without adversely affecting the water quality. However, if the settling tank becomes overloaded with sediment, the settled particles may be mobilized by the flow and be reintroduced to the water. To prevent this, the settling tank must be cleared of sediment at regular intervals. This operation is performed by opening the sludge drain on the settling tank and draining the contents. The inside of the settling tank should be inspected to ensure that the sediment has been removed. The settling tank is then refilled and the system is brought back online.

Electronic valve cleaning (as necessary)

Occasionally, the electronic valve diaphragm may become clogged in the closed or open position because of particulates. While this will be a rare occurrence, the maintenance is simple. The valve can be taken apart with four bolts and the diaphragm wiped off.

UV Bulb Replacement (1-2 years)

The UV light bulb is designed to operate for 365 days of continuous use. Because the system will only likely be used for half a day at most, it is anticipated that that the replacement will be required for at least two years. The replacement cost of the bulb to the Muramba Clinic is estimated to be about $100, including all import taxes and shipping fees.

With a worst case estimate of replacement every six months, this translates to a per liter cost of 0.006 cents. The Muramba Clinic volunteered that this cost was worth the value of the treated water to the Clinic and the community. The Muramba Clinic has been put in touch with a water system supply company in Kigali that can import the bulb.

The UV ballast will alert the user when the bulb needs to be replaced by a sustained beeping noise.

PV system maintenance

The maintenance required for the PV power system is minimal. The solar panel must be wiped down occasionally to prevent decreased irradiation on the surface because of dirt. The truck battery acid level must be monitored and topped off occasionally, which is a task performed easily by community members who are already familiar with such batteries. Personnel at the clinic have been trained in monitoring the PV system for proper operation, and have been instructed in resetting the inverter and charge controller should it become necessary.

Long term filter maintenance

Over its lifetime, the filter will require periodic overhauls. Because this is the first implementation of this filter the exact nature of these overhauls in unknown. However, they will at least include the following.

Pumice replacement

The pumice that comprises the top of the media layer will need to be replaced periodically as it becomes encrusted with filtrand and loses its buoyancy. A supply of pumice was left with the community for this use. If this supply is depleted or lost, pumice can be obtained locally.

Sand replacement

Some of the sand will be lost through normal operation and maintenance of the filter. During overhauls, this lost sand will need to be replaced. To replace the lost sand, the operators will need to sift and clean whatever sand is available and place it in the filter. The necessary screens were left with the system operators to facilitate this. In the event of the loss of these screens, the measurements of the screen mesh sizes were included in the maintenance manual that was given to the operators.

Inspection of plumbing for leaks and obstructions

All the plumbing must be periodically inspected for leaks and those leaks patched. Because of the large amount of locations for possible leaks, it may be infeasible to test every junction for leaks during an overhaul. It is more likely that any leaks will be discovered by visually identifying a leaking component during normal operation. Additionally, a leak may be discovered when users notice that the system is “consuming” some of their water when in tap water backwash mode. This is because the system (excluding the backwash tank) must be filled to the baseline water level before water is allowed to pass through the faucet.

Any leaks in the system will cause the water levels in the system to drop below the baseline water level. Thus, the system will "consume" some of the user's water to replace the water that has leaked and restore the water level to the baseline. Only the remainder of the user's water will be returned to the user.

The mechanism described in the previous paragraph can be used to proactively identify leaks by the following method: The system is filled up with a bucket load of water and the faucet immediately opened to drain any excess water above the baseline water level. The filter is then left untouched overnight and in the morning; a measured slug of water is passed through the system with the backwash contribution valve closed. The difference between the volume of the measured slug and the system output from that slug is equal, by definition, to the water lost by leaks in the filter. If this is a significant volume, say more than 500ml, the system requires a thorough inspection for leaks in rusted out components, cracked pipes or worn out hoses.

7.8 Results

Following the installation of the system, the system was backwashed repeatedly to give the media a final cleansing. This action removed the majority of remaining silt from the media. At the outset, the filter was actually increasing the turbidity of the water due to the residual silt in the media. It took about 10 backwashes of the media to reduce the turbidity of the output water from 40-44 FAU to 0-3 FAU. It should be noted that the water that was used to backwash the system had turbidity in the range of 0-1 FAU. Thus, even after this final backwashing, there was still a small amount of residual silt. It is expected that this residual silt will be eliminated through normal operation and backwashing in the months following the installation.

With the media cleaned to the degree explained above, the system's hydraulics and electronics were thoroughly tested. All the components worked as expected and the system had no identifiable leaks.

The operation of the system was tested by treating containers of water in the same manner as the users would: by pouring a containers' worth of water in the input bucket and then retrieving the water at the output. On average, the system processed a 20 liter container of water in less than two minutes, indicating an average flow rate of at least 10 liters per minute.

7.8.1 Water Quality

Following hydraulic testing, preliminary water quality tests were conducted for a variety of water quality parameters. These tests indicate that the system is in fact removing bacteria from the water. The results are summarized in the table below. The complete results of the tests are detailed elsewhere in this report.

Table 7-10: BYOW Quality results

	Total Coliform (CFU)	Turbidity (FAU)	TDS (mg/l)	Nitrate (mg/l)
Input	0-3	0-2	24-25	4-5
Output	0-2	0-3	28-29	3
Change	Down	Up	Up	Down

Additional water quality tests will be conducted on this unit when the team returns to the community in 2007.

7.8.2 Community Dialogue

All members of the community who were aware of our project were generally enthusiastic about the system and were eager to learn about its operation. Clinic and vocational school personnel, the people who are responsible for the maintenance and operation of the system, paid close attention to explanations and were forthcoming with questions. This helped the team understand which parts of the system they were having difficulties understanding, allowing the team to clarify these misunderstandings. However, due to the complexity of the plumbing of the system and the variety of treatment processes involved, it is likely that there is still some educational work that remains to be done in the future.

To facilitate ongoing education on the system, a set of placards were mounted next to the system detailing its operation. In addition, an operation manual was provided to the system operators. Both the placards and the manual are written in French as well as English.

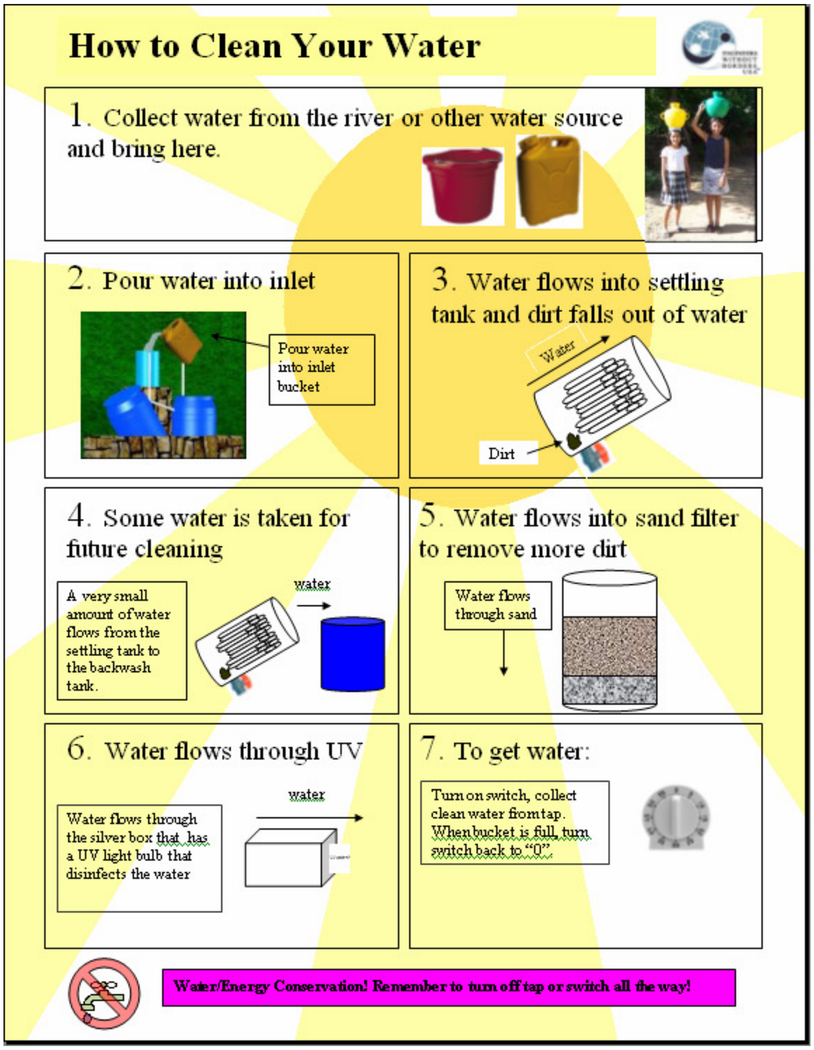

Figure 7-22: The English version of the placards posted next to the system. The version in the field is in French.

Currently the clinic uses boiled water for sterile purposes. The team explained that, while the system will clean water, the output water is *not* sterile and should not be used in place of sterile water for medical purposes. In terms of quality, the water should be regarded as cleaner than the input water but inferior to boiled water.

Following the initial educational efforts, opinions were solicited from the operators regarding the system. They explained that they were concerned that allowing people to use the system independently might result in damage to the electric timer switch. They reasoned that because standard metal ball valves used in the community are frequently damaged through heavy use an electronic timer switch was equally, if not more, vulnerable. Clinic personnel have decided to designate an operator who would be responsible for supervising the use of the system for the first few months of operation. It was agreed that this was a wise precaution and have plans to improve the durability of this component in the future.

7.8.3 Follow up Reports

Five months after the installation of the system, in October 2006, the EWB-USA team requested feedback on the system from the users. The responses indicate the following:

-The system is working without any major problems.

-It is used every day by clinic and pharmacy personnel, patients, and people who live nearby.

-Five times a day, a clinic staff member supervises groups of users who gather to use the system.

-The water used in the system comes from public taps, clinic taps, and containers brought by locals.

-The clinic pipeline has been operational since the installation.

-No major components have broken; however, one of the maintenance valve handles in the valve box is missing and presumed to be stolen. Though the handle is missing, the valve is still operable by using a wrench. This type of vandalism is fairly common in the community. At the time of the email, Mr. Innocent had plans to replace the valve handle.

-The system is backwashed once a month.

-A thorough cleaning of the system was performed three months after the installation. This included cleaning the inside of the tube settler, cleaning the electronic valve, and a backwash.

-Some algae was noted in the “tubes” and removed during the cleaning. It is unknown exactly where the algae was located, but the team presumes that it was in the manometer tube as it is translucent and exposed to sunlight.

-Clinic and vocational school personnel have been educating community members on the use of the system.

7.9 Discussion

7.9.1 BYOW Anticipated Performance based on Literature Review

During the design phase of the BYOW system, a literature review based anticipated performance analysis of the system was conducted to derive worst case performance.

The BYOW system is designed to provide a high volume of water to residents currently drinking turbid and bacteria contaminated water. The BYOW system nominally will not bring water quality up to first world standards, but rather will quickly increase the quality of water for residents accustomed to drinking water of poor quality.

“In most developing countries, the imperative is to get from "bad" quality (say, more than 1,000 fecal coliform per 100 milliliters) to "moderate" quality (less than 10 fecal coliforms per 100 milliliters), not necessarily to meet the stringent quality standards of industrial countries,” (Gadil, 1995).

Rapid sand filtration is a proven technique used to reduce turbidity and bacteria in water. Based on equations provided by (Butler and Mayfield, 2006), the anticipated performance of the PDSF stage of the BYOW system can derived.

A rapid sand filter has turbidity reduction characteristics of between 0.3 log to 0.5 log, and 0.3 log to 1 log reduction of E. Coli (Butler and Mayfield, 2006). Based on a range of inputted turbidity and E. Coli counts, the resultant anticipated performance is shown in Figure 7-23.

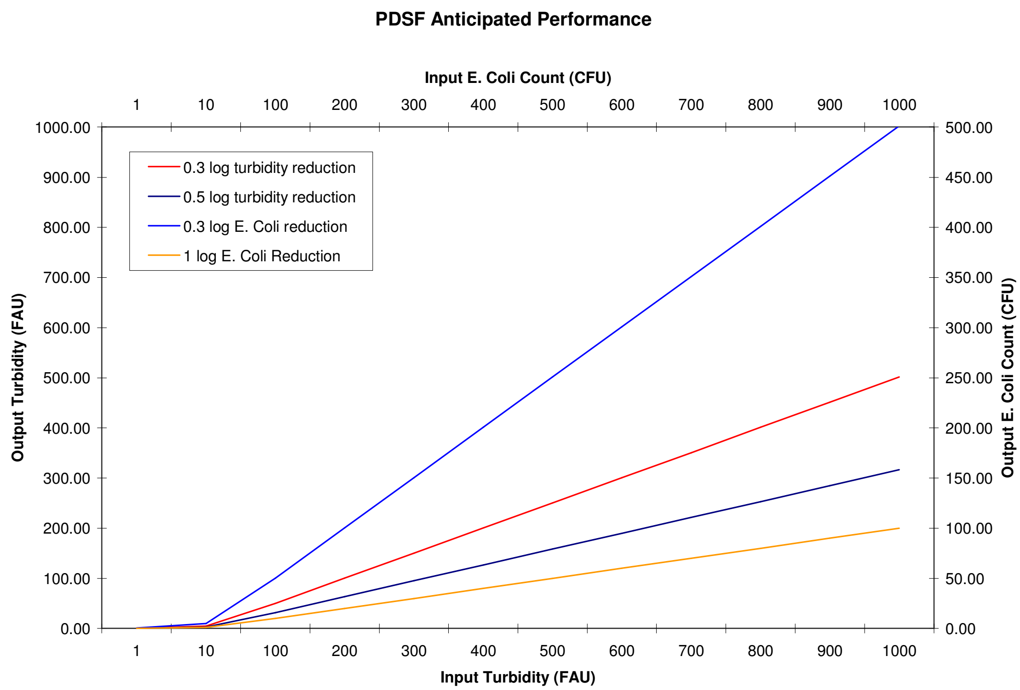

Figure 7-23: PDSF Anticipated Performance

Figure 7-23 indicates that for turbidity the PDSF anticipated performance is to reduction between 50% and 70%, and for E. Coli between 50% and 90%.

The second stage of the BYOW system consists of a solar panel powered UV lightbulb. The specific system used is Sterilight Silver S5Q-PA system manufactured by R-Can Environmental Inc. The bulb operates at 254 nm, and the system is rated to be effective at improving the quality of water to NSF and EPA standards when run at a maximum of 22.7 liters per minute with a turbidity of less than 1 NTU (R-Can Environmental, 2005) (for the purpose of the testing presented here, NTU and FAU are used as equivalents).

While other water quality requirements are recommended, turbidity is the most highly considered. Particulates in the water can interfere and/or absorb the UV radiation and therefore reduce the amount of energy affecting the bacteria (Christensen et al., 2003).

While the recommended turbidity is less than 1 NTU, this is primary because turbidity greater than this is not well understood (Christensen et al., 2003). This should not be confused with the UV treatment being ineffective. The particulates themselves constitute the unknowns, since the particulate size, UV absorption characteristics and concentration dictate the change in UV treatment effectiveness.

The EPA's Interim Enhanced Surface Water Treatment Rule specify that filtration is not necessary for water that does not exceed 5 NTU. Additionally, some laboratory results have shown that turbidity ranges from 7 to 20 NTU have "minimal or no impact" on indicator bacteria inactivation (Christensen et al., 2003).

However, (Christensen et al., 2003) showed promising results for two approaches to determining turbidity effects on UV systems. The first set of data results measured the decrease in UV dose reaching the water as a function of turbidity, with turbidity ranges from 0 to 10 NTU. The second data set measures the decrease in UV dose assumed to be reaching the bacteria, taking into consideration maximum absorption of the UV light by the water. Both data sets showed a nearly linear correlation between turbidity and decreased UV dose. The first illustrates a system like that in the BYOW, wherein the dose emitted by the unit is constant and not corrected for (Christensen et al., 2003).This data set will be considered for extrapolating the BYOW UV unit performance.

The linear results from (Christensen et al., 2003) for 1 to 10 NTU were extrapolated to provide the UV dose reduction up to 100% reduction. These are shown in Figure 7-24. The resulting plot indicates that the dose reduces to zero at approximately 28 NTU. This data was obtained with a transmitted dose of 30 mJ/cm^2 (Christensen et al., 2003).

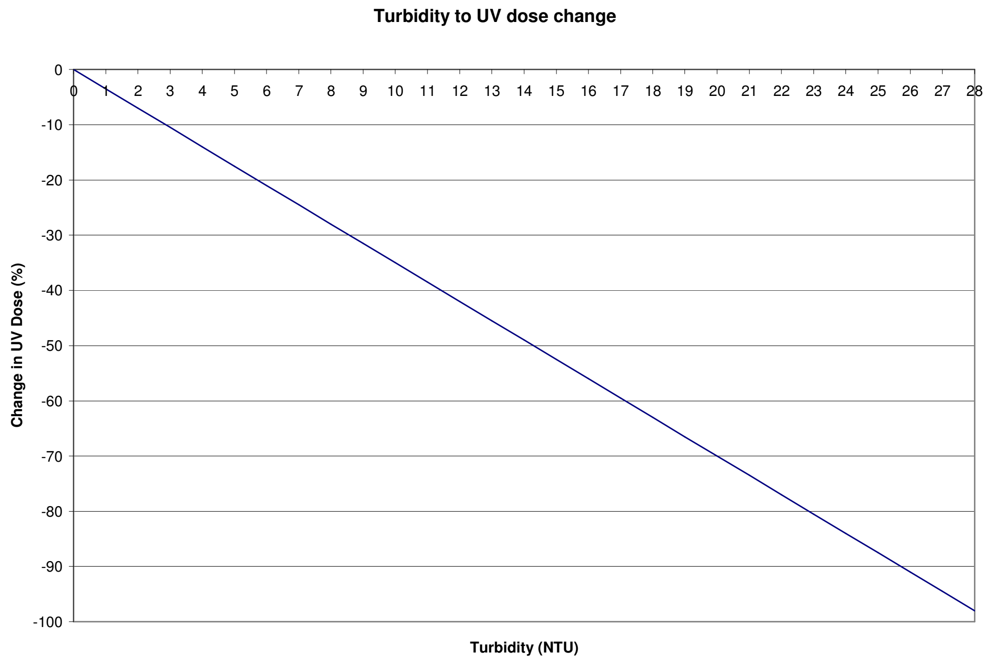

Figure 7-24: Turbidity to UV Dose change (extrapolated from (Christensen et al., 2003))

However, UV dose is a function of residence time, and therefore flow rate. If the flow rate is reduced during turbid events, the dose is increased. The Sterilight device used in the BYOW system has an approximately logarithmic relationship between flow rate and UV dose as shown in Figure 7-25.

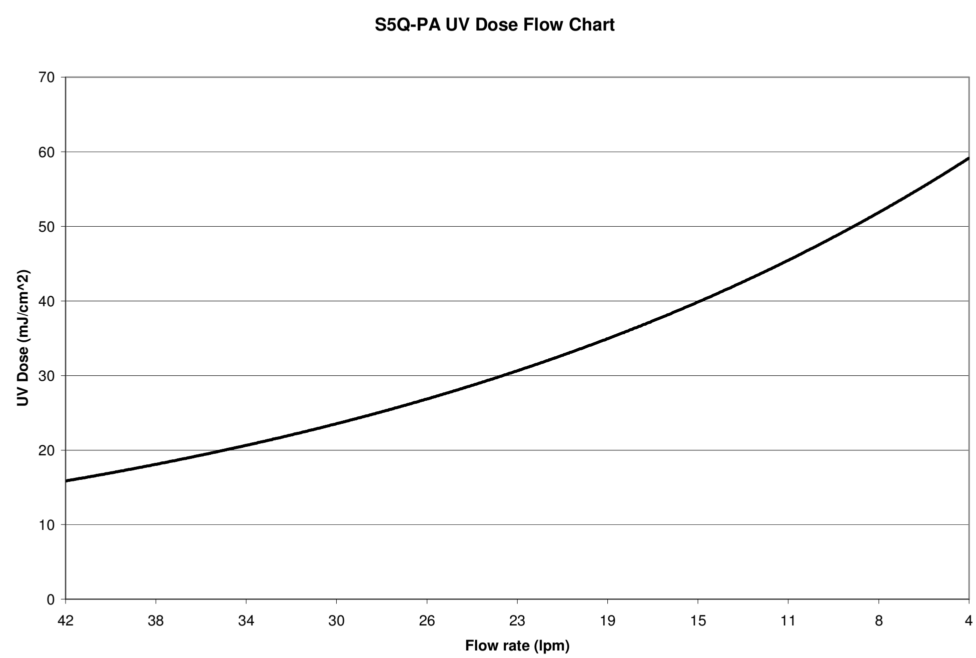

Figure 7-25: Sterilight Dose Flow Chart (extrapolated from (R-Can, 2005))

There is a linear-log relationship between UV dose and inactivation of coliform bacteria (Jolis et al., 2001). This is shown in Figure 7-28.

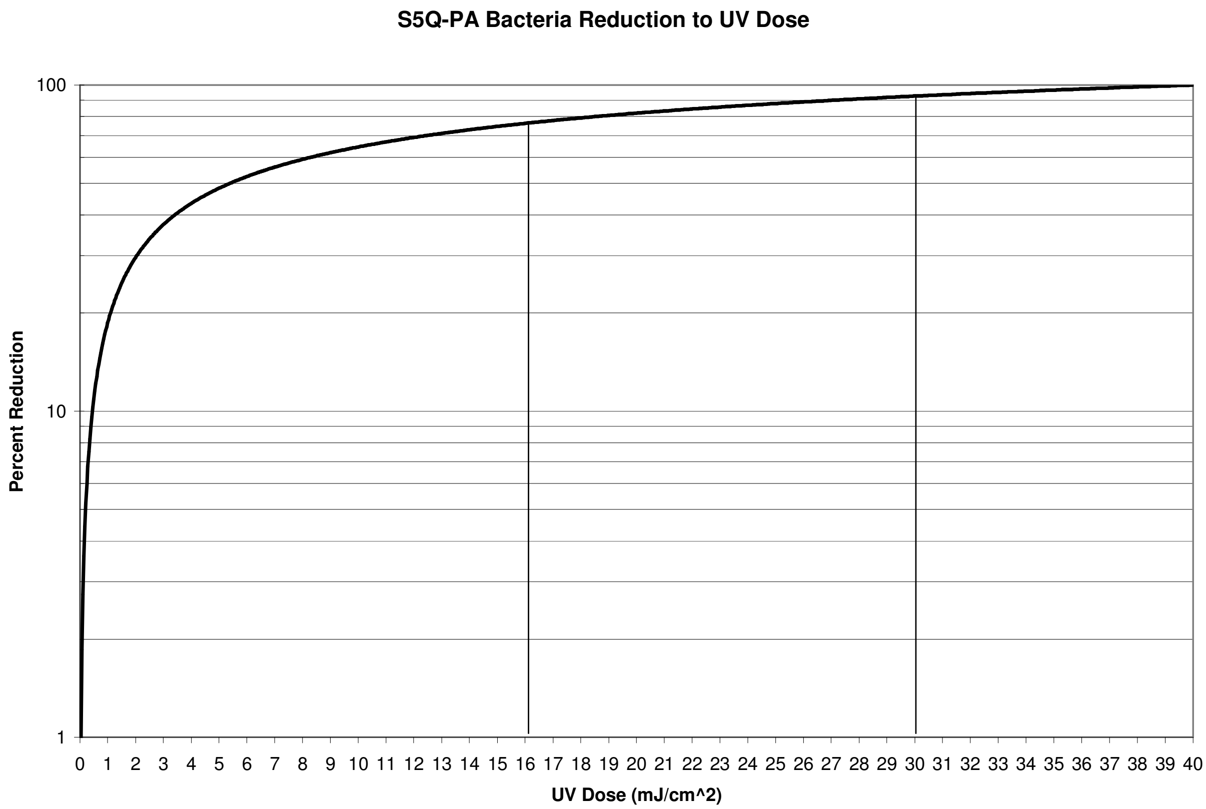

Figure 7-26: Bacteria Reduction Linear-Log (extrapolated from (Jolis et al., 2001))

From these extrapolations, it is then reasonable to extrapolate a BYOW system predicted performance that is anticipated to be appropriate within an order of magnitude. Figure 7-27 shows the resulting anticipated worst case performance of the BYOW system resulting from the above data sets and extrapolations, given varying input turbidities. This plot assumes only 0.3 log reduction in turbidity and bacteria by the PDSF, and a maximum obscuration of UV light of 3.5% per NTU.

Figure 7-28 shows the anticipated average BYOW performance. These curves assume a 0.5 log PDSF turbidity reduction (which is consistent with pilot data results for the PDSF) and a 0.5 log PDSF bacteria reduction. The UV dose reduction is assumed to be 2.5%, given that the range of particle absorption is assumed to be between 1% and 3.5%.

These curves are shown for six different input volume flow rates, and are assumed to be worst case performances in the PDSF and UV filter unit.

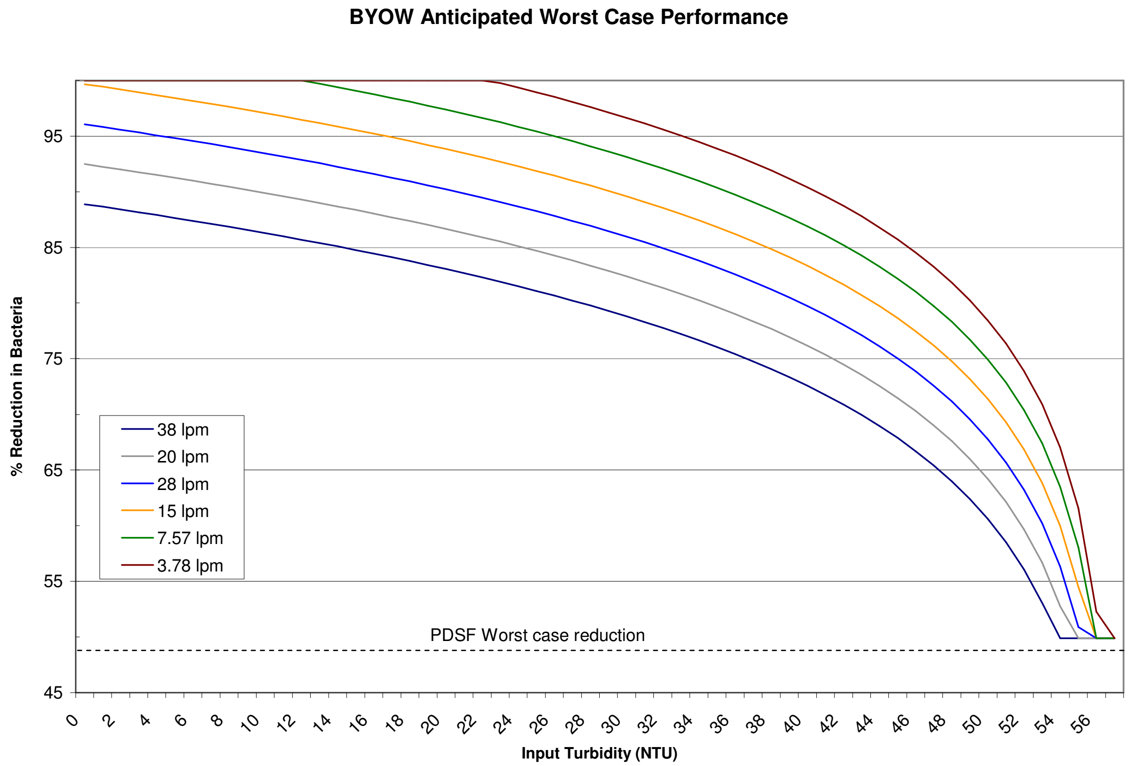

Figure 7-27: BYOW System Anticipated Worst Case Performance

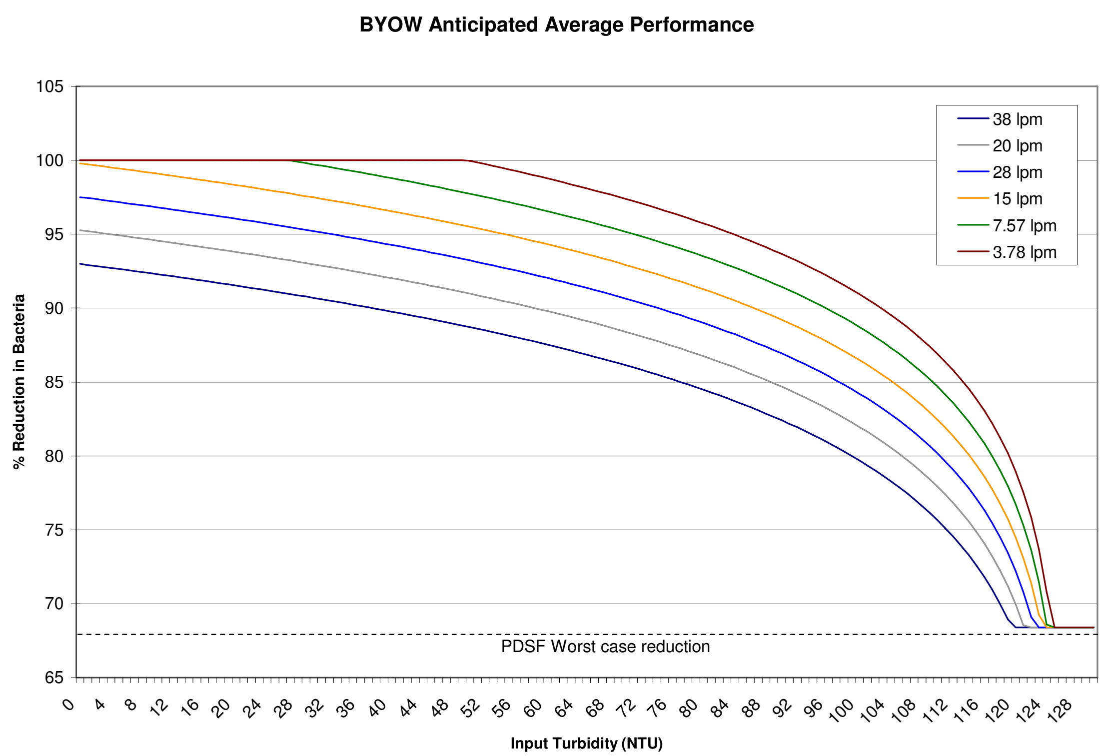

Figure 7-28: BYOW System Anticipated Average Case Performance

7.9.2 Pilot Data Results

A water quality pilot study was conducted on the prototype system prior to the implementation in Muramba. These tests were conducted at the EWB-CU Appropriate Technology Field Laboratory at the University of Colorado at Boulder. The test apparatus utilized an adjustable metal tower constructed from recycled sign posts to create the necessary elevation differential. This tower suspended the upper portion of the system above the PDSF and the UV reactor. The system was fed tap water mixed with silt and horse manure to simulate the bacteria laden, turbid water found in Muramba. The raw water was pumped through the system on an intermittent basis for a period of two weeks to allow the system to stabilize. This intermittent flow was facilitated by the use of an electric valve connected to a timer. Three sets of tests were conducted, taking water samples at the inlet, after the sand filter and after the UV reactor.

Figure 7-29: BYOW prototype at the EWB-CU Appropriate Technology Field Laboratory

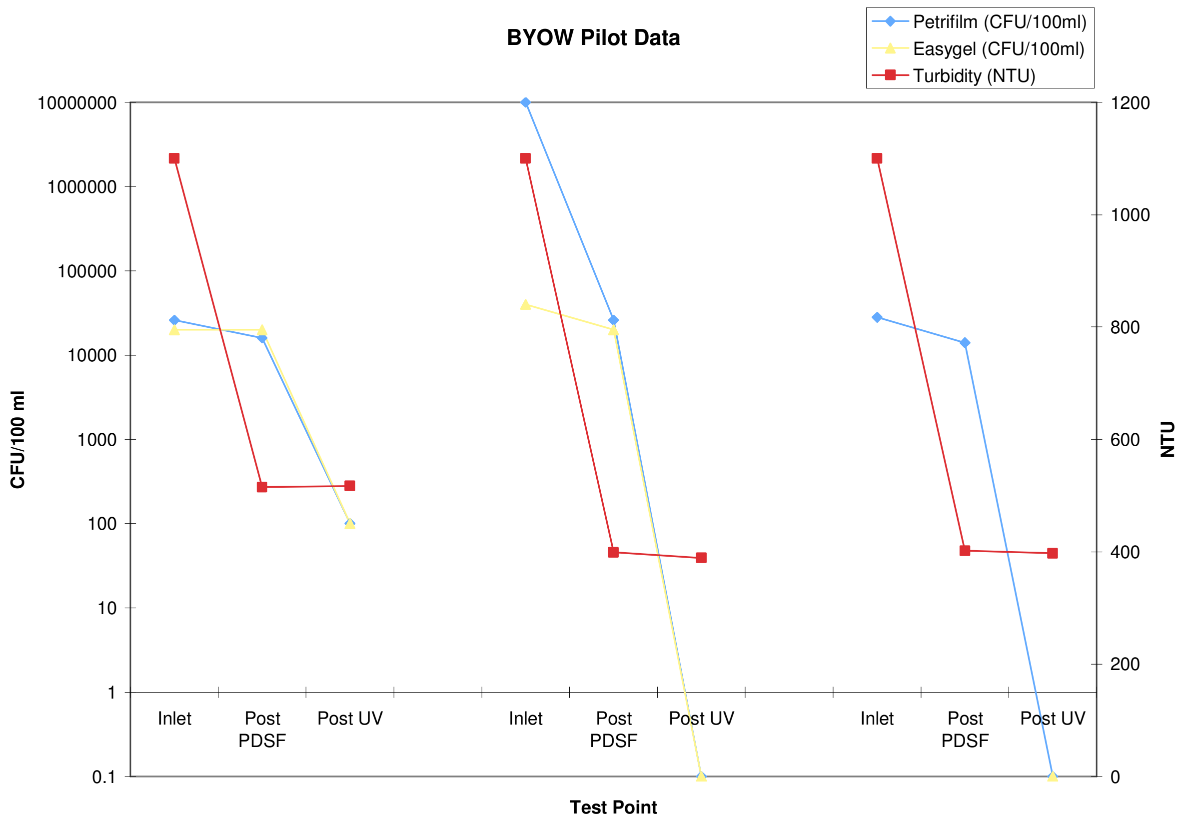

Figure 7-29: BYOW Pilot Data Results

Though the post UV bacterial counts were for the most part zero, the data points were entered to be 0.1, as log graphs can not show zero values. This allows the trends to be seen on the graph. The data was collected at 1:1 and 1:10 dilutions, and the 1:10 dilutions are the data shown on the graph as many of the 1:1 counts were too many to count. 3M Petrifilm provides estimations of CFUs for plates too high to count using several pictures of plates to compare with. Using these pictures, the estimates for the plates too many to count were approximately 10^6 CFU. Coliscan does not provide such information, so the 3M Petrifilm estimations were used. This will be further investigated and hopefully corrected in the near future.

Bacterial tests were done by using 3M Petrifilm tests and Coliscan Easygel tests. The tests were incubated for 23 hours at 35 degrees C. The E. coli counts were taken from 1-ml samples, but multiplied by 100 in order to report them in the standard CFUs/100-ml format. Turbidity measurements were taken using the Hach colorimeter. Readings were taken in units of FAU, which can be taken as equivalent to NTU.

One major concern with our test method is that the bacteria was separate from most of the turbidity as the manure and silt were added separately, and were not taken from a muddy/bacteria filled river or lake. This concern can be seen in the results, such that the sand filter did not contribute to bacterial reduction, and the UV provided a much higher level of reduction than anticipated considering the high turbidity.

However, these results are also encouraging in that the performance of the UV system was significantly higher than the anticipated worst case performance based on the literature review.

7.9.3 Muramba Clinic BYOW System as an Experimental Platform

This installation of the BYOW system is the first field installation of an experimental platform. While all the treatment processes involved are proven technologies, some of them are employed in non-standard configurations. The key difference being that the flow of water through the system is intermittent. It is likely that this alters the effectiveness of some of the processes in one way or another. A major aspect of the ongoing development of this system will involve determining, through research and empirical methods, what these changes are. At this point the team can only engage in educated speculation.

Ethical Concerns

One of the major concerns throughout in the initial development of this system was ensuring that this installation would not, in any way, put the users at risk. Between the reviews of the literature, the supervision of this project by water treatment professionals, and rigorous field testing, the team believes that risks to users have been appropriately minimized.

The most likely worst case scenario would be the finding that is that the system does not provide enough benefit to make the community's effort in maintaining and operating it worthwhile. However, due to the minimal maintenance requirements of the system and its demonstrated ability to improve water quality; this worst case scenario has already proven to be implausible. This assertion remains true even if the relatively fragile UV portion of the system permanently ceases to operate. The other treatment processes employed in the system will still improve the water quality at the Muramba clinic.

It must be noted that our assertion that the system cannot make the water quality worse only applies to the *average* water quality produced by the system. If a user were to pour a bottle of Evian into the system, the water collected at the output would undoubtedly be worse than that of Evian. This is due to the fact that their input water was "perfect" while output water is a treated mixture of other user's lower quality water. This dilution mechanism can be expected to smooth out fluctuations created by variations in input water quality. A more sinister aspect of this mechanism is the possibility that an unscrupulous user would introduce an easily accessible, but entirely undrinkable fluid like urine or battery acid into the system to "steal" treated water from the output, or to poison the water supply. However, sabotage remains a vulnerability for most types of water storage or treatment systems that are not under constant surveillance.

Other possible hazards include the mercury in the UV light that could potentially break and contaminate the water supply. This hazard has been controlled by the design of the reactor that contains the UV lighting within a quartz sleeve, while training has carefully impressed upon the community the importance of proper disposal of the lamp.

Finally, long term stagnation of the system on the order of weeks may present a hazard to the users if hazardous microbes proliferate in the media bed. To address this concern, the operators were instructed to drain the system and clean the media before resuming operation should the system fall into disuse for more than two weeks.

Experimental Process Parameters

As mentioned above, some of the treatment processes in this system are employed in non-standard configurations. What follows is a discussion of the major differences between the processes employed in the BYOW system standard deployments of the processes.

Inclined Tube Settler

The inclined tube settler in the BYOW treatment system is different from a typical inclined tube settler in that the operational loading rate and the settling tube length is significantly lower than those of typical systems. Additionally, the tubes are slightly thinner and the loading of the unit is intermittent instead of constant. While typical tube settlers can effect a 90% removal of turbidity, the performance of the BYOW unit settler is unknown. Raw water entering typical tube settlers is usually pretreated in a flocculator, a process which causes suspended particles to clump together making them more susceptible to settling. The settler in the BYOW system has no such pretreatment. It is likely that this reduces the performance of the settler.

Table 7-10: BYOW tube settler parameters in comparison to typical values

BYOW Inclined Tube Settler Operating Parameters	
Parameter	**Value**
BYOW Inclined Tube Settler Tube Length (m)	0.38
Typical Inclined Tube Settler Tube Length (m)	1
BYOW Inclined Tube Settler Tube Diameter (cm)	**2.8**
Typical Inclined Tube Settler Tube Diameter (cm)	**3 - 5**
BYOW Inclined Tube Settler inclination angle (deg)	55
Typical Inclined Tube Settler inclination angle (deg)	40 - 60
BYOW Inclined Tube Settler Operational Loading Rate (m/h)	**2.24**
BYOW Inclined Tube Settler Average Loading Rate (m/h)	**0.19**
Typical Inclined Tube Settler Loading Rate (m/h)	5 - 7
BYOW Inclined Tube Settler Turbidity Removal Performance (% removal)	Unknown
Typical Inclined Tube Settler Turbidity Removal Performance (% removal)	**95**
BYOW Inclined Tube Settler Operational Reynolds' Number	**42**
Typical Inclined Tube Settler Operational Reynolds' Number	**225**

One of the fundamental principles of tube settler performance is the amount of turbulence in the flow within the tubes: the more turbulence in the tube the less effective the settling action. Generally, these systems are sized to ensure that the tubes are long enough for the flow to transition to the laminar regime long before exiting the tube bank. In this case, the Reynolds number of the flow is smaller than the typical value by a factor of five. It is likely that this compensates for the shorter tube length in the BYOW inclined tube settler.

While the lower Reynolds' number is encouraging, there is little in the literature on intermittent flow tube settlers thus effect of intermittent flow on settler performance is difficult to determine via a literature review. On one hand, the intermittent flow could disrupt the desired sedimentation action. On the other hand, the longer residence time associated with intermittent use could increase sedimentation effect due to the longer time scales involved. Further research will be required to ascertain the effect of the inclined tube settler in the BYOW system.

Plastic Drum Sand Filter

The sand filter in the BYOW system has a few differences from typical sand filters and is in fact a hybrid of a rapid and slow sand filter designs. Foremost of these differences is the fact that there is minimal pretreatment prior to the PDSF. While typical filters have pretreatment processes or other types of influent control, the PDSF influent is quite variable with the only pretreatment process being the tube settler. The likely result of this situation is that the filter will clog more rapidly and the effluent will be of lower quality then in a typical RSF based plant.

To counteract the more rapid rate of clogging associated with running PDSF without standard pretreatment, the filter bed area is oversized by a factor of four. This results in a loading rate that is four times lower during normal operation. To frequency of maintenance is further reduced by the intermittent nature of PDSF usage in the BYOW system. This results in an average loading rate of 0.19 m/h given the current daily throughput of 1200 L/day. This is about 2% of the loading rate in a typical rapid sand filter. Based on these figures and the fact that the filter is backwashed on a monthly basis, it appears that the effect of using raw water with minimal pretreatment in the PDSF results in a seven fold increase in maintenance frequency.

The maintenance process itself is also somewhat experimental in nature. This is due to the relatively long filter runs and the fact that the current backwash system is smaller than the recommended size by a factor of at least two. This situation results in incomplete fluidization of the media bed during the backwash. To offset this effect, the operators must perform the harrowing process concurrently with the backwash. During the harrowing process, the operator stirs the media to ensure that the accumulated filtrand is completely dislodged from the media and discharged with the backwash water.

On a traditional rapid sand filter this process is not needed as the backwash is performed daily and the flow is strong enough to remove all the accumulated filtrand. Because the sand filter in this implementation is quite different from a traditional rapid sand filter, the optimal filter washing strategy is unknown. It is likely that the longer filter runs produce a more tenacious bio layer on the top of the media. This could necessitate harrowing regardless of filter size in order to prevent "mud balls" from forming during backwash. The current maintenance procedure is probably sub optimal and improving it may require changes in the hardware and the maintenance protocol. Any updates to the maintenance protocol will have to account for the fact that the maintenance frequency will be affected by changes in system usage numbers and seasonal fluctuations in source water quality.

Table 7-11: BYOW operating parameters compared to those of rapid and slow sand filters

BYOW Plastic Drum Sand Filter Operating Parameters	
Parameter	**Value**
Daily Users (Persons)	60
Daily Water Consumption (L/Person/Day)	20
Total Water Consumption (L/Day)	1200
Amount of water treated (L/month)	36000
Operating Flow Rate (L/min)	10
Average Flow Rate (L/min)	0.83
Total System Volume (L)	603
BYOW System Residence Time (h)	12
PDSF Media Effective Size, D_{10} (mm)	0.55
Typical RSF Media Effective Size, D_{10} (mm)	>0.55
Typical RSF Media Effective Size, D_{10} (mm)	0.25 - 0.3
PDSF Media Depth (m)	
Pumice	0.10
Sand	0.38
Gravel	0.15
Typical RSF Media Depth (m)	
Sand	0.6 - 0.7
Gravel	0.30 - 0.45
PDSF Filter Bed Area (m^2)	0.27
Typical RSF Filter Bed Area for this operating flow rate (m^2)	0.01
Typical SSF Filter Bed Area for this operating flow rate (m^2)	0.20
PDSF Operating Loading Rate (m/h)	2.24
PDSF Average Loading Rate (m/h)	0.19
Typical RSF Loading Rate (m/h)	5 - 20
Typical SSF Loading Rate (m/h)	0.1 - 0.4
PDSF Operating Pressure (m H_20)	4
Typical RSF Operating Pressure (m H_20)	1
PDSF Filtration Run Duration (days)	30
Amount of water used for backwashing (L/month)	241
PDSF Head Loss (m)	
Initial	1
Final	3
Typical RSF Head Loss (m)	
Initial	0.3
Final	2.5
Backwash Tank Storage Volume (L)	241
Typical RSF Backwash Tank Storage Volume for this area (L)	560 - 2810
Backwash duration (min)	2
Typical RSF Backwash durration (min)	3 - 15
Backwash Flow Rate (m/min)	0.45
Typical RSF Backwash Flow D_{10} = 55, % expansion = 30% (m/min)	0.7
% of User Water Needed for Maintenance (%)	0.7
Typical RSF %	4 - 6
Typical SSF %	0.2 - 0.6
Observed PDSF % Turbidity reduction at 1000 NTU	50%
Typical RSF % Turbidity removal at 1000 NTU	60%
Observed PDSF % Coliform removal at 1000 NTU	73%
Typical RSF % Coliform removal at 1000 NTU	75%
Typical SSF % Coliform removal at 10 NTU	99.9%

The use of intermittent sand filtration is also a somewhat experimental endeavor. Traditional sand filters are almost always continuous flow systems. Recently however, there have been some implementations of household scale intermittent slow sand filter like the Bio-sand filter made by Bushproof in the United Kingdom. Because the PDSF is, in some ways, a hybrid of rapid and slow sand filters, findings on the performance of the Bio-sand filter are probably not entirely applicable to the PDSF. In fact, due the use of RSF sized media in the PDSF, it is probably more appropriate to view the PDSF as a rapid sand filter operated at a low loading rate rather than a slow sand filter with a backwash tank. This assertion is bolstered by the fact that the treatment performance of the PDSF is very similar to that of a typical rapid sand filter.

UV Disinfection Unit

The relevant literature indicates that the UV disinfection unit is not capable of disinfecting water with turbidity higher than 30 NTU. Due to the performance limitations on the tube settler and the PDSF, it is possible that very turbid inputted water may not be fully treated. In order to address this concern, the literature review presented earlier in this paper was conducted.

7.9.4 Actual System Performance

The hydraulic performance results are promising. The system seems to be functioning very well in terms of mechanics and hydraulics while the preliminary treatment results are somewhere between adequate and promising.

According to reports from the community, clinic personnel operate the system for groups of patients and local residents five times per day. Assuming that these groups contain 12 people on average, each of whom treats 20 liters of water; the throughput of the system would be 1200 liters per day or 36,000 liters per month. Reports indicate that the operators have been backwashing with a full drum of water once per month. This works out to backwash losses about 240 liters per month, less than 1% of the total throughput.

The system is being backwashed with water from the pipeline as the clinic line has been operational since the installation. Because of this, the backwash contribution feature has remained off and users have been retrieving all the water that they pass through the system. In the event that the pipeline is shut off and backwash water is unavailable the operators will have to activate the contribution feature on the system. Fortunately, the contribution will likely be unnoticeable to the users as less than one percent of their water will be required.

Results of water quality tests

It is likely that the preliminary water quality test results are not completely indicative of the true performance of the system as the media in the sand filter has not yet reached an equilibrium state. There is still some soluble material in the media that is being dissolved and removed during normal operation. This is indicated by the increase in TDS (total dissolved solids) from input to output readings. As mentioned above, some silt remains in the media. This is indicated by the increase in turbidity from input to output. Furthermore, any potential biological treatment action in the media would not have developed by the time of testing.

Table 7-31: BYOW Quality results

	Total Coliform (CFU)	Turbidity (FAU)	TDS (mg/l)	Nitrate (mg/l)
Input	0-3	0-2	24-25	4-5
Output	0-2	0-3	28-29	3
Change	Down	Up	Up	Down

Additionally, the water used to fill, operate, and test the system was relatively clean during the installation. This was due to seasonal fluctuations in water quality and supply in the area. During periods of lower water quality, the performance of the system is expected to be more pronounced. One such period is during the rainy seasons, when runoff washes more contaminants into collection points. Another situation where the input water would be significantly more contaminated is when the pipelines around the clinic are turned off. When these lines are off, water is collected from rivers which are often highly contaminated. A more comprehensive series of tests will be conducted on our next visit as part of our ongoing monitoring program

7.9.5 Economic Analysis

The total cost of installing the BYOW system was about $2700. Assuming a ten year system lifetime *and current usage numbers*, this works out to less than a tenth of a cent per liter of water treated. The typical unskilled laborer in rural Rwanda makes about a dollar per day. Assuming they consume 3 – 4 liters of water per day, the cost of clean drinking water is less than a third of a percent of their income.

Table 7-12: Economic Figures

BYOW Economics		
Capital Costs		
UV disinfection System	$900	
PV Power System	$1,000	
Drums, Pipes and Fittings	$500	
Construction Materials	$250	
Hired Labor	$80	
Total	**$2,730**	
Lifecycle Analysis		
Estimated lifecycle	10 years	
Estimated annual maintenance costs	$50	
Lifecycle cost	$3,230	
Treatment Cost		
Daily users	Lifetime water throughput (ML)	Cost of Treatment (¢/L)
60 (estimated current usage level)	4.32	0.075 ¢
100	7.2	0.045 ¢
200	14.4	0.022 ¢

When compared to a lead competing technology the Filtron, which requires on average replacement every 1-2 years of two dollars and filters about 2 liters per hour, and therefore a cost of 0.027 cents per liter, the BYOW system even with low current usage levels, is more affordable.

7.9.6 Potential System Improvements

The BYOW design is currently being improved upon based on experiences during the initial implementation. The improved design will be implemented in the summer of 2007 through upgrades to the existing clinic system and a new implementation, in slightly different conditions at the Mugonero Orphanage in Kibuye. The redesign and retrofit process will likely continue for the next few years as wrinkles are ironed out of the system. Potential improvements identified during the Muramba implementation include the following:

Electronic Switch Improvement

The electronic switch used to control the UV reactor is a plastic timer switch similar to what would be found in a typical sauna. It is unlikely that a part of this quality will last another year and a search is currently underway for a more robust replacement. The replacement should be industrial grade and preferably made of corrosion resistant metal. Upgrading this component will encourage the clinic administrators to allow unsupervised use of the system which should result in more frequent usage.

Manometer Improvement

One of the main functions of the manometer is to indicate the degree of filter head loss so the operators know when it is time to backwash the filter. Presently however, the manometer is not used for this purpose because the operators were instructed to backwash at monthly intervals instead. As those responsible for the system become more familiar with its workings, we intend to begin using this feature in order to increase the effectiveness of the maintenance process. In preparation for the larger role this feature will play in maintenance operations, we will need to make an improvement to the visibility bobber that is used to make the fluid level in the manometer more visible to the operator. The current bobber is prone to adhering to the inner surface of the manometer tube and remaining suspended above the actual fluid level. This is likely caused by the cylindrical shape of the current bobber which presents a larger contact surface to the inner wall of the manometer. The size of this contact surface is proportional to the surface tension forces causing the undesirable adhesion. Therefore, the replacement bobber should be spherical in shape to minimize the area of the contact surface and the adhesion associated therewith.

Incomplete Backwash Fluidization

As stated in the “experimental” section of this report, the backwash mechanism may need some improvements. Work is currently underway to determine the best course of action. Some of the options being considered are as follows:

-Investigate the pre and post backwash output turbidities for existing strategy and leave it unchanged if the results are acceptable. There is a chance that the harrowing process compensates for the undersized backwash system resulting in an adequate backwash strategy. The testing procedure for this determination would also involve monitoring post backwash head loss to see if it is increasing over time. A gradual increase in this value would indicate that the filtrand which is not completely removed with the current maintenance strategy is accumulating in the media.

-Increase the diameter of the plumbing on the PDSF and backwash tank beyond the present value of 1". This would make the backwash process more effective by increasing the velocity of the wash water.

-Redesign the underdrain to distribute the backwash flow more evenly. Currently, a column of media in the center of the bed fluidizes completely, while the surrounding media expands less than 5% in volume. By resizing and re positioning the holes in the underdrain, more uniform bed expansion may be achieved. However, even with the optimal underdrain, the flow rate might still be too low to achieve proper bed expansion (see Table 7-11). One strategy for reconfiguring the underdrain would be to reposition the holes toward the outside of the filter drum. This might alter the fluidization pattern so that the fluidization occurs on the outer portion of the media bed. During backwashing, this would result in a freestanding column of unfluidized media in the center of the bed. This unsupported column might collapse into the outer region of the media bed and result in cycling (similar to convection in a kinematic sense) of the media through the partially fluidized bed.

-The current maintenance procedure calls for the lid of the filter to be removed to allow for harrowing. This places the lower limit of the backwash driving head at the top of the filter body. If the harrowing process can be eliminated from the maintenance strategy, the lid can remain closed during backwashing. In addition to simplifying the maintenance process, removing the harrowing process could also allow the backwash to operate with a larger driving head by routing the wash water output to the bottom of the filter housing. Positioning the backwash outlet at the bottom of the system adds an additional meter of head to the process by increasing the elevation differential between the backwash tank and the outlet. This effect is due to the suction induced by the water traveling down the backwash discharge pipe.

-There is a nearly linear inverse relationship between media size and bed fluidization (Okun 1985). Decreasing the media size could allow an increase in backwash efficiency without changing the plumbing in the system. This would have side effects that include lower output flow rate, more frequent maintenance and higher filter performance.

(It should be noted that this implementation of PDSF has a longer maintenance interval and lower loading rate than a typical RSF (see Table 7-11). This may lead to an increase of biomass growth on the media. If present in large enough quantities, this biomass may require mechanical harrowing regardless of improvements to the backwash system. This would be due to the cohesive nature of the bio mat which may be too strong to be disrupted by high velocity water).

Backwash Contribution Overrun and Backwash Water Quality

When in user backwash contribution mode, the system is designed to draw off a fraction of the user's input for use storage in the backwash tank. This is regulated by a valve on the diversion pipe that routes part of the users from to storage. When the user charges the system with a buckets' worth of water, the water level in the system rises above the level of the diversion pipe and water flows into the backwash tank. This continues until the user opens the outlet and begins to retrieve their water. As the user collects their water, the water level in the system decreases below the level of the backwash diversion pipe and flow to the backwash tank ceases. Because of the mechanism at work here, the time it takes the user to move to the outlet and activate the switch is roughly related to the size of their contribution to the backwash supply. Thus, for a given contribution volume, the correct contribution valve aperture is inversely proportional to the average time between user input and collection. With this mechanism in place, a user who delays retrieving their water from system is at risk of making a disproportionately large contribution to the backwash supply.

One way to address this issue would be to position the backwash contribution diversion after the output valve. This would change the mechanism so that water only flows to the backwash tank while the user is retrieving their water. Because the amount of time spent retrieving the water is proportional to the amount of water treated, this would have the effect of making the contribution size proportional to input volume rather than the length of time between input and collection.

Another benefit of this modification would be that the water which is routed to the backwash tank would be treated. This would be an improvement in that the water which is currently used for backwashing is untreated. The result of using untreated water for backwashing is that some of this water remains in the media after backwashing is complete and eventually ends up in the system effluent. It should be noted that while the current backwashing scheme uses water that has not yet passed through the filer or UV unit, it does spend a few weeks in the tank before being introduced to the media during the backwash. This storage time likely has a slight treatment effect on the wash water through the die-off of harmful microbes and the settling of suspended solids.

While this modification would kill two birds with one stone, it is not without drawbacks. For one, there would have to be some major modifications to the plumbing. Secondly, the tank might have to be lowered relative to the input bucket in order to ensure that the treated water can reach the backwash tank after overcoming the head loss of the media. Because of the difficulties involved in implementing this solution on an existing system, it is unlikely that it will be implemented on the Muramba Clinic BYOW system. However, this feature may be useful on other implementations.

Backwash Tank Filling Without User Contribution

Currently the maintenance protocol dictates that, when the pipeline at the clinic is running and the filter is not in user contribution mode, the contribution valve remains closed. This requires the operators to remove the lid from the backwash tank when they want to fill it. To simplify matters it would be better to have the operators leave the contribution valve completely open in this mode.

Prior to backwash, the hose would be placed in the input bucket and the system filled to the top of the input bucket giving the system a final charge. The backwash procedure would then be run. This would have the effect of increasing the volume of the backwash slug beyond the capacity of the backwash tank by adding volume of the final charge to the flow. The hose remains in the input bucket while backwashing is completed and the valves are restored to standard operating position. The hose is left in the input bucket until the backwash tank is refilled. Once the tank is full, the hose is removed and filter is ready for use, with the backwash water for the next wash already in place.

While the contribution valve would remain open during the entire filter run, no user water would be diverted since the backwash tank is already full. The result of implementing this protocol is that the operators are forced to refill the backwash tank following a wash; otherwise, the system will consume user water until the backwash tank is full. In the event of pipeline failure, this ensures that the system has wash water for one final backwash before transitioning to user contribution mode. Additionally, forcing the operators to fill the backwash tank directly after a wash increases the quality of the wash waster by maximizing the storage period as explained above. Finally, this would also decrease the complexity of the backwash process.

7.9.7 Monitoring plans

The Muramba community is working closely with EWB-USA to monitor the performance and usage characteristics of the BYOW system. Parameters of interest include input and output water quality, source of water input, number of people using system per day and per season, maintenance tasks, and backwash interval. These monitoring steps are conducted over email, and planned visits by EWB-USA.

Interim Monitoring

In this period between implementation and our next visit, there are a few matters that we are keeping an eye on. These matters include:

-Keeping tabs on usage statistics
-Monitoring for component failures
-Monitoring the status of the clinic pipeline
-Filter media performance: Is the current maintenance protocol working?
-User and operator opinions and suggestions

Field Monitoring

The team is currently developing a set of monitoring tasks that will be performed on our next visit. At present, this list includes the following:

-Run a battery of flow rate and head loss measurements to determine ant long term changes in hydraulic performance

-Run a through battery of water quality tests at various points in the system while controlling for the systems position in the maintenance cycle:
-Source buckets
-Settling tank output (can be drawn from contribution valve)
- Backwash tank
- Filter input
-Filter output
-UV disinfection unit output

7.9.8 Education Plans

Due to the evolving nature of the system and our understanding of its performance, the contents of the written educational materials will be updated on a regular basis. This is to ensure that the manuals and placards reflect any changes in the operating protocols and the design of the system. The next edition of the educational materials will include the following:

-Updates to reflect any changes made in summer 2007

-Updates to the maintenance protocol to reflect the improvements suggested under the "*Backwash Tank Filling Without User Contribution"* heading in section 7.9.6.

-A warning that advises operators against opening the PDSF when it is pressurized, an act that could cause injury or damage to the system.

-A step by step tutorial on the maintenance of the electric valve in the UV unit.

-A basic explanation of the treatment principles used in the system. This will serve to demystify the system to its operators

-A detailed schematic and component descriptions similar to the content of section 7.4.1 of this report.

7.9.9 Lessons Learned

Among the numerous learning opportunities that came with taking a system from the drawing board to implementation in a developing community, there were two lessons that are particularly relevant to others attempting to do similar projects in the future:

First, the value of a comprehensive assessment cannot be understated. Furthermore, all assessments should be accompanied by follow up communications to monitor changes in the community that can influence the implementation. A good illustration of this need comes from our experience with the pipeline at the clinic.

Our assessment of the clinic indicated that the pipeline was rarely operational and that it could not be relied upon for design purposes. In the interim between that assessment and our implementation, the pipeline was improved and connected to a new source. When we arrived, we found that the pipeline had been operating consistently for months. Had we known of these improvements, we may have decided upon a different treatment solution for the clinic. A facility with a pressurized distribution line can be improved with a wide array of traditional treatment methods that rely on the pressure pipeline for their functionality. In this scenario, traditional systems are cheaper and better understood than our experimental system which was designed for a facility without running water. However, it remains to be seen how reliable that pipeline is in the long term.

Given the uncertainty about the long term reliability of the pipeline and the fact that our directive is to implement systems that can operate in variable conditions; we probably would have installed the BYOW system regardless of any prior knowledge about the line. This is because the BYOW system can treat water from the line as well as water from alternate sources, making it more versatile than a system whose functionality depends on the status of the pipeline. Either way, it would have been nice to know about the line prior to our arrival. This is something that could have been achieved through post assessment follow-up communications.

The second major lesson that we learned relates to a more technical matter: filter media. The sand that was used to fill the PDSF took an incredibly long time to wash and the process consumed thousands of liters of water. Our original intention was to wash the sand by running the backwash process several times over. However, the sand contained so much silt that multiple backwashes did not significantly reduce the high turbidity of the wash water. This indicated that the sand was still unacceptably dirty after these initial washes. As a result, the sand had to be removed from the filter and thoroughly washed by hand in parcels no larger than a few kilograms. Washing the sand by hand proved to be an incredibly long process that required a very large amount of water and a team of 10 laborers working for two full days. Future implementations of sand filters should take into account the time and water required to wash the filter media. This can be done by scheduling extra time for media washing and securing an appropriate source of wash water beforehand. An alternative to washing sand is to procure pre-washed sand from a commercial supplier if one can be located.

7.9.10 Project Sustainability and The Way Forward

At this point, the BYOW treatment system is still a prototype. Ultimately, we want to get Muramba Clinic system to a point where if the EWB team never returned, the system would continue to work for at least 5 years. However, because this system is an evolving prototype, both EWB-USA and the community recognize that continued involvement by EWB-USA over the next several years will help ensure the success of this design and identify improvements. With continued development, we believe that this type of system could eventually become a viable option for communities who are looking for a low cost, community-scale water treatment solution that can be constructed with locally available skills and materials.

In the short term, the system's success will be measured by continued use of the system for treating residents' water and reduced prevalence of water borne illnesses at the Muramba Clinic.

In the long term, success will be measured by ongoing community maintenance of the system and the replication of the system at other facilities in the region.

To encourage long term sustainability, the EWB team must convey a complete understanding of the system to the operators so that they can maintain the system and fix components as they break. A critical component of this effort is the creation of a comprehensive manual that details the operation of the system in its final state. However, due to the evolving nature of the system at this point, the creation of a final manual is not possible. First, the system must be improved to the point where it can be finalized. This will require building on the initial design to address the remaining issues. Concurrent to the finalization of the Muramba system will be research into the generalized case of the BYOW system. Some possible R & D avenues are listed below.

- Research the treatment capabilities of the system rain a better understanding of the relationship between system parameters and treatment performance

  - A good starting point for this effort would be to compare the BYOW processes to their traditional counterparts as discussed in section 7.9.3.
  - Investigate the performance of the inclined tube settler.
  - Quantification of biological treatment action in the BYOW system: Is bio action present? What kinds of microbes are living in the media? Are they aerobic or anaerobic?
  - Evaluate the performance of the UV unit.
    -How effective is reducing the loading rate by oversizing the unit or reducing flow rate?
    -What is the effect of bulb warm-up time on disinfection?

- Research the possibility of modularizing the system components so that they may be installed individually or in concert in a variety of scenarios

  - The use of BYOW components in conjunction with a pipeline as opposed to a bucket based system

- Research the cost optimization of the BYOW design
  - Find replacements for parts that have a high failure rate
  - Can the drums be replaced with masonry or concrete vessels? This would require minimizing leakage and seepage to prevent the system from "consuming" users' water.

- Research the use of alternate filter media including:
  - Textile filters
  - Diatomaceous earth
  - Coconut fiber
  - Burnt rice husks
  - Ceramics
  - Anthracite coal

- Activated carbon
- Gravel filtration - a roughing filter based on the PDSF
- Different sand sizes - a slow sand filter version of the PDSF

♦ Research the backwashing ideas presented in the "Potential System Improvements" section
  - Investigate the use of chlorine in the maintenance of the system: Is it reasonable to add chlorine to the backwash water in order to periodically shock the system?

♦ Research the effect of stagnation on the BYOW system
  - How dangerous is system stagnation?
  - What kinds of microbes does stagnation favor?

♦ Research the feasibility of using a hydraulic jet flocculator between the input bucket and the tube settler. This may increase tube settler performance.

7.10 References

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8.0 MUGONERO ORPHANAGE ASSESSMENT

8.1 Potential Projects

EWB-CU spoke with Victor Monroy who is the director of the L'esperance Children's Aid Orphanage, which is located in South West Rwanda along lake Kivu about one hour drive on a dirt road south of Kibuye. Victor has been at the orphanage for 9 months (as of June 2006) and plans to stay for at least 4 more years. Currently, there are 110 children ranging from 1.5 to 25 years in age.

Figure 8-1: Location of Mugonero

While in the community, EWB-CU asked Victor to list the orphanage's needs in order of importance. The following was discussed:

1) Water Supply for general usage

The children must walk about 15-20 minutes down a steep hill to collect water from the local tap. This water is used for all of their needs including hygiene, cooking, cleaning, drinking, bathing etc, and it is a lot of water for children to carry. According to the Water Treatment Processes, each person should have 10L of drinking water per day and approximately 80 L per day for proper hygiene, drinking and cooking.

The tap water was tested by EWB-CU in January 2006 and is a relatively clean source with only some coliform bacteria found in the water. There was an initiative to pump this water to the orphanage, but the community was not happy with the orphanage taking the water, and the project was abandoned.

As a partial solution in July of 2006, a German NGO has managed to install a water pump to bring water from a small stream at the bottom of 100m hill to the orphanage. The water in the stream is highly contaminated according to the testing performed by EWB-CU in January 2006. There is also some concern as to the longevity of the pump because of the dirt contained in the water and the increased ware that this will cause the pump.

Victor wants to diversify his water supply and hopefully provide a more sustainable water supply for the orphanage. Since it rains almost 8 months out of the year in this part of Rwanda, rainwater catchment seems to be one of the best options for providing water to this community.

2) Energy for Cooking

The orphanage is unable to sustain its current wood usage for cooking, and they cannot afford to purchase wood for all of their cooking needs. This year they had to cut a lot of trees for increased agricultural production, however this wood will not sustain the orphanage for long. Therefore either a new method for cooking must be found or the amount of wood needed for cooking needs to be reduced.

3) Water for agriculture

While it rains almost 8 months a year, there is a 3-4 month dry season where additional water is needed to water crops. There are two especially large roofs on the school at the base of the orphanage, and these buildings could potentially provide enough water for agriculture provided a large enough containment was built.

4) Lighting

There was some thought that additional solar lighting would be beneficial at the orphanage. Currently, the orphanage only has some solar electricity in one building to help run the school's computer.

Designator	Name	Dimensions	Description
M01	Victor's Living & guest quarters		Victor's living area. Can house up to 5 guests
M02	Tank		Future Tank Location for German NGO. May bring water from a stream up 100m to orphanage
M03	Generator Room		Generator is available for emergencies.
M04	Living Unit #3	37'x40'	No Gutters
M05	Living Unit #4	39'x'37'	Pitched in Middle Gutters on both sides
M06	Storage House/Future Guest house	39'x38'	Storage house No Gutters
M07	Office		Solar panels on top
M08	Latrines	20'x15'	4 latrines and 4 washrooms
M09	Living Unit #2	40'x38'	No Gutters
M10	Living Unit #1	37'x40'	Pitched on 40' side at 20' Has gutters on both sides
M11	Kitchen for Units #1&2	20'x25'5"	Has Chimney for ventilation building Split into 2 units
M12	Tiolets & Washrooms	18'x17'	3 Shower rooms & 2 Latrines
M13	Kitchen Admin	23'x15'	Sleeping room for cook Stove area 8'5"x3'
M14	Admin Dining Room	26'x19'	Pitched in Middle on 19' side Has gutter on one side Sleeps one person
M15	Living Unit #5	40'x40'	Men's Quarters
M16	Kitchen	18'x19'	Kitchen
M17	Latrines	19'x23'	4 latrines and 4 washrooms
M18	Kitchen for Unit #3	14'x16.5'	
M19	Latrine for Unit#5	18'5"x18'	2 latrines and 4 washrooms
M20	School #1		School Building #1
M21	School #2		School Building #2

Table 8-1: Layout of the Orphanage

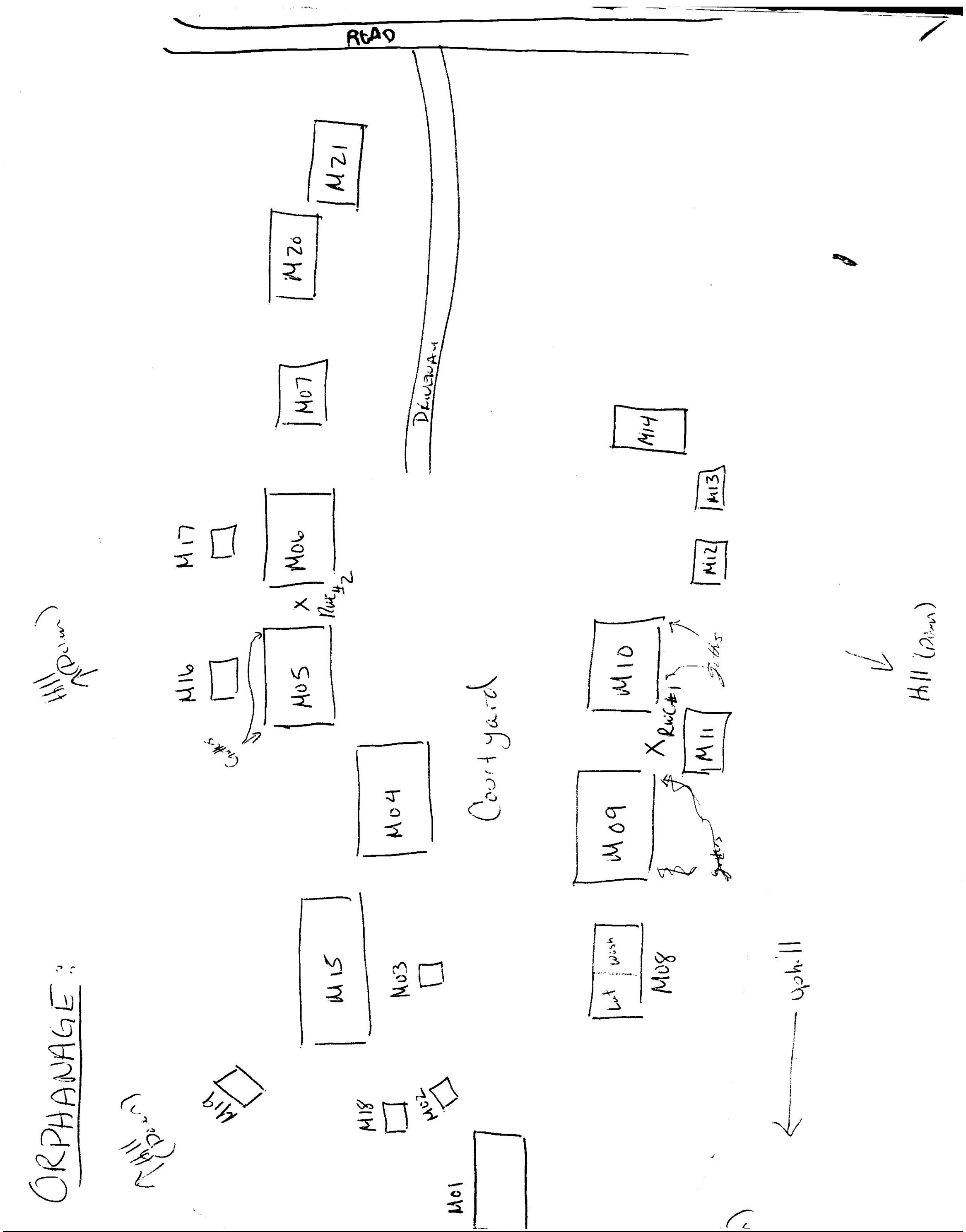


Figure 8-2: Layout of the Orphanage

8.2 Engineering Components Considered

There are two projects that EWB-CU will undertake during the 2006-2007 school year to address the orphanage's concerns: Rain Water Catchment and Higher efficiency stoves. EWB-JSC will address the contaminated water that the German NGO's pump is delivering to the school.

<u>Rainwater Catchment at Orphanage:</u>
Rainwater catchment (RWC) will help with their water supply problems. There are already some gutters on two of the buildings; however, water is just collected in buckets and pans at this time.

The first system will be installed on buildings M09 and M10 with the tank placement between the two buildings. This will locate the system near the kitchen M11, which will be convenient for cooking and washing. Building M10 already has gutters installed, but additional gutters should be added to building M09 and piping will need to be brought to the tank. The tank will require a concrete pad. An estimated materials list for this system is below:

Table 8-2: Materials List for RWC System #1

Gutters (Both sides of building M09)	TBD
Downspouts:	4
90deg elbows:	8
Tees:	4
Endcaps:	6
Screening	TBD
Piping:	TBD
Concrete Anchors:	TBD

Building M09	**Building M10**
	

Figure 8-3: Gutter Locations for RWC System #1

Figure 8-4: Tank Location for RWC System #1

The second RWC system will be installed on buildings M05 and M06 with the tank placement between the two buildings. This will locate the system near the kitchen M16, which will be convenient for cooking and washing. Building M06 already has gutters installed, but additional gutters should be added to building M05 and piping will need to be brought to the tank. This tank will also require a concrete pad.

Table 8-3: Materials List for System #2

Gutters (Both sides of building M06)	TBD
Downspouts:	4
90deg elbows:	8
Tees:	4
Endcaps:	6
Screening	TBD
Piping:	TBD
Concrete Anchors:	TBD

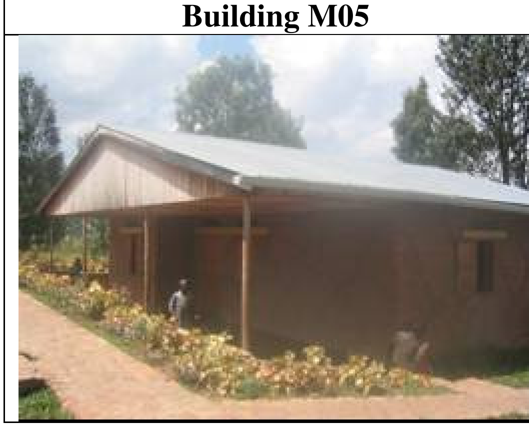
Building M05	Building M06
	

Figure 8-5: Gutter Placement for RWC System #2

Figure 8-6: Tank Location for System #2

Higher Efficiency Stoves:

The second project, higher efficiency stoves, would help reduce the orphanage's wood usage and would reduce or eliminate the need for purchasing additional wood for cooking. It is believed that the existing kitchens can be retrofitted with higher efficiency cook stoves, providing an easy transition to the new technology. The newer stoves would not emit as much smoke, and the smoke they do emit would be channeled outside of the buildings to improve the health of the cooks.

Other cooking methods were investigated and were eliminated for various reasons:

Solar Cookers: Since it rains on and off each day for eight months, solar cookers would only be useful during the four dry season months. However, this is also a large deviation from Rwandan's normal cooking methods and it also changes the taste since there is no smoke involved with cooking. These reasons make solar cookers less attractive.

Biogas: Biogas is a viable option for the orphanage. It would require redesigning the location and the operation of the latrines and kitchens. However, it is a very expensive project, and not one that can be implemented quickly. Wood would still need to be used for cooking since biogas would most likely not supply all of their cooking energy needs.

The existing cooking areas were investigated, and the following information was gathered on the hearth's dimensions.

Table 8-4: Hearth Dimensions

	Width	Length	Height
Building M11	3'	4'	6'
Building M11	3'	4'	6'
Building M13	3'	8'6"	2'
Building M16 (right)	2'3"	6'3"	1'8"
Building M16 (left)	3'5"	6'8"	2'
Building M18	3'5"	8'8"	2'

Figure 8-7: Typical Hearth at the Orphanage

Figure 8-7: Typical Kitchen

<u>Water Purification Project</u>

The Mugonero Orphanage water supply is provided by a community gravity fed water system. However, the taps are located outside the orphanage grounds and do not provide enough water for the community as well as the orphans. Another NGO has installed a water pump to bring up water from a nearby stream. However, storage of this water remains unresolved, and the water quality is very poor (refer to January 2006 report).

The EWB-JSC team is developing plans to address water treatment and storage concerns at the Mugonero Orphanage. The design will be based on the successful implementation of the BYOW system in June 2006 in Muramba.

Design guidelines

- Address the particulate fouling of the ram pumps
- Address the bacterial contamination in the Orphanage cistern
  - Clean up to 100 liters of water per hour for 10 hours per day
  - Water quality should be brought up to 'reasonable' standards (TBD 'reasonable')
- Design system using materials reasonably expected to be in Rwanda
- Maintenance costs should be less than $50 per year

Existing water pump system

The ram-style pump installed by the German family owners of the L'Esperance Children's Aid Orphanage in August 2006 is pumping water from a contaminated and turbid stream. The water is pumped into a six-meter high water tower on the orphanage grounds.

8.3 Assigning of Components

EWB-CU will undertake the design and implementation of the rainwater catchment systems and the improved stove design while EWB-JSC addresses the water treatment concerns.

References

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9.0 BUDGET & FUNDING

9.1 Detailed Budget

EWB-JSC Budgeting June 2006

Item	Description	Cost Per Item	Number of Items	Total Item Cost
Labor	Foreman (Contributed by Community)			$0.00
	Labor Workers (Contributed by Community)			$0.00
			Subtotal	**$0.00**
Logistics	Plane Tickets USA - Rwanda Round Trip (3 people)	$1,914.00	3	$5,742.00
	Transportation in Rwanda			$18.00
	Lodging in Kigali (4 days, 3 people)	$15.00	12	$180.00
	Food/Lodging in Mugonero (10 days, 3 people)			$270.00
			Subtotal	**$6,210.00**
Supplies	Tank bulkhead fittings (Bailiff Enterprises, Houston)			$197.34
	10,000 L tank (Magasin, Kigali)			$1,471.29
	200 L Foul flush tank (Federation, Kigali)			$35.71
	Gutter elbows, PVC glue (Sonatube, Kigali)			$109.18
	Gutters, gutter fittings, gutter brackets, PVC pipe, PVC fittings (Muhirwa, Kigali)			$781.39
			Subtotal	**$2,594.91**
Tools	Cordless drills, hand saw, chalk line, tape measure, etc. (Lowes, Houston)			$490.33
			Subtotal	**$490.33**
		Total Labor Cost		$0.00
		Total Logistics Cost		$6,210.00
		Total Supplies Cost		$2,594.91
		Total Tools Cost		$490.33
		Total Cost		**$9,295.24**

Funding Sources

Funding Committed to Project	
Booz Allen Hamiliton Grant	$750.00
JSC Co-op Intern Fundraiser	$500.00
Rwanda Convention Donation	$100.00
Pete's Barn Charity Concert	$1,800.00
The ERM Group Foundation Grant	$3,000.00
Bands Without Borders Concert	$6,835.00
Mystery Mural Fundraiser	$1,600.00
Bastion Technologies	$1,000.00
Miscellaneous donations	$2,025.00
Total:	**$17,610.00**

EWB-CU actual expenditures for June 2006 trip

EXPENSES		
Airfare	Airfare	$20,538.86
Airfare	Airfare (NCIIA paid for part of Cameroon visit)	$ (982.40)
Conferences	Conferences-EWB Rwanda Project Related	$ 1,642.40
Equipment	Equipment (AmCom Insurance Gift)	$ 1,280.00
Equipment	Equipment (NCIIA expenses)	$ 901.50
Equipment	Equipment [Biodigester project (FDWU Funds)]	$ 2,000.00
Equipment	Equipment [Water Subproject (FDWU Funds)]	$ 2,594.48
Equipment	Equipment and Tools	$ 4,838.86
uncategorized	EWB-CU Project Expenses-Rwanda (uncategorized)	$ 308.82
Freight	Freight	$ 4,445.07
Indirect Costs	Indirect Costs	$ 228.13
On the Ground Expenses	On the Ground Expenses	$ 6,343.43
Postage	Overnight or Express Mail	$ 20.34
Patent/Prototype	Patent&Prototype (NCIIA expenses)	$ 2,794.50
Publicity	Publicity	$ 30.00
Supplies	Supplies	$ 336.40
Supplies	Supplies (NCIIA expenses)	$ 993.25
Technical Services	Technical Services (NCIIA expenses)	$ 262.40
TOTAL EXPENSES		$48,576.04

EWB-CU on-the-ground budgeting

Date	Vendor	Description	Amount USD
10-May	CU	Initial CU funds	$13,780.00
15-May	Wells Fargo	Wells Fargo TC charge	-$60.00
15-May	Wells Fargo	Wells Fargo transaction fee	-$5.00
22-May	Houston Shopping Mall	Sunglass gifts for JP Muligo and JP Habanabakize	-$56.25
22-May	WalMart	Digital Camera for JP Muligo (gift/EWB project monitoring)	-$161.79
24-May	Ethiopian Airways	Excess Baggage Charge	-$102.14
3-Jun	Kenya Airways	3 x tickets to Nairobi	-$627.00
3-Jun	Hotel Somatel	3 rooms (3 * 32500 CF / 450 CF/ $) (450 CF / $ hotel rate)	-$216.67
5-Jun	Hotel Somatel	3 rooms (3 * $48)	-$144.00
8-Jun	Djeuga Palace Hotel	3 rooms 6/5, 6/6, 6/7	-$800.00
8-Jun	Djeuga Palace Hotel	EWB-CU/EWB Cameroon Dinner excluding Drinks	-$163.78
4-Jun	Mobil Essomba	Replacement Toiletries (ET, MG, JJ) 12550 CF / 450	-$27.89
5-Jun	La Fiesta	EWB-International Dinner Excluding Drinks	-$88.89
4-Jun	ASAP Conference	Shirt/Belt replacement / and taxi cab from airport	-$57.89

6-Jun	Taxi	Cab fare to conference center x 4	-$17.76
8-Jun	Restaurant	Team/ASAP staff dinner departure from Cameroon	-$56.22
8-Jun	Taxi	Taxi cab to airport	-$33.33
8-Jun	YAO Airport	Airport tax (6 * 10,000 / 450)	-$133.33
10-Jun	Peter Muligo / USAID	Landcruiser / fee / gas	-$579.54
13-Jun	Restaurant	Lunch with Kamali Kalisa / Mugonero Hospital	-$71.43
9-Jun		Replacement clothing	-$44.64
12-Jun		Replacement Toiletries	-$23.93
12-Jun	KIST / CITT	Biogas Reactors	-$1,300.00
14-Jun	Casements LTD	Solar Panel frames	-$397.61
13-Jun	Sofaru Sarl	Silicone, plumbing	-$10.36
12-Jun	Hardware Store	2 x 10,000 liter tanks	-$71.43
12-Jun	Sonatubes	PVC	-$9.39
13-Jun	Sonatubes	PVC, Plumbing, PVC Glue	-$86.34
12-Jun	Sofaru Sarl	Gate Valves, Rebar, etc	-$222.68
14-Jun	Peter Muligo / USAID	Landcruiser /truck / fee	-$1,100.00
14-Jun	Peter Muligo / USAID	Fuel	-$303.57
		NA (Receipt assigned to EWB-USA Account)	
14-Jun	Sulfo Rwanda	4 110 Amp Hour Batteries	-$454.28
14-Jun	Hardware Store	35 bags of cement	-$400.71
14-Jun	Grocery Store	18 20 L boxes of water	-$241.07
14-Jun	Hardware Store	Metal Screws	-$10.71
14-Jun	Hardware Store	Hacksaw / 4 blades	-$5.54
16-Jun	Hardware Store	Metal plumbing unions, etc	-$16.25
17-Jun	SJ Spare Parts	Battery terminals	-$7.14
16-Jun	Mugonero Hospital	Sand / Gravel	-$35.71
16-Jun	Mugonero Hospital	Bus fare for CITT staff to return to Kigali	-$17.86
20-Jun	Gas Station	Truck Fuel (transport for JP to Gitarama and return)	-$48.04
20-Jun	Mugonero Hospital	Truck Fuel (team transport to Muramba)	-$337.50
20-Jun	Mugonero Hospital	EWB-CU Team stay in Mugonero	-$890.00
23-Jun	Muramba Votech School	Vocational School BYOW assistance	-$126.79
24-Jun	Muramba Votech School	Bricks	-$80.36
24-Jun	Muramba Votech School	Mason Labor for BYOW	-$51.07
27-Jun	Muramba Parish	Stay in Muramba, EWB-CU team	-$900.00
29-Jun	Hotel Castel	Stay in Kigali	-$210.71
29-Jun	JP Habanabakize	Muramba Labor	-$101.25
29-Jun	Quincaillerie	Plumbing parts	-$56.43
30-Jun	Palm Beach Hotel	4 rooms 1 night	-$160.71
1-Jul	Dian Fossey Lodge	8 rooms, 2 nights	-$321.43

1-Jul	Muramba College	Transportation from Muramba to Gisenyi	-$200.00
2-Jul	Hotel Stay	Hotel Stipend, NK, IE, KB	-$107.14
2-Jul	JP Habanabakize	Fee 20 days (6/13 - 7/2) * 20 USD	-$400.00
2-Jul	JP Habanabakize	Driving School fee to enable EWB-CU assistance	-$78.57
1-Jul	Peter Muligo / USAID	Car / Landcruiser / Fee	-$950.00
1-Jul	Peter Muligo / USAID	Fuel	-$71.43
2-Jul	Peter Muligo / USAID	Materials / Repair costs Mugonero UV system	-$220.00
29-Jun	Bank of Kigali	TC cashing fee	-$50.57
2-Jul	MTN	Total phone cards for trip	-$78.57
3-Jul	Cash Remaining		-$177.30
		Total:	$0.00

9.2 Funding Sources

Funding for the EWB-CU project came from the Rotary Club of Boulder, First Data Western Union, the Engineering Excellence Fund, the Undergraduate Research Opportunity Fund, the CU-Boulder Outreach Committee, EWB-USA, EWB-CU, EWB-JSC, the Manna Energy Foundation, AmCom Insurance Services, The UNESCO Mondialogo Engineering Award, the EPA P3 grant, and private donations.

9.3 Donated Hours (Mentor, students, etc)

A number of people put varying amounts of work into the EWB-CU portion of the project. Six students donated between 15 and 35 hours each per week for the project, and mentors and additional students donate approximately 4 hours per week.