Scalable, Solar Powered Membrane-Based Water Purification Systems for Community Development in Developing Countries

Yung Wong

Embry-Riddle Aeronautical University - Daytona Beach

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SCALABLE, SOLAR POWERED MEMBRANE-BASED WATER PURIFICATION SYSTEMS FOR COMMUNITY DEVELOPMENT IN DEVELOPING COUNTRIES

by

Yung Wong

A Thesis Submitted to the College of Engineering Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

Embry-Riddle Aeronautical University
Daytona Beach, Florida
May 2014
SCALABLE, SOLAR POWERED MEMBRANE-BASED WATER PURIFICATION SYSTEMS FOR COMMUNITY DEVELOPMENT IN DEVELOPING COUNTRIES

by

Yung Lun Wong

This thesis was prepared under the direction of the candidate's Thesis Committee Chair, Dr. Marc D. Compere, Assistant Professor, Daytona Beach Campus, and Thesis Committee Members Dr. Charles F. Reinholtz, Professor, Daytona Beach Campus, and Dr. Yan Tang, Assistant Professor, Daytona Beach Campus, and has been approved by the Thesis Committee. It was submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.
Acknowledgements

This work would not be possible without the strength and perseverance of the Haitian people. They have welcomed us in and have taught us so much. I hope that we have been able to positively impact your lives as well. Our in-country partners are truly agents of change. Keep doing what you are doing; it is an inspiration to us all.

I would also like to thank my thesis committee Dr. Marc Compere, Dr. Yan Tang, and Dr. Charles Reinholtz and the entire mechanical engineering department at Embry-Riddle Aeronautical University for welcoming me into your community and providing me with so many opportunities for growth. All of your mentorship has undeniably shaped me into a more mature, and driven individual ready to tackle the real world and solve some global challenges.
Abstract

Researcher: Yung Wong

Title: SCALABLE, SOLAR POWERED MEMBRANE-BASED WATER PURIFICATION SYSTEM FOR COMMUNITY DEVELOPMENT IN DEVELOPING COUNTRIES

Institution: Embry-Riddle Aeronautical University

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This manuscript style thesis presents a community development model developed at Embry-Riddle Aeronautical University (ERAU) to deliver sustainable water purification systems and originate a companion micro-business to sell excess clean water in communities in Haiti. Since 2010, students and faculty from ERAU have partnered with strategic partners to not only provide clean water to their in-country operations but also provide an opportunity for economic growth through a clean water selling micro-business. Water, sanitation, and hygiene (WASH) training is also implemented to aid in community buy-in. Lessons learned from the history of foreign aid to developing countries is taken into account but it is the lessons learned from implementing the model that the project has been able to improve significantly year after year. This model is a short-term, focused, and specialized approach that has a well-defined process and has proven to be successful and is described throughout the thesis and in the conference paper in Appendix C.
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thesis Review Committee</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Abstract</td>
<td>iv</td>
</tr>
<tr>
<td>List of Figures</td>
<td>viii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>ix</td>
</tr>
<tr>
<td>I Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Significance of the Study</td>
<td>1</td>
</tr>
<tr>
<td>Thesis Statement</td>
<td>2</td>
</tr>
<tr>
<td>List of Acronyms</td>
<td>2</td>
</tr>
<tr>
<td>II History of Project Haiti</td>
<td>3</td>
</tr>
<tr>
<td>Nehemiah Vision Ministries</td>
<td>3</td>
</tr>
<tr>
<td>Anne Clemande Julien Foundation School</td>
<td>4</td>
</tr>
<tr>
<td>Lessons Learned</td>
<td>6</td>
</tr>
<tr>
<td>Post Project Haiti 2011</td>
<td>6</td>
</tr>
<tr>
<td>III System Design</td>
<td>8</td>
</tr>
<tr>
<td>Quality of Water</td>
<td>8</td>
</tr>
<tr>
<td>I. Physical Aggregate</td>
<td>8</td>
</tr>
<tr>
<td>II. Chemical Constituents</td>
<td>9</td>
</tr>
<tr>
<td>III. Microbiological Contaminants</td>
<td>9</td>
</tr>
<tr>
<td>IV. Radiochemical Constituents</td>
<td>10</td>
</tr>
</tbody>
</table>
Filtration Technologies

I. Conventional Water Treatment

II. Direct and In-line Filtration Treatment

III. Membrane Filtration

IV. Reverse Osmosis Treatment

V. Disinfection

System Requirements

Purifier Technology

Sediment Filter

Membrane Filter

Carbon Filter

Ultraviolet Light Filter

Motor Selection

Control System

Power System

Loads Analysis

Battery Bank

Solar Array

Charge Controller

Requirements Analysis

IV Community Development Model

Partner Selection

Training
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health Education</td>
<td>31</td>
</tr>
<tr>
<td>Monitoring and Evaluation</td>
<td>32</td>
</tr>
<tr>
<td>IV Results</td>
<td>33</td>
</tr>
<tr>
<td>Onaville Tent City</td>
<td>33</td>
</tr>
<tr>
<td>Ryan Epps Home for Children</td>
<td>35</td>
</tr>
<tr>
<td>Dayspring Missions Orphanage</td>
<td>36</td>
</tr>
<tr>
<td>V Discussion, Conclusions, and Recommendations</td>
<td>38</td>
</tr>
<tr>
<td>Discussion</td>
<td>38</td>
</tr>
<tr>
<td>Conclusions</td>
<td>38</td>
</tr>
<tr>
<td>Recommendations</td>
<td>38</td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
</tr>
<tr>
<td>A Bibliography</td>
<td>39</td>
</tr>
<tr>
<td>B High Tech High Touch: Lessons Learned from Project Haiti 2011</td>
<td>41</td>
</tr>
<tr>
<td>C Community Development through a Sustainable Micro-Business Selling</td>
<td>49</td>
</tr>
<tr>
<td>Clean Water</td>
<td></td>
</tr>
<tr>
<td>D Project Haiti 2012 User Manual</td>
<td>65</td>
</tr>
<tr>
<td>E 2014 Purifier Control Circuit</td>
<td>93</td>
</tr>
</tbody>
</table>
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>9</td>
<td>34</td>
</tr>
<tr>
<td>10</td>
<td>35</td>
</tr>
</tbody>
</table>

1 2010 Water Purifier
2 2011 Water Purifier
3 Membrane Filter Diagram
4 Membrane Filtration Technologies
5 Indicator Pathogens for Removal
6 Purifier Hydraulic Flow Schematic
7 CAD Drawing of 2014 Purifier
8 Feed Pump Curve
9 Bucket Fill Rail
10 Water Quality Tests from Competing Businesses in Onaville
List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water Pathogens</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Major Purifier Components</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>Total System Pressure Drop</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Daily Energy Required by Purifier</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Locally Sourced Deep Cycle Battery Choices</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>Filter Maintenance and Replacement Cost</td>
<td>28</td>
</tr>
</tbody>
</table>
Chapter I

Introduction

Significance of the Study

Safe and clean drinking water is a human right essential to the full enjoyment of life and all other human rights, as stated by the United Nations General Council. However, over 780 million people still lack access to this basic right [1]. Without clean water, people’s wellbeing suffer as 60% of the adult human body and 75% of the infant body is made up of water [2]. Being in a constant state of low energy and poor health negatively impacts every aspect of life. Children are not able to get a proper education and adults have trouble keeping a job, and have difficulty taking care of family. Many times, children are forced out of the home because their parents do not have the resources to take care of all of their children as noted by the fact that two out of every three people without access to clean water live on less than two dollars a day.

Haiti, just a couple hours flight from American soil, still has over 36% of their population using water from an unimproved source [3]. Even those using an improved source do not have a guarantee that the water is clean and safe to drink. After the earthquake in 2010 which devastated the Port-au-Prince area where the majority of Haiti’s population resides, the already poor conditions got worse. An opportunity to aid in disaster relief set in motion the creation of Project Haiti on Embry-Riddle Aeronautical University’s (ERAU) Daytona Beach campus. The mission of Project Haiti was to tackle the problem of universal clean water access, starting with Haiti.
**Thesis Statement**

Providing clean water to a community in a developing country requires a multifaceted approach. It requires not only the clean water solution, but also the right community conditions. A compatible partner who has a willingness to better themselves and the community around them is crucial. Project Haiti’s solution includes a partner selection process, a scalable high technology water purification system that can be operated on or off grid, a health education component, and an opportunity to generate revenue through a micro-business to sell extra clean and well water to the community.

**List of Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>GPM</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>KDF</td>
<td>Kinetic Degradation Fluxion</td>
</tr>
<tr>
<td>kWh</td>
<td>kiloWatt-hour</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-governmental organization</td>
</tr>
<tr>
<td>NSF</td>
<td>National Sanitation Foundation</td>
</tr>
<tr>
<td>NTU</td>
<td>Nephelometric Turbidity Units</td>
</tr>
<tr>
<td>PSI</td>
<td>Pounds per Square Inch</td>
</tr>
<tr>
<td>RO</td>
<td>Reverse Osmosis</td>
</tr>
<tr>
<td>UF</td>
<td>Ultrafiltration</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>WASH</td>
<td>Water, Sanitation and Hygiene</td>
</tr>
</tbody>
</table>
Chapter II

History of Project Haiti

Nehemiah Vision Ministries

After the earthquake on January 12, 2010, Pastor Esperandieu Pierre decided to expand on the work of Nehemiah Vision Ministries (NVM) to support American relief workers as they traveled to Haiti to assist in the disaster response. The summer of 2010 was devoted to building up a secure camp for the workers. Over the course of several months, 150 college student volunteers traveled to Haiti for the effort. ERAU was responsible for designing, developing, and bringing a water purification system to be the sole water source for all the workers.

![Image](image_url)

*Figure 1.* 2010 Water Purifier. One gallon per minute.

The system, as shown in Figure 1, was completely solar powered and used cartridge filters and ultraviolet (UV) light to purify well water at one gallon per minute (gpm). The 2010 system was a success as everyone’s water needs were met and no one became sick from
drinking the water that had gone through the system. The publicity generated paved the way for the future projects.

**Anne Clemande Julien Foundation School**

A few months after returning from the 2010 trip, the team was contacted by someone who had read about the 2010 project in the newspaper. They wanted a water purification system to be designed and installed at a school in Chambellan, Haiti which had seen an influx of children due to the earthquake the year before. The school served 600 children and the team jumped at the challenge of a larger system.

The problems began as soon as the project was accepted. Communication went through the US based project sponsor who had never visited the site and was unclear about their requirements. Any attempt at direct communication with the site manager in Haiti was futile because of the language barrier and limited availability of internet.

Further, the well had not been dug yet and only an estimated depth was provided making it difficult to engineer a system around. An underpowered well pump would not work and an overpowered well pump could result in a system more costly than necessary. Once the well depth and system requirements were more clearly defined, the team had to design the water purification system. The team scaled up the one gpm system at NVM and designed a system that would purify at four gpm for up to 1200 gallons of water per day. Figure 2 shows the system installed at the site. It has five stages of filtration. The first two stages are sediment filters to filter out the larger particles. The next two stages include activated carbon to filter chemicals and improve taste and smell and kinetic degradation fluxion (KDF) filter media to remove the heavy metals from the water. The last stage is a UV lamp to disinfect the water of microbiological material.
Although this system is able to purify the well water to drinking water quality, the filters need to be replaced roughly every six months. For an orphanage 12 hours from Port-au-Prince, this was not a sustainable solution as the team learned later on. A few months after installing the system, the team stopped receiving any communication and has no idea as to the status of the system to this day. This is very common in many humanitarian projects as the community is receiving a hand out rather than a hand up. If what they get stops working or they feel it is not worth it for the upkeep, they will revert back to the way it was before the technology was introduced.

Over the course of the project, the team had to develop customer relations skills. When the customer learned that solar power would be involved, they requested for their entire facility to be connected to the system. However, the system being designed just large enough for the
purification system, the team had to explain that they would need to increase the system capacity by purchasing more solar panels in order to power their facility.

The 2011 project also taught the team to be aware of culture. The team had brought water fountain spigots to install for the children to drink from. However, once the spigot rail was assembled, the site manager did not want it because it wasn’t a cultural norm and water would be wasted. The norm is to carry water in buckets so he requested that a bucket fill rail be installed instead. In the end, both the spigots and a bucket fill rail were used. The waste from the spigots ended up being used for gardening purposes. Additional information on the 2011 project is included in Appendix B.

**Lessons Learned**

The 2011 project taught the team about humanitarian engineering. Having only focused on the technical aspects, the team encountered problems in dealing with the partner and the community. The relationship was more of a giver-receiver type rather than a partnership. This is something the team worked on changing for future projects.

**Post Project Haiti 2011**

After Project Haiti, the team developed a community development model based on their lessons learned and from conversations with people who had been working on humanitarian engineering projects. In addition to the technology, the team developed a partner requirements list in order to vet potential partners and ensure smooth communication and compatible goals. Also, the team started to do water, sanitation and hygiene (WASH) training during the installation trip. These included visual activities for the community to see how contaminated water makes them sick and best practices for proper hygiene.

Between the time of Project Haiti 2011 and 2012, the team also developed a relationship with Miller-Leaman, a local water filtration company who manufactures high
volume water filtration systems using ultrafiltration (UF) membranes. Slightly modifying their systems would produce clean drinking water. This was an opportunity for community economic growth by adding a microbusiness aspect into the community development model. Chapter III is an in depth look at the technology. Chapter IV is an overview of the community development model as it is now and Chapter V explores the effect of applying the model to the post-2011 clean water projects.
Chapter III
System Design

This chapter presents the solar water purifier’s design. This includes a review of different water treatment processes, system design requirements, purifier components selection, solar power system design, and evaluated the design against the requirements. All requirements were met for the 2012, 2013, and 2014 units. As of this thesis' writing, all three units are installed and in daily service in 3 separate locations in Haiti. The 2014 purifier represents a relatively stable 3rd generation design.

Quality of Water

There are numerous constituents in water which may negatively affect the human body if consumed. In the United States, the Environmental Protection Agency (EPA) regulates the levels of over 90 contaminants and their acceptable levels in the drinking water supply. In developing countries like Haiti, however, regulations either do not exist or are not followed because a large percentage of the population do not have access to treated water and are uneducated as to the effect of consuming contaminated water. These populations gather and consume contaminated water that lead to health problems. Without the luxury of water piped into their homes, they need to go in search of water that they deem acceptable. This is usually the water source that is most clear and odorless. They rely on the physical characteristics of the water, but it is the unseen and unfiltered chemical, microbiological, and radiochemical contaminants which can lead to serious or fatal health consequences. These four water constituents are summarized below.

I. Physical Aggregate Particles in water come from soil-weathering processes and biological activity. Suspended solids such as clay, silt, sand, and other inorganic soils along
with living organisms such as algae, diatoms, minute animals, and fish make up the larger contaminants found in water sources [4].

II. Chemical Constituents While sediments are a concern in any situation, chemicals do not behave similarly. Chemical constituents usually cause adverse health effects only after prolonged periods of exposure except in cases of accidental contamination from human error [5]. There are many chemicals that may occur in drinking water, but without testing for each one, it is only possible to make estimated guesses as to what chemicals are present. The two major categories of chemical constituents are inorganic and organic compounds with the difference being that organic compounds have strong carbon-carbon bonds. The World Health Organization (WHO) has developed guidelines for certain common chemicals of health concern. These can be found in Annex 3 of their fourth edition Guidelines for Drinking Water Quality report [5].

III. Microbiological Contaminants In developing parts of the world, like Haiti, where water treatment is limited, water borne diseases such as cholera and typhoid spread quickly and become epidemics. These diseases are frequently from contamination by pathogens. Pathogens are defined as microorganisms capable of causing disease in humans, including bacteria, viruses, protozoa, helminthes, and algae [4]. These pathogens are the cause of the majority of water related health problems and is the priority for the Project Haiti systems. Table 1 lists various pathogens, their associated size in microns, and some examples of each. For reference, a human hair is 100 microns wide.
### Table 1. Water Pathogens

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Approx. Size (microns, µm)</th>
<th>Specific Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>0.2 - 2</td>
<td>E-coli, cholera, typhoid (salmonella), shigella, fecal coliform, STREP, STAFF (food poisoning)</td>
</tr>
<tr>
<td>Viruses</td>
<td>0.02</td>
<td>Polio, Hepatitis-A, influenza</td>
</tr>
<tr>
<td>Spores</td>
<td>6 – 8</td>
<td>Dormant phase of protozoa, chlorine resistant</td>
</tr>
<tr>
<td>Protozoa</td>
<td>6 - 10</td>
<td>Giardia, Cryptosporidium</td>
</tr>
<tr>
<td>Algae</td>
<td>&gt;10</td>
<td>Green and brown Blue/green give off toxins</td>
</tr>
<tr>
<td>Helminthes</td>
<td>&gt;20, eggs</td>
<td>Parasites, tapeworm, roundworm, flukes, trichonosis; adults 5cm – 1m.</td>
</tr>
</tbody>
</table>

**IV. Radiochemical Contaminants** Radionuclides occur naturally through the erosion and decay of natural and man-made deposits of certain minerals. Ingesting radionuclides may result in internal damage and increased risk of cancer as the element decays. Acceptable levels for radionuclides in drinking water can be found in Annex 6 of WHO’s fourth edition Guidelines for Drinking Water Quality report [5].

**Filtration Technologies**

To remove the above constituents from water, a filtration process needs to be developed depending on the quality of the water source. Different filtration technologies are used for different water constituents. For example, the technology to purify salt water will be different than the technology used to purify wastewater. In many situations, a combination of technologies will be necessary.

For freshwater from a protected well as has been the case for each of the Project Haiti systems, there are several treatment trains, or combination of unit processes, that can be utilized to obtain water of drinking water quality at high flow rates. These include conventional water treatment, direct and in-line filtration treatment, membrane filtration treatment, and reverse osmosis treatment [4]. Each of these treatment processes use similar logic in that they
start with the larger contaminants and each successive stage removes smaller and smaller contaminants.

I. **Conventional Water Treatment** Turbidity is the cloudiness of water due to suspended solids. When the turbidity, measured in nephelometric turbidity units (NTU) is greater than 20, conventional water treatment is effective. This treatment process includes the unit processes of coagulation, flocculation, sedimentation, granular media filtration and disinfection. During the coagulation and flocculation processes, chemicals are added to the water to destabilize the sediment and cause aggregation of the particles. Once the contaminants cluster together, gravity causes the solids to sink of the bottom. The water is then sent through a bed of granular media which traps the aggregate. Disinfection is the last step which removes or kills any remaining microbiological material and methods for disinfection will be explored at the end of this section.

II. **Direct and In-line Filtration Treatment** This treatment train utilizes coagulation, flocculation, granular media filtration, and disinfection. Similar to the conventional water treatment process, it does not, however, include sedimentation as this process is used when the source water is of higher quality with turbidity typically less than 15 NTU. The aggregate from the flocculation process is removed through the granular media rather than in a sedimentation tank.

III. **Membrane Filtration** Membrane filtration uses a semipermeable material to separate constituents in the feed stream into a product stream and waste stream [4], as shown in Figure 3.
They are designed to filter water with relatively high quality, but can be used for any situation if paired with filters that can get the water to be less than 10 NTU. Therefore, a pre-straining process to remove the larger water constituents is usually incorporated. Membranes use a straining, or size exclusion, process that removes particles larger than the pore sizes of the membrane. Figure 4 outlines the different membrane technologies and what pathogen sizes they are capable of removing. In order of increasing pore size, the membrane types are reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF). Although RO and NF are included in this chart, they are substantially different than the UF and MF membranes. These will be discussed in the next section. Although some UF and MF membranes are capable of removing bacteria and viruses, some have pores which still allow some pathogens to pass through. In these cases, a disinfection process is necessary.
IV. **Reverse Osmosis Treatment** The RO and NF membrane processes are capable of desalinating sea and brackish water. Rather than targeting particles in water, they are designed to remove dissolved solutes. These processes require substantially higher pressures as they use the difference in solubility or diffusivity to exclude the targeted constituents rather than the straining mechanism of the UF and MF membranes.

V. **Disinfection** This section will discuss disinfection methods available for use with the four treatment processes described above. The most common method of disinfecting water is through boiling. This requires a rolling boil for at least 5 minutes to ensure disinfection. This, however, requires a lot of energy input and is difficult to disinfect a large volume quickly. Reverse osmosis, which desalinates water, also disinfects water. However, if any part of the membrane is torn, contaminants can easily pass through. Ultraviolet light filters utilize the part of the UV spectrum which is believed to be the cause of skin cancer in humans. When microbiological material is exposed to this part of the UV spectrum, their DNA is inactivated preventing them from reproducing. Reverse osmosis and UV disinfection are effective, but do not provide a residual. A disinfectant residual in water continues to keep the

![Figure 4. Membrane Filtration Technologies](image)
water disinfected while in storage. If water is not being stored for an extended period of time, a residual may not be necessary. A disinfection method which provides a residual is chlorine, or bleach. In developing countries, bleach can easily be found and is an effective water disinfectant. Other methods include using chloramine, ozone, sodium hypochlorite, and chlorine dioxide.

**System Requirements**

When designing a system for a new partner, the first thing the partner needs to be able to reveal is the amount of water that they will require and if they have a body of water or well nearby that will sustain that amount of water. Next, an understanding is reached that they are expecting us to provide a sustainable solution which will be able to purify their water source to clean, drinking water. The system requirements are therefore:

1. Filter out sediments to below 0.3 NTU, the level of acceptable turbidity set by the EPA
2. Filter the indicator pathogens in figure 5
3. Produce water with no objectionable taste, odor, or color
4. Produce sufficient water volume to sustain operations
5. Design with low maintenance needs that can be accomplished by in-country locals on-site
6. Design an easily operable system with safety components for an end user with minimal science education. These include fuses, circuit breakers, overload relays, flow meter, inverter with low voltage cut-off, smart charge controller, timer relays to prevent overrunning of system, and alarm notification.
7. Provide a reliable system with no or minimal down time.
Purifier Technology

To design a more sustainable system than the 2011 unit, the team researched different filtration technologies and membrane filtration seemed favorable for the following reasons:

1. High filtration surface area
2. High flow rate at low pressure drops leading to lower power needs
3. Able to be completely solar powered without the need to rely on Haiti’s unreliable electric grid
4. Low sensitivity to large solids in feed water
5. Low replacement and maintenance needs
6. No special chemicals required
7. Minimal water waste
8. Effluent water quality is independent of feed water quality
9. System can be compact and automated, if desired

Figure 6 shows the hydraulic schematic for the Project Haiti membrane based system. This system has been used for the 2012 to 2014 projects. Completely solar powered, these purifiers are capable of producing water at 10 to 12 gpm for up to 8 hours a day. This is sufficient clean water for each of our partner’s needs as well as having surplus to sell to the community.
Sediment Filter There are a wide variety of sediment filters. The team searched for one that required minimal to no replacements. Going through Miller-Leaman’s product line provided us with two potential choices. One was a stainless steel wire mesh strainer and the other, a disc filter made up of plastic rings compressed together. Both of these solutions are capable of filtering down to 50 microns. The team decided to go with the disc filter for its field serviceability and ease for hand cleaning. It is also capable of flows up to 100 gallons per minute (gpm) with a very low differential pressure of one pound per square inch (psi).

Membrane Filter As mentioned earlier, membranes are best suited for water with low water turbidity (<10 NTU). If the feed water into the membrane is high in sediment count, fouling will occur faster on the membrane through pore blocking, pore constriction, and cake formation. Fouling creates a film on the membrane surface, effectively decreasing the surface area reducing flow output and, from Crittenden [4], can be modeled as:
\[ J = \frac{\Delta P}{\mu(k_m + k_c + k_p)} \]  

(1)

Where:

- \( J \) = volumetric water flux through membrane
- \( \Delta P \) = differential pressure across membrane
- \( \mu \) = dynamic viscosity of water
- \( k_m \) = membrane resistance coefficient
- \( k_c \) = chemically reversible fouling resistance coefficient
- \( k_p \) = pore constriction resistance coefficient

The reversible component of fouling is removed through a process called backflush. This process passes high velocity air, along with clean water at roughly double the filtration cycle flow rate, backwards through the membrane to release the contaminants in the membrane pores and flush out the suspended particles. The use of air improves the material removal and also reduces the volume of concentrated foulant to be flushed [6]. The backflush cycle, lasting just one minute (20 seconds air followed by 40 seconds of air and water), is run for every hour the purifier is in operation. An enhanced chemical backflush is also used. This involves adding chlorine at 20 ppm to the backflush water once a week [7]. The chlorine is able to destroy organic matter that accumulates on the membrane surface and repressing microbial growth [8].

Miller-Leaman carries an ultrafiltration membrane cartridge which filters down to 0.1 microns. This will reject all bacteria in the water as bacteria range from 0.1 to 100 microns [9]. With 480 ft² of surface area, this filter is capable of flow rates up to 12 gpm with low transmembrane pressures ranging from 3 to 8 psi. If higher flows are required, additional UF membranes can be added on. With proper maintenance through backflush, this membrane will last 4 – 6 years.
**Carbon Filter** A granular activated carbon filter is used in the system. The activated carbon’s role is to control the taste and odor as well as the toxic organic compounds that may be present in the groundwater. For a 12 gpm flow rate, four cubic feet of media was used. This media will be at its max adsorption level in roughly one year. The media will then need to be replaced.

**Ultraviolet Light Filter** The last stage of filtration is ultraviolet light (UV) which deactivates the DNA of any remaining microbiological material. The only pathogens which would be capable of reaching this point would be viruses which can be as small as 0.01 micron.

The UV spectrum spans the wavelengths from 100 to 400 nm. Between 200 and 300 nm is called shortwave UV-C. At these wavelengths, UV is absorbed by the DNA in bacteria and viruses and prevents reproduction. With a high enough dosage, this disinfects the water. The National Sanitation Foundation (NSF) has established a minimum dosage of 40 mJ/cm² to disinfect water contaminated by pathogenic bacteria and viruses.

The energy of each photon can be represented by Equation 2 below. Smaller wavelengths mean higher energy of the photon. The higher the energy, the more dangerous it is for living organisms. In humans, it is believed that UV-C is the cause of skin cancer.

\[
E = \frac{hc}{\lambda}
\]  
(2)

Where:

- \(E\) = energy in each photon
- \(h\) = Planck’s constant
- \(c\) = speed of light
- \(\lambda\) = wavelength of radiation
Motor Selection During the filtration cycle, an inline feed pump pushes well water from a storage tank at 10 gpm through the purifier. In addition to flow rate, the pressure drop across the entire system needs to be known to select the appropriate pump. After designing the system in CAD, shown in figure 7 with a legend in table 2, the pressure drop across the system was calculated.

![Figure 7. CAD Drawing of 2014 Purifier](image)

**Table 2. Major Purifier Components**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control Box</td>
</tr>
<tr>
<td>2</td>
<td>Flow Meter</td>
</tr>
<tr>
<td>3</td>
<td>Control Valves</td>
</tr>
<tr>
<td>4</td>
<td>Helix Disc Filter</td>
</tr>
<tr>
<td>5</td>
<td>UV Filter</td>
</tr>
<tr>
<td>6</td>
<td>Carbon Filter</td>
</tr>
<tr>
<td>7</td>
<td>UF Membrane Filter</td>
</tr>
<tr>
<td>8</td>
<td>Air Blower</td>
</tr>
<tr>
<td>9</td>
<td>Backflush Pump</td>
</tr>
<tr>
<td>10</td>
<td>Inline Pump</td>
</tr>
</tbody>
</table>
The pressure drop across each filtration element was established experimentally. The pressure drop in the plumbing from the storage tanks to the clean water tank can be calculated through the Darcy-Weisbach equation for head loss.

\[ h_f = \left( K_p + K_1 + K_2 + \ldots + K_n \right) \frac{v^2}{2g} \]  

(3)

Where:

\[ h_f = \text{head loss} \]

\[ v = \text{velocity of fluid} \]

\[ g = \text{acceleration due to gravity} \]

\[ K_p = \sum f \frac{L}{D} \]

\[ K_{1\ldots n} = \sum f_n \frac{L}{D} \]

\[ f = \text{friction factor} \]

\[ L = \text{length of pipe} \]

\[ D = \text{inner diameter of pipe} \]

Table 3. Total System Pressure Drop

<table>
<thead>
<tr>
<th>Component</th>
<th>Minimum Pressure Drop [psi]</th>
<th>Maximum Pressure Drop [psi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc Filter</td>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>Membrane Filter</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Carbon Filter</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>UV Filter</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Head Loss</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Line Loss</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>39</strong></td>
<td><strong>53.5</strong></td>
</tr>
</tbody>
</table>
Knowing the system pressure drop and the desired flow rate allows for a pump to be selected. This requires researching and finding a pump curve which matches the desired flow rate at the pressure ranges. An ideal pump would have a fairly horizontal curve so that the flow rate at the min and max pressure drop of the system is similar. Figure 8 shows the curve for the pump used on the one membrane system for Project Haiti.

![Figure 8. Feed Pump Curve](image)

The pump curve above is for Pedrollo Pump Model PK-05A16S. It is a half horsepower, 115VAC peripheral pump. At the minimum system pressure, it pumps at 11 gpm. At the maximum system pressure, it pumps at 8.2 gpm. Although the flow rate at the maximum system pressure is slightly lower than desired, the system will not reach this pressure until the end of the membrane’s life in 4 – 6 years.
The following are key features to look for after finding a pump curve with the appropriate flow rate and pressure.

- **Power Requirement**: Does the pump require DC or AC power and at what voltage? With respect to Project Haiti purifiers, there is always a battery bank available which produces 24 VDC and, if needed, a DC to AC inverter can be used to produce 110VAC.

- **Continuous Duty**: The pump must be able to pump for one hour without stopping.

- **Open Drip Proof (ODP) vs. Totally Enclosed Fan Cooled (TEFC)**: These refer to how the motor is cooled and how protected they are. If splashing, or flooding may occur, choose a pump with a TEFC motor.

- **Self-priming**: When a flooded suction line is not always available, a self-priming pump is necessary. This feature allows the system to still operate even with some air in the pump without having to manually flood the pump each time.

These conditions are also used in the selection of the backflush pump. Since the backflush pump only involves the membrane filter, the design pressure is that of the pressure and the head loss from the pump to the membrane to the outlet.

For the air blower for the backflush cycle, the necessary specifications are determined experimentally by the membrane manufacturer.

**Control System** The Project Haiti purifiers are not fully automated. The control circuit uses electromechanical components and has been designed to turn the system off and alert the operator when the hour long filtration cycle has completed and is able to control the backflush sequence. No computer boards are used reducing complexity and chance of failure. Appendix E includes a full electrical schematic of the control system. There is a motor starter for each of the three motors on the system. These motor starters consist of a contactor and an overload relay. The contactor reduces the current going to the on-off switch. This increases safety for the
user and prevents dangerous electrical arcs. The overload relay prevents too high currents reaching the motors and serves as a circuit breaker. To control the timing, three electromechanical timer relays are utilized. One shuts down the system after one hour has passed. The other two control the logic of the backflush sequence. These relays have been designed for one million cycles before needing to be replaced.

**Power System**

**Loads Analysis** The purifier’s three motors and UV light filter require power to operate. Since Haiti’s power grid is unreliable, solar power is utilized. The following section will go through the design of 2014’s solar power system.

The first step is to calculate the energy required, using equation four, for all loads. The four loads are the feed pump, backflush pump, air blower, and UV bulb.

\[
E = P \times t
\]

Where:

- \(E\) = energy [kWh]
- \(P\) = power [W]
- \(t\) = time [hrs]

Table 4 sums the total energy required by the purifier from the sun each day. Since the UV bulb needs to be on at all times, margin has been included for days without sun.
Table 4. Daily Energy Required by Purifier

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Pump</td>
<td>373</td>
<td>8 hours</td>
<td>2.98</td>
</tr>
<tr>
<td>Backflush Pump</td>
<td>373</td>
<td>8 minutes</td>
<td>0.05</td>
</tr>
<tr>
<td>Air Blower</td>
<td>373</td>
<td>8 minutes</td>
<td>0.05</td>
</tr>
<tr>
<td>UV Filter</td>
<td>42</td>
<td>24 hours x 2 days margin</td>
<td>2.02</td>
</tr>
<tr>
<td><strong>Total Energy</strong></td>
<td><strong>5.1 kWh</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Battery Bank** The total energy allows for the calculation of battery bank size. Since there will be a high inflow (charging) and outflow (draining) of energy, locally sourced deep cycle batteries are used. It is recommended to avoid draining deep cycle batteries past 50%. Therefore, it will be necessary to double the number of batteries. To calculate the number of batteries, the capacity of the chosen battery must be known. Since the battery selection in Haiti can vary, the batteries that have been used every year has differed. The 2014 project utilized Trojan 8D-Gel Deep Cycle Batteries. These are 12 volt, 225 amp-hour batteries. This equates to 2.7 kilowatt-hours per battery of energy storage.

\[
\text{# of batteries} = \frac{\text{Total Energy Required}}{\text{Battery Energy}} \times 2 \quad (5)
\]

\[
= \frac{5.1 \text{ kWh}}{2.7 \text{ kWh}} \times 2 = 3.8 = 4 \text{ batteries}
\]

The above equation, used to calculate number of batteries required, yields four Trojan 8D-Gel deep cycle batteries to sufficiently contain the capacity to run all four of the purifier’s loads.
With four twelve volt batteries, a bank voltage of 12, 24, or 48 volts is possible. The bank voltage will depend on the charge controller selection and availability of inverters.

Table 5 compares the Trojan 8D-Gel Deep Cycle Battery with two other batteries that can also be found in Haiti and how many would be required for the 2014 system if they had been in stock instead.

Table 5. Locally Sourced Deep Cycle Battery Choices

<table>
<thead>
<tr>
<th>Battery</th>
<th>Voltage</th>
<th>Amp-Hours</th>
<th>Energy Storage [W-Hrs]</th>
<th># Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trojan 8D-Gel</td>
<td>12</td>
<td>225</td>
<td>2700</td>
<td>4</td>
</tr>
<tr>
<td>Rolls Surrette 530</td>
<td>6</td>
<td>400</td>
<td>2400</td>
<td>4</td>
</tr>
<tr>
<td>Trojan T-105</td>
<td>6</td>
<td>225</td>
<td>1350</td>
<td>8</td>
</tr>
</tbody>
</table>

**Solar Array** The amount of solar power required can be calculated by dividing the number of peak hours of sun at the site location from the energy requirement of the system.

\[
P_{solar} = \frac{\text{Total Energy Required}}{\text{Hours of Peak Sun}} = \frac{5.7 \text{ kWh}}{5 \text{ hours}} = 1.14 \text{ kW}
\]  

(6)

With five hours of peak sun in Haiti, the amount of solar power required is 1.14 kilowatts. An 80% derating factor is added to this value as solar panels do not operate at their nameplate rating due to high temperature, line losses, and dust on the surface. Therefore, the actual amount of solar power required is 1.37 kW. For the 2014 project, six 250 watt panels are used providing 1.5 kW of power.

**Charge Controller** The 1.5 kW of power from the solar array needs to transfer to the battery bank. To safely do this, a charge controller is needed. A charge controller regulates the
power to the battery preventing overcharging, overheating, and other unsafe conditions. The most important factor when choosing a charge controller is to ensure that the controller is able to handle the max possible current from the solar array to the battery. Ohm’s Law, stated in Equation 7, can be used to calculate this current.

\[
I_{max} = \frac{P_{array}}{V_{batt}}
\]  

(7)

Where:

- \( I \) = current
- \( P \) = power
- \( V \) = voltage

It is usually better for the battery bank voltage to be higher as this will decrease the current. A lower current is desired because line losses occur through current and higher currents also require thicker and more expensive wire. From equation 8, line losses are greatly affected by current.

\[
P_{losses} = I^2R
\]  

(8)

For the 2014 system, the four 12 V Trojan batteries were wired to create a 24V system. Using equation 7, the max possible current to the battery bank is 62.5 amps.

Another important factor is the charge controller’s maximum open circuit voltage from the solar array. The open circuit voltage (\( V_{oc} \)) is the voltage that is read from the solar array with no load. The chosen controller must be able to handle this voltage or it may run the risk of burning out the controller. For the six 250 W panels in the 2014 system, each panel’s \( V_{oc} \) is
37.47 V. If the panels are wired in series, the total $V_{oc}$ would be 224.8 V. The Midnite Solar Classic 200, which ended up being the charge controller used, has a max $V_{oc}$ of 224 V. For safety, the final layout was two parallel strings of three panels each. The total $V_{oc}$ for this arrangement was therefore 112.4 providing the system with a factor of safety.

**Requirements Analysis**

The Project Haiti purifier outlined in the previous sections accomplishes all of the system requirements set forth at the beginning of this chapter. This section will remark on each of those requirements.

1. The membrane based purifier produces consistent quality water. Over its lifetime, the ultrafiltration membrane unit will produce water that meets the EPA’s 0.3 NTU level for turbidity.

2. The ultraviolet light filter will deactivate the DNA of every pathogen listed in figure 4 as long as the UV bulb is replaced when required.

3. The carbon filter that is part of the system removes bad taste and smell from the water to produce aesthetically pleasing water.

4. The purifier has been over designed to ensure that each project partner does not run out of water. It also allows the partner to create a microbusiness and sell the surplus water to the community.

5. Maintenance is required once a year for replacement of certain filter elements. Table 6 shows the frequency of necessary maintenance procedures and the associated cost.
Table 6. Filter Maintenance and Replacement Cost

<table>
<thead>
<tr>
<th>Filter Element</th>
<th>Maintenance Frequency</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>UF Membrane</td>
<td>Once every 4 – 6 years</td>
<td>$1100</td>
</tr>
<tr>
<td>Carbon Filter</td>
<td>Once a year</td>
<td>$350</td>
</tr>
<tr>
<td>UV Bulb</td>
<td>Once a year</td>
<td>$75</td>
</tr>
</tbody>
</table>

6. The Project Haiti purifier has been described by a customer as the “army jeep” of purifiers. Operation requires little skill and pictorial instructions are included for anyone to operate the system.

7. The system uses solar power for operation. In Haiti, the electrical grid is very unreliable but the solar power is available year round. The purifier is also rugged and designed to withstand the dusty and hot environment. The 2012 system has been in operation for two years with no problems.
Chapter IV
Community Development Model

As mentioned earlier, it takes more than introducing a technology to a community for a long lasting impact. The following model has been developed by the Project Haiti team to design clean water solutions for social change. Not only is a partner organization receiving clean water, but also being given an opportunity for financial growth. The model, built around the technology, outlines partner requirements, handover of ownership, community buy in through health education, origination of microbusinesses, and monitoring and evaluation for improved future projects.

Partner Selection

The project partner is the most important aspect of a successful project. Before committing, each year’s partner goes through a vetting process. The partner must fulfill each item on the partner requirements checklist in order for the team to work with them. The following six requirements have been developed through the years and is reviewed and updated after every project. Currently, there are six partner requirements which the team views as important to continued project success.

1. Compatible Vision and Mission Children have “heightened susceptibility to the negative effects of risky environments and to the beneficial effects of supportive environments” [10]. They require proper nurturing in a safe and welcoming environment. This is why Project Haiti targets project partners who deal directly with children. The partner organization must express a desire for a sustainable water purification system and have the means to operate and maintain such a system. This is why the next partner requirement is the ability to cost share.
2. **Cost Sharing** Sharing the cost of the project hardware ensures that the partner is sufficiently capable of fundraising and operating the multi-thousand dollar pieces of equipment. A model that works is ERAU paying for the purifier, solar panels, shipping, and customs to get the hardware to the site while the partner paying for any infrastructure upgrades, water tanks, and other pre-installation site costs.

3. **Open Communication** Communication is required pre, during, and post trip to ensure that everyone is aware of what needs to get done and is able to ask questions and clear up any uncertainty. Although the system ownership and responsibility is transferred to the partner, the ERAU team still feels committed to each installed system and will assist if necessary.

4. **Secure Location** To ensure the proper protection of the investment, the partner must show that they have sufficient security measures in place. This means having all or most of the following: a high security wall, barbed wire around the perimeter, locked purifier room, and/or a security guard 24/7. Having proper security is necessary as theft is commonplace and thousands of dollars of hardware becomes tempting with minimal security.

5. **Understand Local Culture** The partners Project Haiti chooses to work with must understand that the Haitians need to be given the tools to break out of the poverty cycle themselves. Currently, the Haitian economy is based on foreign aid and very few opportunities to achieve financial independence exist. Project Haiti aims to provide a hand up. The water is never given out for free but rather at a very cheap rate. The exchange of money forces community members to generate income by working in order to purchase basic necessities. As more and more money is exchange, the local economy begins to grow and slowly, they are able to break out of the poverty cycle.
6. **Entrepreneurial** The partner must see the benefit of selling the surplus water from the system to the community. Although they can use the system only for their purposes, when it comes to replacing the filters at the end of the year, they will have to pay out of pocket. The creation of a micro-business around the purifier creates jobs and generates income for the maintenance of the system. All of the organizations Project Haiti works with in Haiti are doing development work so they understand the value of the microbusinesses and value the opportunity highly.

It has been shown that a positive correlation exists between increased economic activity from entrepreneurs and economic performance [11]. By nurturing entrepreneurial activities, Project Haiti aims to create new jobs, generate increased wealth for the partners, and improve the livelihoods of all those involved.

**Training** During the installation, the team makes sure that the daily system operator is around and aware of what is being done. After the installation, the operator is handed a pictorial operation guide. The guide uses pictures to show how to operate the system. The training team goes through the guide once and then goes through different situations which the operator may encounter to ensure that they fully understand the system. In addition to the pictorial guide, a technical user manual with computer aided drawings (CAD), water and electric schematics, all system component datasheets, and a troubleshooting guide is provided for future reference.

Appendix C includes more information relating to the technology, and Appendix D includes the user manual from 2012 including the pictorial quick start guides.

**Health Education**

Since our project partners deal mainly with children’s growth and wellbeing, a health education portion was introduced. This team is responsible for interacting with the children
with visual and interactive activities to teach about WASH (water, sanitation, and hygiene) principles. The community health education portion in the paper in Appendix C goes over some of the activities which are employed. These activities leave a strong impression even on the adults.

**Monitoring and Evaluation**

To continue Project Haiti’s success, a monitoring and evaluation component will be implemented beginning with the 2014 system. This will allow the team to track system health, amount of water being produced and sold, and how the income is being distributed. Table 3 from Appendix C shows the major components of Project Haiti to include the partner and their needs, the water purifier, the business opportunity, and the health education component. Each of these components has outputs and outcomes that can be tracked. If monitoring whether these outcomes are successful or fail will aid in figuring out what works and what parts need to be reassessed.
Chapter V

Results

Onaville Tent City

The Onaville tent city, one of the largest in Haiti, is located on the foothills outside Port-au-Prince. After the earthquake, over 100,000 internally displaced persons (IDPs) were displaced here. Non-governmental organizations (NGOs) provided water and other support to the makeshift communities on the mountain until the water trucks simply stopped. Pastor Pierre from NVM became involved with the community and started a church in the community for people to gather and have a central location. He also had a 350 foot well dug on the church property and requested ERAU to design a water purification system for the community. Having developed a relationship already with Miller-Leaman, the team was able to design and build a two UF membrane system with UV disinfection. The system, capable of purifying up to 20,000 gallons of water per day, was only partially solar powered. With limited initial funds, a diesel generator was necessary to power the solar well pump in order for it to provide 25 gpm.

This was the first year a microbusiness was launched. A direct sales model was used. A bucket fill rail was installed on the side of the shipping container, as shown in figure 9. An operator was hired to backflush the system every hour and to collect money from sales. Several months later, the team learned that enough income was being generated to cover the cost of the diesel fuel, income for the operators, and had extra for community events. They also planned on building a more culturally standard water selling building in hopes that it would generate more sales.
Figure 9. Bucket Fill Rail.

The system is currently not producing to its capacity. To scale the business, the partner is currently exploring selling the water to the other water selling businesses in the community. The pitch is that the water they are buying from water trucks that come from Port-au-Prince may not be clean. In 2012, the team tested the water quality at three of the local water selling businesses. Figure 10 shows at least one of the three businesses was selling contaminated water. Further, by purchasing from the purifier, they would be supporting the local community economy.
Ryan Epps Home for Children

The Ryan Epps Home for Children (REHC), located just east of Port-au-Prince, is an orphanage with roughly two dozen children permanently living at the site. It is also a school for 200 children to attend during the school year. It is run by an American based board of directors and has a permanent Haitian site manager who runs the daily operations. Having purchased 5 gallon jugs from the local grocery store at a cost of $1 for every 5 gallons for several years, they looked for a way to reduce their water cost. They discovered Project Haiti and a partnership was developed.

The REHC and Project Haiti visions were compatible. REHC dealt directly with kids and were looking for ways to incorporate clean water technology to lower their water costs and solar power to have a reliable source of power. The vetting process was efficient as the board was knowledgeable about the daily operations and was able to communicate daily if needed. Their facility already had a security wall with barbed wire and planned on hiring a security guard.

Figure 10. Water Quality Tests from Competing Businesses in Onaville.
During the design phase, they worked with the team to build up the necessary infrastructure. They laid a concrete foundation, built a platform to put the clean water tank on, put a roof over the structure, and built a storefront for the microbusiness.

The cost of the project was shared. ERAU was responsible for the water purification system, the solar power system, and the shipping and custom fees. REHC was responsible for the additional required infrastructure including the concrete rooms, three water tanks, and the locally sourced deep cycle batteries.

A health education session, in the form of WASH training described in Appendix C, was done for the children who were there during the installation trip in August 2013. They learned about water contaminants, the effect they can have on the human body, and proper hygiene. They also received a few hygiene items like toothbrush, toothpaste, and soap to reinforce good hygiene practices. When the water purification system was commissioned, one of the orphans jumped up and down and said, “I can trust this water. I can drink it.” This was a very impactful moment for the team.

Communication is still ongoing. The team plans to visit in May and want to implement some monitoring measures to see how much water is sold, make sure the system is operating properly, and make sure that there are no problems. The team also plans to discuss some strategies to sell more water.

**Dayspring Missions Orphanage**

The 2014 project partner is Dayspring Missions. Like REHC, they have an American based board of directors. One member, located in Florida, attended the 2013 post trip presentation and approached the team afterwards to see if they could be the next partner. Similar to REHC, they look after roughly two dozen orphans, but the orphans at Dayspring are
still located at a temporary location. The permanent orphanage is still under construction and was in progress while the team was installing the 2014 purifier.

Dayspring also has an established food distribution network with three locations in the Port-au-Prince area. This created an opportunity to create microbusinesses selling clean water at each of these locations.

Before the team’s arrival, the Dayspring team reinforced their existing building infrastructure to support the weight of the solar panels for the system. They also purchased a larger vehicle to deliver water to each of the microbusiness locations. An operator is currently operating the system on a daily basis and tracking how much water is being delivered to each of the three locations. The business model at the moment is Dayspring provides the water at 15 Haitian Gourdes (35 cents USD) for every 5 gallons. The businesses sell the water at 25 Gourdes (58 cents USD), so they make a profit of 10 Gourdes (23 cents USD) for every five gallons.
Chapter VI
Discussion, Conclusions, and Recommendations

Discussions

Technology is advancing more rapidly and shaping our everyday world faster than humans may be able to process the non-technical consequences of this change. A change in the engineering mindset is necessary for global challenges to be solved. It is not enough for engineers to develop a technical solution to a problem. In the case of providing clean water solutions to developing countries, the technology must be sustainable, appropriate, and culturally accepted.

Conclusions

Project Haiti has evolved from just donating a piece of technical equipment to a community with a need for clean water to a project where that technology is a centerpiece for social change. The technology not only fulfills a basic need, but also provides the opportunity for improved livelihoods and community growth. Although there have been many lessons learned along the way, the Project Haiti team is able to reflect and improve the project year after year to positively impact every community that they have and will partner with. The multifaceted community development model is constantly being improved but is a framework for successful, sustainable water projects for communities in developing countries.

Recommendations

Further work is required in the monitoring and evaluation area as it was not implemented until the 2014 project. Before then, the project results were presented as the total number of people that the system could potentially impact. It would be more beneficial to know exactly how many people or families each system is impacting and using the other date
collected from the monitoring of the systems, figuring out strategies to increase customer base and consequently impact.
Appendix A

Bibliography


Appendix B

High Tech High Touch: Lessons Learned from Project Haiti 2011
Abstract – In this paper, we will share our experiences and lessons learned from a design project (Project Haiti 2011) for providing clean water to a Haitian orphanage. Supported by funds from a renewable energy company and the university president’s office, five engineering students and two faculty members from Embry-Riddle Aeronautical University successfully designed and installed a solar powered water purification system for an orphanage located in Chambellan, Haiti. This paper discusses the unique educational experiences gained from unusual design constraints such as ambiguity of existing facilities due to limited communication, logistics of international construction at a remote village location, and cross-cultural differences in water usage. Multiple positive outcomes were achieved such as our students developing a global perspective, our faculty gaining experience in leading an overseas student trip, and the provision of daily water for children and surrounding community in Haiti. Our student perspectives will be shared as well as the framework for support from our community and university administration. Project Haiti 2011 was a big success for all the participants and the stakeholders. We hope that this paper inspires others to pursue similar service learning experiences and find a repeatable engineering education model for international community improvement projects.

Introduction

In January 2010, Haiti was struck by a devastating earthquake which killed hundreds of thousands of people, caused significant damage to key infrastructure, and left survivors without food and potable water. The orphanage of the Ann Clemende Julien Foundation (ACJF), a non-profit organization dedicated toward providing an education to impoverished Haitian orphans living in Chambellan, Haiti, has seen an increased number of children since the deaths of their parents during the earthquake. Provision of clean water for these children is extremely important to keep them healthy because they may easily have life-threatening water related diseases due to inadequate water and sewage treatment which has caused the cholera outbreak in October 2010 in Haiti. A team of faculty advisors from mechanical engineering and students from different engineering fields at Embry-Riddle Aeronautical University was assembled to take this mission to design and install a purification system. It took the team four months to design and test the system. In August 2011, the team successfully delivered and installed the system at the orphanage. This project not only has benefited the orphans by providing sanitary drinking water, but also provides a great learning experience for team members as the team has tackled several design challenges and overcome many unexpected issues.

We will share our experience from design to installation in the paper. The paper will be organized as follows. We will first present the design challenges and several issues encountered during the project. Then we will summarize our lessons learned from this project. Through this paper, we are trying to develop a model that can be used by other engineering educators to create similar service learning experiences.
Design Challenges and Logistic Issues

Project Overview

This project was intended to design a solar powered water purification system to provide clean, purified water for 600 orphans. The untreated underground water is pumped from a well with a depth of 150 feet and then goes through a five-stage water filtration system to produce clean drinking water at the flow rate of 2 gallons per minute. The system also needs to store, regulate, and distribute 1,200 gallons of water.

As shown in Figure 1, the system is composed of five major components including the solar panels, the submersible pump, the water filters, the storage tank, and the battery pack as an alternative power source. The four 135 watt solar panels provide power for the submersible pump, the UV filter, and slight lighting needs. The submersible solar pump can deliver up to 6 gallons per minute and lift up to 200 feet maximum depth capability. The pump will turn off automatically by a float switch when the storage tank is full. The five-stage water filters (Figure 2) include one 20 micron pre-filter and one 1 micron sediment pre-filter to remove sediments, one KDF/GAC filter and one carbon GAC filter to remove heavy metals and enhance the taste, and a UV filter to kill bacteria and germs. These filters are designed to remove 99.9% of all contaminants and 99.999% of all microorganisms, and can purify up to 200,000 gallons of water per year. The batteries are only used when the solar panels cannot provide enough power such as during cloudy or rainy days.

After the system was installed, we compared the water quality of the treated water from the system and untreated city water these orphans usually drink. The results (Figure 3) show a significant improvement in water quality.

As an extracurricular activity, the project took the team four months from design to delivery and successful installation. Although the system is mainly made up of off-the-shelf parts, due to lack of communication with end users, it was very hard for the team to finalize the design. Furthermore, the team was challenged by several logistic issues during delivery and installation of such system in the orphanage, which is located 10-hour driving distance away from the
Haiti’s capital Port-au-Prince. We will present the design challenges and logistic issues in the next section.

![Figure 3 (a) The untreated city water which has numerous bacteria growth spots with multiple species](image1)

![Figure 3 (b) The filtered well water which shows only 2 bacteria growth spots](image2)

**Figure 3 Water Purification Result**

**Design Challenges**

The design challenges arose from uncertainty and ambiguity about end user needs. Since there was no direct communication such as email or phone available in the orphanage, we were not able to get in touch with the staff there to know their needs and obtain the site information. All the information we had was from the project sponsor, a renewable energy company CEO, and the director of ACJF who is a pastor in Redding, Connecticut. Neither of them can provide a clear list of needs. On the other hand, the well was not drilled yet, so we were unaware of the well depth and water quality. Such ambiguity created uncertainty on our design decision as follows.

For the pump selection, we were told the well depth would be around 200 feet which was estimated based on a recently drilled well nearby at a higher elevation. Since the depth was an estimation figure, the decision based on this number may result in either an overqualified pump or one which cannot be used to provide enough lift. Both scenarios will increase the budget and jeopardize the investment. On the other hand, the uncertainty on pump selection also places a hold on sizing the power of solar panels. The project halted at this stage for about couple of weeks until we received the sponsor’s agreement on this estimation.

The initial need of the project was provision of clean water to the orphans. When students almost finished the design and testing, new requests arose such as providing utility water for construction, lighting needs in the whole building and extra power for appliances and computers. After negotiating with the sponsor and the orphanage director, we decided that these needs will not be addressed at current design. However, such change did give the team certain setbacks.

The effectiveness and duration of the water filters mainly rely on water quality. However, since the well was not drilled yet and no water analysis was available for us to predict the water turbidity, sulfur level, arsenic level, and microorganism density. Therefore, the team had to
adopt a common configuration of a water filtration system, which may not last as long as used in normal situations.

One interesting design issue arose due to culture difference. When we designed the final water delivery system, we naturally came up with a design using a fountain with multi water bubbler faucets (Figure 4). However, our design did not please the staff at the orphanage because they could not figure out how to use them. As a result, we modified the design by adding a normal faucet they are familiar with so that they can use it to fill buckets easily.

![Figure 4 The Fountain with Multi Water Bubbler Faucets](image)

Tackling these design challenges gave students the experience of solving open problems with constraints and adopting working solutions even without sufficient information.

**Logistic Issues**

Compared to the above design challenges which mostly can be foreseen, several logistic issues were encountered unexpectedly. Some of these issues may even possibly result in failure of the project. Based on our experiences through Project Haiti, we strongly suggest that these logistic issues should be paid more attention especially for such projects implemented in a third world country.

**Travel Embargo**

Some airlines have summer box and bag embargo on certain flights. Under the embargo, oversize, overweight and excess baggage will not be accepted on these flights. Haiti is on the seasonal embargo list of American Airlines, which means that we cannot check those oversized and overweight parts, including the solar panels and a box holding water filters and the pump.

Fortunately, not all airlines enact the embargo. We successfully brought these oversized parts to Haiti by buying tickets from the airline without embargo. If we were aware of the embargo, we may either choose different travel dates or different airline to avoid embargo.
Accommodation and Dining

Our flight destination was Haiti’s capital Port au Prince, while the orphanage is located in Chambellan which is 10-hour driving distance away. A safe place to stay in Port-au-Prince before we headed for the orphanage was extremely important to ensure the team’s safety. Through our contact with Nehemiah Vision Ministries (NVM), an international organization focused on transforming the lives of Haitians, we were able to stay safe and healthy in Port-au-Prince (Figure 5).

![Figure 5(a) The NVM Volunteer Dorm](image1) ![Figure 5(b) The NVM Dining Hall](image2)

 Translator

Although we brought most parts to Haiti, we still need to buy other components there such as pipes and fittings. On the other hand, it was a ten-hour bus ride from Port-au-Prince to Chambellan, and we had to go through several check points during the trip. Such purchase and travel needs cannot be completed without a translator. Our local translator “Junior”, a language teacher at the University of Haiti, has provided us tremendous help in shopping and passing check points.

Lessons Learned

All team members felt that this trip was a life changing experience. Just as the University president Dr. Johnson said when he commented on our project: “we are more than high-tech – we are high touch. It’s a nice blend of engineering and caring for people”, we would like to extend our success to have broader impacts. As many references indicate that project-based service learning (PBSL) not only benefits a community but also provides a rich learning experience [1-4]. We hope what we learned from this unique PBSL experience will motivate more engineering educators to explore effective projects and strategies in PBSL to enhance engineering education.

Winning Factors

We have successfully commissioned a solar water purification system in Haiti. When reviewing the whole process from design to installation, we all agreed on the following determining winning factors: the support from the sponsor and the university administration, the committed team, and the past experience of travel in Haiti. If any of these factors had a weak link, we will not be able to complete the project.
The biggest barrier to complete the project is the cost. The sponsor raised and matched funds to pay for all hardware and contract the drilling of a 125 foot well. However, in order to send the team to the orphanage to install the system, we still need around ten thousand dollars of travel funds. We were very thankful that the president generously provided us with the travel support when he heard of our financial needs. Such high-tech-high-touch vision not only leads to the success of this project, but also transforms how our students perceive their identities as engineers.

We could not imagine we can complete this extracurricular project without this committed team. All students in this team spent a lot of their spare time in designing, communicating with end users, and trouble-shooting problems. None of the students had worked on the similar project, so they easily get overwhelmed by the above design challenges. All students were motivated by the meaning of the project, and their hard work and perseverance took the project to a successful end for sure.

As explained above, any logistic issue could easily turn to be a failing factor if not resolved. One faculty member’s past experience of traveling in Haiti as a volunteer has helped us achieve a hassle-free trip in Haiti where there still remains a danger of violent crime. Without the Haitian translator and the accommodation and dining we received from the NVM and the orphanage, our health and even safety may be threatened, not to mention the completion of the project.

**Recommendations**

Although we have successfully completed the project, we realized that we had benefited from some lucky factors which may not be repeatable. As a result, our once success in PBSL may not be sustainable and make broader impact on other engineering education community interested in PBSL. We still would like to provide some recommendations based on our limited experiences. We will conduct more qualitative and quantitative analysis to develop a PBSL model including finding project resources and funding support, to logistics arrangements and project implementation.

More and more universities may intend to integrate PBSL in engineering education due to several benefits such as achieving higher retention rate in engineering and enhanced awareness of social impact of engineering. Those, who are interested in doing similar projects in a third world country, may wonder how to find these opportunities. Establishing a partnership with those nonprofit organizations (NPOs) helping third world countries would be a good approach. These organizations have strong needs and rich experiences in taking volunteers working on the projects in third world countries. All the projects we have been involved were initiated through such NPOs. Campus Crusade for Christ International is such an example of NPO.

As we explained above, the sponsorship is critically important for implementing similar projects due to the high travel cost. Many NPOs may only provide project opportunities without funding support. As a result, the team needs to be responsible for fund raising. Based on our experience, we would suggest trying the following resources: university administrations, university’s Board of Trustees, alumni association, and local churches and communities etc.
In addition, logistic issues should receive more attention. For example, if your project requires shipping of oversized baggage, you need to ensure the travel dates and flight will not be affected by the travel embargo. You also need to be fully aware of primitive living conditions in order to plan for the trip to ensure the health and safety of the team during the stay.

Conclusion

This paper presented our experience of designing and installing a solar powered water purification system for a Haitian orphanage. We reviewed our experience from the perspectives of design challenges and logistics issues. We also identified winning factors which led to the successful completion of the project. Although we were unable to develop a PBL model through this project, we will conduct more qualitative and quantitative analysis for future similar projects such that other universities may benefit from our results.

Bibliography

Appendix C

Community Development through a Sustainable Micro-Business Selling Clean Water
Abstract— This paper presents an ongoing, multi-year, student-run project to provide access to clean water at specific, targeted communities in Haiti. Project Haiti is a yearly student research, design, fabrication, test, installation, and training effort at Embry-Riddle Aeronautical University (ERAU) to deliver sustainable water purifiers and originate a companion micro-business to sell excess clean water to the community. Haiti’s rebuilding effort after the 2010 earthquake highlighted the need for sustainable development and cooperation among partnering NGOs in localized communities. Poorly managed relief and development efforts were characterized by lack of coordination, lack of local ownership, and resulting hardware and projects that were unsustainable. Lessons learned from the history of US-based aid to developing countries are taken into account each year. Specific criteria were developed for installation partner and community selection. Either a fully or partially solar-powered water purifier was installed in Haiti for operation by trained locals. Water, sanitation, and hygiene (WASH) training was also implemented among the local community using a translator. This community development model is a short-term, focused, and specialized approach that brings in the right people to partner with an existing long-term organization. The goals and timeline for this Solution Focused approach are clear and well-defined.

Keywords—drinking water; membrane filter; ultraviolet disinfection; community development; sustainability

Introduction
January 12, 2010 is a day marked by a 7.0 magnitude earthquake ten miles from Port-au-Prince, the capital of Haiti. This event was the worst humanitarian and economic disaster in the western hemisphere killing more than 230,000 people, displacing over 1 million people into makeshift camps, injuring hundreds of thousands more, and causing $7.8 billion in damages and losses [1]. Four years later, the number of displaced has dropped 89 percent to 146,000. However, these internally displace persons (IDPs) are still facing
many challenges including, but not limited to, gender-based violence, health issues, and limited access to basic services [2].

The unimaginable devastation in Port-au-Prince was widely televised across America and motivated people to donate towards relief efforts. At Embry-Riddle Aeronautical University (ERAU), Project Haiti was founded by faculty and students who decided to use their engineering skills to assist the people of Haiti in rebuilding. The need for clean water was evident; lack of clean water is not only a problem in Haiti, but many areas around the world. At the time, over 1 billion people globally lacked access to an improved water source. Today, over 780 million people are still without clean water. At the end of 2011, 36% of Haiti’s entire population still used water from unimproved sources [3]. As described by UN Secretary General Ban Ki-Moon, “safe drinking water and adequate sanitation are crucial for poverty reduction, crucial for sustainable development, and crucial for achieving any and every one of the Millennium Development Goals.” Children suffer the most from unsafe water and the team saw the opportunity to improve this crisis and set forth to develop a solution to bring clean water to the people of Haiti.

Having previously designed a small scale, solar-powered water purification system for academic purposes, the team decided to scale up the technology for use in communities within Haiti. Starting Project Haiti required the development of a vision and a mission which are shown in Table 1 below.

<table>
<thead>
<tr>
<th>Vision</th>
<th>Universal clean water access</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission</td>
<td>Install water purifiers powered by solar power for communities in Haiti</td>
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</table>

Utilizing the university’s professional network, a project partner with an expressed need for clean water was found for 2010. The partner was a NGO who was setting up a camp for American relief workers. The 1 gallon per minute (gpm) purifier was vital as it was the only water source for several dozen American workers. Soon after, a larger permanent unit was purchased to produce significantly more water for the ever growing population at the camp. The publicity generated from this project generated a project partner for 2011. This time, the purifier would be installed at a school of roughly 600 children. A system was designed and installed at the school, but not long after returning home from what felt like a success, the communication stopped and the team was left unclear as to whether the system was in use. This lack of post-installation communication prevented proper system monitoring to ensure that it continued to work properly. Furthermore, the installation and training also yielded some additional lessons. After
talking to the locals, it became obvious that future systems needed to be low maintenance, sustainable, and ensure ongoing communication before, during, and after the project. To better serve future partners, the team reassessed Project Haiti’s vision and mission, as shown in Table 2.

Table 2: Revised Project Haiti Vision and Mission

<table>
<thead>
<tr>
<th>Vision</th>
<th>Universal clean water access in economically stable communities</th>
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</thead>
<tbody>
<tr>
<td>Mission</td>
<td>Generate social change by providing targeted Haitian partner organizations with clean water through sustainable solar powered, water purification</td>
</tr>
</tbody>
</table>

To carry out this mission, a community development model was developed for future water projects. The developed model is a focused, and specialized approach which brings together an engineering team with an existing long-term organization with specific community needs and goals. This paper will go through the components within the community development model. This model has been used for the Project Haiti 2012, 2013, and 2014 systems.

Community Development Model
The water crisis will not be solved by one solution. It will take a multitude of different technologies and strategies to obtain universal clean water access. The Millennium Development Goals for water measure people’s access to improved water sources. However, these sources may not be providing safe drinking water as most of these are not purified in any manner but rather sourced from a protected water source. For the Project Haiti team, providing clean drinking water is the most important goal.

The first step in the community development model developed by the Project Haiti team targets specific partners who have compatible vision, mission, and goals. Once a partner has shown that they meet the requirements, a purification system that meets their needs is designed, built, and installed. The locals are trained on operation and maintenance. A pre-discussed business model to sell the water to the community is also implemented with these locals. While the installation and business are being implemented, a separate team is doing interactive health education activities with the children and locals in the community to teach about clean water, and proper hygiene practices.

Project Partner Selection
Choosing an appropriate partner is a critical task which requires transparency on both sides. The lessons learned from Project Haiti 2011 drove the development of the following partner requirements.
**Compatible Vision and Mission**

When choosing a project partner, the Project Haiti team focused in on targeting organizations working with children, either as an orphanage or as a school. The reason behind the thinking is that children have “heightened susceptibility to the negative effects of risky environments and to the beneficial effects of supportive environments” [4]. This vulnerability requires proper adult role models who can nurture positive habits and lifestyles. Through providing clean water and health education, these children can grow up with adequate health, nutrition, and educational opportunities that will shape their life.

The project partner must value the educational portion as much as the technology which will provide them with clean water. Americans take clean water for granted as it comes out of every fixture we install in our home; however, this is not a luxury many in the world have. All of Project Haiti’s partners understand and value this view. They, too, believe that the children are our future and everything possible needs to be done to protect it.

**Entrepreneurial Locals**

The Project Haiti mission calls for social change. The team views this not only as investing in Haiti’s future, but also encouraging and shaping economic development in the community where the systems are installed. The water purifiers are engineered to provide more water than the partner requires. This extra water is then sold to the local community through an on-site micro-business. These micro-businesses create jobs and generate income for system sustainability. The project partners must search for trustworthy locals with an entrepreneurial spirit pre-trip so that they can familiarize themselves with the technology and help with the installation.

**Open Communication**

The major lesson learned during Project Haiti 2011 was that communication is needed at every stage of a project. In 2011, very little useful communication occurred pre-trip. When asked for a site layout, the team received a hand-drawn, not-to-scale drawing shown in Figure 1. The installation ended up being completely different from what was known and the team learned that pre-planning would have made the installation process easier and quicker.

It has also been mentioned above that post-trip communication stopped shortly after the team returned. Without knowing whether the system is still in commission, the team can not accurately evaluate the impact of their work. If it still is in commission, it is unknown if they have kept up with the necessary filter replacements.
This requirement has shaped the new project partners. Since 2011, the partners have a leadership team who either visits the U.S. or is an American based board of directors. This allows for a constant stream of questions and discussions which helps in preparation of the installation trip. The site can be prepared to the necessary specifications, the team can learn about the community, and the team can receive feedback once they have returned to the U.S. The team has found success using a private Facebook group where all past partners can read and comment on communications with the new partner.

**Provide Security**

Security is a major concern in developing countries. Theft is commonplace and safeguards need to be in place to protect investments. The partner must be able to provide a secure location for the solar power system components and the purification system. Project Haiti’s partners have utilized the following security measures including a security wall with barbed wire, a security guard, a building with a padlock, and a welded frame around the solar array.

**Cost Sharing**

The partner will be required to cost share in the development of the site. A model that works for Project Haiti is the team pays for the cost of the purifier, solar panels, shipping, and customs while the partner pays for pick-up of the hardware, any necessary construction and other infrastructure needs. Cost sharing is beneficial because it develops a partnership, rather than a giver-receiver dynamic. It gives ownership and responsibility to the partner. It also helps ensure that the project partner is communicating with the team and is able to operate within the Haitian culture.
Understand Local Culture
The Haitian culture and lifestyle is vastly different than what Americans are used to. This affects the way they see life and the way they interact with foreigners. Junior Rene, Project Haiti’s in-country guide, says that the Haitian people see Americans as rich, know everything, and are trustworthy. This view can be dangerous for the well-being of the Haitian people and the effects of this can be seen in the streets of downtown Port-au-Prince. Driving through the city, people are begging at every street corner. At no fault of their own, they have been brought up in a culture where asking others for a handout is an acceptable behavior. To change this, they need to be empowered and given a hand up and shown that they can rely on themselves to get out of poverty. This aspect has been a centerpiece around which Project Haiti has grown.

Technology

A. Purifier Design

1) Design Goals

The team wanted to design a modular purification system that was scalable for every partner site and therefore, would standardize a majority of the system. Since the systems are operated and maintained by local Haitians with limited science education, the most crucial design goal is to build a sustainable system requiring minimal maintenance and simple operational tasks.

The main filtration components of the purifier can be backwashed or cleaned manually, which extends the life of the ultrafiltration (UF) membrane. A system that requires frequent cartridge replacements increases the overall maintenance cost of the system and with limited availability in Haiti, this would lead to the partners having to import the desired filter cartridges from overseas more often than necessary.

The design avoids the use of complex automated electronics by using simple valve mechanisms to switch from the filtration and backflush modes thus allowing for field serviceability. Mechanical timer relays control the filtration and backflush run-times. Avoiding sensitive electronics has also led to a simpler design that is easier to maintain and repair.

Stages of filtration
As illustrated in Figure 2, the system utilizes three stages of filtration. First, the microbiologically laden water passes through a disc filter which removes sediments larger than 50 micron. As the water passes from the outside of the discs to the inside, grooves molded into the surface of the discs trap the sediments. These discs, made of plastic, can be manually cleaned and be reused. A high velocity centrifugal action inside the filter housing causes the sediments to spin away from the disc cartridge to the base of the filter [5]. The accumulated sediments can then be flushed from the filter through the flush port connection at the bottom of the filter. This minimizes the maintenance required on the discs.

Next, a 0.1 UF membrane filter is used. The UF membrane removes all types of bacteria and a majority of viruses. The filter has a large surface area allowing for low transmembrane pressure at high flow rates. With proper maintenance, the membrane filter has a 4-7 year design life [6].

The third stage of purification is a germicidal ultraviolet (UV) filter. The UV rays deactivate the DNA of any remaining microbiological material. The UV bulb, costing less than $100, provides 9000 hours (375 days) of consistent ultraviolet output before needing to be replaced.

The last stage of filtration is an activated carbon filter. This is a new addition after an email from the 2013 partner stated that they were having trouble selling the water because of the taste. Activated carbon is used primarily to remove taste and odor, but is able to remove chemicals, some metals, and volatile organic compounds. The partner will be required to refill the carbon once a year.

**Purifier Operation and Maintenance**

After being in operation for a period of time, the suspended particles in the water source

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**Figure 2: Purifier Hydraulic Flow Schematic**

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form a cake layer on the membrane surface which results in an increase in transmembrane pressure. A backflush system is utilized to lift off the cake layer and flush out the suspended particles. Purified water, mixed with a dosage of chlorine (6 ounces of chlorine to 30 gallons of purified water), is passed through the UF membrane filter in reverse direction. In addition, high velocity air is blown through the filter simultaneously to increase the backwash efficiency. The use of air during backwash improves material removal and also reduces the volume of concentrated foulant to be flushed [7]. The chlorine that is added into the backflush promotes chemical breakdown of foulants. Chlorine is able to destroy organic matter that accumulates on the membrane surface and repressing microbial growth [8]. Therefore, the use of chlorine during backwash prevents the formation of biofilm on the membrane surface.

The overall effectiveness of backflushing to enhance membrane productivity is directly related to the characteristics of the well water that is passed through the filter and the frequency at which backwash cycles are performed. For this reason, the system is backflushed every hour by the Haitian operators. The entire cycle takes just one minute. Air scouring occurs in the first 20 seconds to agitate the fibers in the membrane. The final 40 seconds includes air and water flushing out the fiber pores and expelling them out of the system.

**Electrical Power System Design**

Haiti’s power grid is extremely unreliable with power available only a couple hours a day, and the cost is extremely expensive at over three dollars per kilowatt-hour (kWh). The ERAU team cannot rely on this power source and has installed off grid solar power systems for purifier operations. When required, a solar well pump system is installed alongside the solar purification system. Figure 3 illustrates the schematic for both of these solar power systems.

2) **Well Pump**

The wells that the ERAU have encountered have ranged from 100 feet to 350 feet. For each of these, a solar well pump system has been utilized. These are battery-less systems; water pumps as long as there is solar power available. The solar well pump is a direct current (DC) pump that accepts a wide range of input voltages. This is necessary because the voltage of the solar array varies depending on sun intensity and cloud cover.
Solar Power System
The solar power systems for the purifier are designed to be off-grid and include a charge controller and battery bank. A charge controller monitors and regulates the power transfer from the solar panels to the battery bank for maximum efficiency. It also prevents the battery bank from overcharging which could lead to a dangerous situation. The batteries for the systems are purchased in Haitian hardware stores.

Some components on the purifier require alternating current (AC) power. Since the batteries provide direct current (DC) power, a power inverter is required. The full load current of all the loads and the startup current for the motors that will be connected to the inverter need to be known to determine the correct inverter size.

Installation, Training, and Commissioning

B. Microbiological Testing

After installing the systems in Haiti, bacteria tests were performed on a well water sample and a purified water sample to ensure water safety. More than 5 colonies of bacteria is considered an unsafe amount of bacteria and water purification is required. Figure 4 compares the two samples after 48 hours. The well water on the left has sufficient colonies of bacteria to cause illness. After passing through the purifier, not only does the water appear clear, it has also drastically reduced bacteria levels. The water was then determined as safe for consumption and becomes the water source for the team.
Training and Commissioning
After installation, a full day is allocated to train the local operators and to educate them about the functionality of the purifier. To help ensure understanding of operation, the team develops a quick-start pictorial guide. The quick-start guide is designed to facilitate the daily operations of the purifier. The operators simply follow the diagrams laid out on the manual. In addition to the pictorial guides, a technical user manual containing computer aided drawings (CAD), schematics, datasheets and troubleshooting guides are also provided to the partner organizations. In case the system malfunctions, the user manual contains sufficient information to solve the problem at hand.

Micro-Business Startup
Project Haiti includes the startup of a micro-business because entrepreneurial activities are essential for a community to break the cycle of poverty. Nurturing these activities lead to new jobs, increased wealth, and improved livelihoods. It has been shown that a positive correlation exists between increased economic activity from entrepreneurs and economic performance [9].

The high volume purification systems that have been installed are an opportunity for the partner organizations to generate revenue for new jobs and for maintenance fees. Several business models have been developed based on the different situations at each location.

The 2012 project partner’s site at Onaville Tent City in the foothills on the outskirts of Port-au-Prince is located within a church. Serving as the center of the community, it began as a direct sale business serving individual community members. However, a
bigger opportunity is in the works to sell in bulk to the already established water selling companies. Currently, those companies purchase their water from a water truck that drives in from Port-au-Prince. However, it will be more beneficial for the community for them to purchase their water from a local source because they know the water will be safe, it will help the local economy, and it will be cheaper because the water does not need to be transported as far.

The 2013 project partner is the Ryan Epps Home for Children. Home to 25 children and serving as a school for 200, the purifier is providing them with more than enough clean water. They have set up a water selling business and have shown their entrepreneurial spirit by also selling electricity from the solar power system.

The 2014 project partner is Dayspring Missions who runs an orphanage of several dozen. Their business model will take advantage of their already established food distribution system. A micro-business will be established at each of the three food distribution locations to sell the water. Five gallon jugs will be filled up at the purifier site and trucked with the food to each location.

**Monitoring and Evaluation**
Monitoring and evaluation, within the social science field of evaluative research, serves to collect information on the design, implementation, and effect of projects on targeted populations in order to improve the project and develop better practices for future projects [10].

The main goal of incorporating these practices into Project Haiti is to keep communication open. Although ownership and responsibility of the systems are transferred to the partner organizations, the team is still committed to each system and wants to ensure that the partner has someone to turn to if necessary. Levinson splits monitoring and evaluation into four principal components including inputs, outputs, outcomes, and impacts. Table 3 below breaks down the components of Project Haiti used to develop the performance measures for monitoring purposes.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
<th>Outcomes</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine Partner Water Needs</td>
<td>Purifier Designed and Built</td>
<td>Purifier Installed and Commissioned</td>
<td>Orphans have clean water everyday reducing sickness</td>
</tr>
</tbody>
</table>
These components, which stem from the project’s vision and mission statements, are used to determine specific performance measures in order to achieve the project’s mission. Although the project components for each water project may be the same, the performance measures for each location may change depending on the exact circumstances. For example, the 2014 Dayspring Missions business model is one where the water is distributed to three different locations. For this location, the amount of water to each external site will be tracked. For the 2013 REHC location, this is an unnecessary measure; rather, the total sales will be tracked.

**Community Health Education**
After refocusing the project in 2012 towards impacting children, education became an important piece of the model. Rather than doing a lecture, interactive and visual activities were developed. Figure 5 shows a pictorial banner with Haitian Creole warnings that illustrates the sources of contaminants and the consequences of drinking contaminated water. This is one banner which the team uses in order to educate the children and orphans about contaminants in water.
To further illustrate the effect of bacteria on humans, the community is shown the results of the team’s water quality tests. The team utilizes the Hach Pathoscreen test kit which is a powder that is put into a water sample that accelerates bacteria growth. With contaminated water, the sample turns black within 24 – 48 hours and begins producing a putrid smell. Figure 6 shows the results of the water quality tests from several local vendors where people in the community purchase drinking water. From the figure, J&J is selling bacteria-laden water. This is a very strong activity which not only impacts the children but also adults who have never seen contaminated water in this way.

Figure 5: WASH Training Poster

Figure 6: Water Quality Tests from Local Vendors in Haiti
Additional health education activities include a coloring book with banners such as in Figure 5: WASH Training Poster that the children can hang up by their bed, how to properly wash their hands with soap, and how to clean buckets with bleach that carry drinking water so they don’t recontaminate the water.

Conclusion
The Project Haiti team has learned that providing clean water by installing a water purification system in a community is not enough. If the system breaks, they will revert back to drinking the contaminated water from before. Instead, the Project Haiti team selects strategic partnerships with established organizations who express a need and desire for a water purification system. After ensuring that they fit the partner requirements, a plan is put together that not only includes the water purifier, but also a health education and a microbusiness portion. Educating the community about why they get sick from drinking contaminated water helps get buy in and providing an opportunity to obtain an income by using the water purification system helps transfer the responsibility for the system to the Haitians.
References


Appendix D

Project Haiti 2012 User Manual
2012 Project Haiti Water Purification System
A 3rd Generation ERAU Water Purification System

Engineering Binder

Kyle Fennesy
Yung Wong
Shavin Pinto
Farrah Hassan
Dr. Marc Compere
## Contents

1 General Points of Information ........................................... 1

2 System Overview ............................................................. 1

3 Installation ........................................................................ 2
   3.1 Solar System ................................................................. 2
   3.2 Plumbing and Pump Priming ............................................... 3
   3.3 Electrical ................................................................. 3

4 Modes of Operation .......................................................... 4
   4.1 Normal Operation ......................................................... 4
   4.2 Turning Off ................................................................... 6
   4.3 Storage ......................................................................... 6
   4.4 Back flush ................................................................... 6
   4.5 Cleaning ......................................................................... 9
      4.5.1 Sediment Filter ....................................................... 9
      4.5.2 Membrane Filter ..................................................... 9
   4.6 Troubleshooting ............................................................ 9
      4.6.1 Electrical (Energy Flow) ........................................... 9
      4.6.2 Water Flow ........................................................... 10
      4.6.3 Back Flush ............................................................ 11

5 Maintenance Schedule and Log .............................................. 12

6 Technical Specifications ...................................................... 14

7 Glossary ................................................................................. 14

8 Liability Information .......................................................... 15

9 Contact Information ............................................................ 16
1 General Points of Information

- Read this entire User Manual before using the water purifier system
- **Do not** run this system over 14 psi (measured from sediment filter pressure gauge). This could result in broken components and/or reduce the life span of the system.
- Do not run the purifier system for more than 1 hour without back flushing
- Always double check that your valves are pointed in the correct direction prior to starting the system
- This water purification system is not designed to improve the taste or smell of the water. Purified water can be free of all harmful pathogens yet maintain a taste or odor.

2 System Overview

The 2012 Project Haiti Water Purification System

![Diagram of the water purification system](image)

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UF # 1</td>
</tr>
<tr>
<td>2</td>
<td>UF # 2</td>
</tr>
<tr>
<td>3</td>
<td>Sediment Filter</td>
</tr>
<tr>
<td>4</td>
<td>Ultraviolet Light (UV)</td>
</tr>
<tr>
<td>5</td>
<td>Three way valve</td>
</tr>
<tr>
<td>6</td>
<td>Control Box</td>
</tr>
<tr>
<td>7</td>
<td>2 way valve</td>
</tr>
<tr>
<td>8</td>
<td>2 way valve</td>
</tr>
<tr>
<td>9</td>
<td>Back Flush Pump</td>
</tr>
</tbody>
</table>

This is a 3 stage water purification system. It consists of a Miller-Leaman Helix HD Sediment Filter, 2 Miller-Leaman Ultra-Pure Ultra Filtration (UF) Membrane Filters, and a Sterilight SC-600 Cobalt Series.
Ultraviolet (UV) System. The system uses an AMT 368A-95 Inline Pump to transfer unfiltered well-water from a reservoir through the filters to remove all contaminants down to 0.1 micron, then pass the filtered water through a UV system to deactivate any remaining bacteria and viruses. The clean water is then pumped into a fresh water reservoir.

Filter life is increased by utilizing a back flush system. The back flush system uses a separate AMT 368A-95 Inline Pump and an AC/Power Vortex Blower 1200G to pump air and freshwater back into the system to agitate the UF filters and remove sediment build up.

The pumps and blower are powered by a 20kW diesel generator and the UV filter and lights are powered using 6 235-Watt solar arrays.

3 Installation

To set up the 2012 Haiti Water Purification System for operation:

3.1 Solar System

The UV light is designed to stay on at all times (24 hours a day, 7 days a week). Turning the bulb on and off reduces the bulb's lifespan.

Precautions

- Check all circuit breaker switches are in off position.
- Ensure there are no exposed wires.
- Ensure all wires are connected securely.

Setup

1. Connect solar arrays 1 and 2 and the inverter to electric combiner box.
2. Connect the electric combiner box and battery bank to the charge controller.
3. Connect inverter to the battery bank.
4. Connect loads to inverter.
5. Turn on the two 15A solar circuit breakers.
6. Check that the charge controller is indicating a battery bank state of charge, where G: Green; Y: Yellow; R: Red.

<table>
<thead>
<tr>
<th>Color</th>
<th>SOC Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>80% to 95% SOC</td>
</tr>
<tr>
<td>G+Y</td>
<td>60% to 80% SOC</td>
</tr>
<tr>
<td>Y</td>
<td>35% to 60% SOC</td>
</tr>
<tr>
<td>Y+R</td>
<td>0% to 35% SOC</td>
</tr>
<tr>
<td>R</td>
<td>Battery is discharging</td>
</tr>
</tbody>
</table>

7. Turn on inverter circuit breaker.
8. Turn on loads.
3.2 Plumbing and Pump Priming

1. Make sure that all hoses are in the proper place and secured properly.
   
   (a) One 2" hose should go from the dirty well water tank to the “main” pump
   (b) One 1.5" hose should go from the “main” pump to the side of the sediment filter
   (c) One 2" hose should go from one of the clean water tanks to the “back flush” pump
   (d) One 1.5" hose should go from the back flush pump to the PVC plumbing
   (e) A discharge hose should be attached at the bottom of the back flush PVC piping and discharge the dirty back flush water at least 20 ft from the system. This is will be harmful waste water, not to be consumed.

2. Ensure that both pumps are primed (have water inside of them). If pumps are not primed, they will break. To prime pumps:
   
   (a) **Main pump:** to prime the main pump, first have the inlet and outlet hoses connected to the pump. Water source should be higher than the pump inlet and water should fill up the inside of the pump half-way. To fill up the rest of the pump and complete the priming, turn the system on (see normal operation quick start guide section 4.1) for 1-2 seconds then turn the main switch to ‘OFF’. Turn the switch to ‘ON’ for another 1-2 seconds then turn switch to ‘OFF’. You should now be able to see water in both the inlet and outlet hoses of the main pump; this indicates that it is primed. If there is no visible water in the outlet hose of the main pump, turn the main switch to ‘ON’ for 1-2 seconds, then ‘OFF’.
   
   (b) **Back flush pump:** to prime the back flush pump, first have the inlet and outlet hoses connected to the pump. Water source should be higher than the pump inlet and water should fill up the inside of the pump half-way. To fill up the rest of the pump and complete the priming, turn the system to back flush (see back flush guide section 4.4) for 1-2 seconds then turn the main switch to ‘OFF’. Turn the switch to ‘back flush’ for another 1-2 seconds then turn switch to ‘OFF’. You should now be able to see water in both the inlet and outlet hoses of the main pump; this indicates that it is primed. If there is no visible water in the outlet hose of the main pump, turn the main switch to ‘back flush’ for 1-2 seconds, then ‘OFF’.

3.3 Electrical

The control box on the main filtration system provides the power from the diesel generator, controls the two inline pumps for filtration, the air blower, the timers and the alarm. This system is separate from the solar power system which powers the UV light and lighting for inside the shipping container.

To start system:

1. Make sure that the electrical box is turned off.

2. Plug the system into the generator.

3. Make sure that the generator is properly functioning and has fuel, then turn on.

4. Make sure the valves are in the correct positioning before turning switch to the left for normal filtration, or to the right for back flush.

The secondary control box behind the main control box contains the timers and the alarm. There are two timers: one for normal filtration and one for back flush. The timer for normal filtration will turn the system off after ____ minutes, indicating that it is time to back flush the system. There is no need to reset the timer after it turns the system off. The timer for back flush is set at 60 seconds. The alarm in the secondary control box will turn on after the back flush is done and will not turn off until you turn the main switch to the off position.
4 Modes of Operation

4.1 Normal Operation

1. Configure the grey three way valve to point to the right, i.e. pointing towards the label “Normal Operation”.

2. Configure the two yellow valve handles so that both point towards the labels “ON” (left valve pointing down, right valve pointing to the right).

3. Turn the switch on the control box to the left towards the label “ON”. You should be able to hear the pumps and see the water flowing through the flow-meter and into the clean water tank.

4. After one hour the system will automatically turn itself off. This is normal and means that it is time to back flush the system.
Normal Operation Quick Start Guide

1. Plug into generator
2. Turn on generator
3. Ensure that pumps are primed (have water in them)  
   *See user’s manual on how to prime
4. Turn left valve down (open)  
   Turn right valve right (closed)
5. Turn three-way valve right
6. Turn switch on to ‘ON’
4.2 Turning Off

To turn the filter off, turn the switch on the control box so that it is pointing up towards the label “Off”.

4.3 Storage

Storing the system might be necessary if a component is malfunctioning and it will take time for a technician to fix the system. If the system will not be operated for more than 48 hours at a time for any reason, the following procedure is to be used to prepare the system for storage. If the system is not stored properly, then permanent damage may occur or the filters’ life span may be reduced. To properly store system:

1. Add 3 liters of alcohol-based mouth wash (Scope, Listerine, etc.) to the back flush reservoir. Back flush the system for one complete cycle (see section 4.4).
2. Turn control box to ‘OFF’.
3. Turn off generator.
4. Unplug system from generator.
5. Turn solar panel circuit breakers off.
6. Close valves to both the clean and dirty water tanks.
7. Connect a garden hose to the bottom of the sediment filter.
8. Drain the sediment filter using the flush port valve until water stops flowing from it.
9. Open right yellow valve by turning it upward. This should allow some water to drain from the system through the discharge hose. Then close this right valve.
10. Carefully take the 1” hoses off of the bottom and the top (water inlet) of the UF filters and replace with the cam lock caps. Water will spill out and this has to be done quickly. Be careful of electronics. Have towels available.
11. Take off all other hoses and allow to dry except for the blower/air hoses; leave these on.

Please contact the Embry-Riddle Aeronautical University Project Haiti group if it is necessary to store the system for longer than 1 week. When starting up the system again after storage, reconnect all hoses and electrical connections then run the back flush cycle 10 times before normal operation.

4.4 Back flush

Back flushing is needed to rejuvenate the UF filters. See section 5 for maintenance schedule. To turn back flush the system:

1. Check that the “Waste” hose is pointing away from all persons and property.
2. The system can be configured to back flush both UF filters at the same time or each one individually. It is best to back flush UF#2 (see following illustration) first to guarantee that UF#2 contaminants do not enter UF#1. Configure the grey three way valve to point up.
3. Configure the two yellow valve handles so that both point towards the labels “Back Flush” (left valve pointing left, right valve pointing up).

4. Turn the switch on the control box to the right towards the label “Back Flush”. The blower and back flush pump should start automatically. The system is on a timer, so when a back flush cycle is complete, the blower and pump will stop automatically and the alarm will go off.

5. You must now back flush UF#1. To do this, repeat this procedure after switching the three-way valve selection to UF#1 by pointing the three way valve down.
Back flush Operation Quick Start Guide

1. Turn switch ‘OFF’

2. Turn left valve left (closed)
   Turn right valve up (open)

3. Turn three-way valve up

4. Turn switch right to ‘Back flush’

5. Wait 1 minute for alarm to go off, then turn switch to ‘OFF’

6. Turn three-way valve down

7. Turn switch right to ‘Back flush’

8. Wait 1 minute for alarm to go off, then turn switch to ‘OFF’
4.5 Cleaning

4.5.1 Sediment Filter

1. Turn system off and open flush port at the bottom of the sediment filter. Pressure gauges mounted on the filter housing must read zero.

2. Unlatch the band clamp assembly and remove the filter lid.

3. Remove the blue (or red) filter cartridge from the filter body. The filtration cartridge seats tightly into the filter body. If necessary, rock the cartridge gently from side to side to facilitate removal.

4. Rinse the exterior of the cartridge in a bucket of purified water to remove any loose debris on the exterior surface of the discs/screen.

5. Unscrew the threaded wing bolt until bolt and cartridge cover plate are loose. Do not remove the wing bolt from the filtration cartridge. The filtration discs will be loose and can freely move on the filtration cartridge frame. Rinse the filtration discs in the bucket of purified water until all contaminants are removed. Restack the discs onto the cartridge frame, position the cover plate and retighten the threaded wing bolt, hand tighten only. IMPORTANT: Be sure all particulates have been thoroughly rinsed from the space between discs. Particles caught between discs could affect filtration integrity.

6. Reposition the filtration cartridge into the filter body. Push firmly to seat the o-ring on the cartridge into the filter body.

7. Securely fasten the filter lid to the housing with the stainless steel band clamp.

4.5.2 Membrane Filter

See section 4.4 back flush.

4.6 Troubleshooting

4.6.1 Electrical (Energy Flow)

The system is plugged in but nothing comes on when I turn the switch on.

1. Make sure the generator is on.

2. The water level in the dirty water tank is too low or clean water tank is full.

   (a) There is a float switch in the dirty water tank that will turn the system off (or keep it from turning on) when the water level is too low in the tank.
There is another float switch in the clean water tank that will turn the system off (or keep it from turning on) if the clean water tank is full. This prevents over filling the tank.

Wait for water levels to return to appropriate level then try again.

### 3. There is a blown fuse

(a) Turn switch off.

(b) Unplug from generator.

(c) Check fuses with multi-meter. Turn the multimeter to measure resistance (200 Ω setting). Touch the red wire tip to the top metal part of a fuse. Touch the black wire tip to the bottom part of the same fuse. If the multimeter reads infinite resistance then the fuse is blown. Pull out with pliers carefully and replace with a new one. If the multimeter reads a small resistance then that fuse is good and try the next two repeating the same process.

(d) Check electrical connections. Ensure that all wires in the electrical box have not come out of their terminals or are unplugged. Also check exterior wires to see if they have been severed in any way.

### 4. High current may have tripped overload relays.

(a) Reset by pushing red reset button on the front of the overload relay inside the control box.

### The UV light is not turning on.

1. Plugs may have come loose.

   (a) Turn inverter off

   (b) Make sure that the plug on top of the UV is securely connected.

   (c) Make sure that the plug from the UV controller is securely connected to the inverter.

   (d) Turn on circuit breaker and see if it is now working

2. Electrical problem with inverter, charge controller, battery bank.

   (a) Ensure the inverter is on and connected to the battery bank. Check the battery voltage. Total battery bank voltage should be 48 V\text{DC}. Individual battery voltages should be 6 V\text{DC}.

3. After 1 year the UV controller will turn itself off. If it is August 2013 the life span of the bulb may be expired.

### 4.6.2 Water Flow

**No water is flowing**

1. Check the valves are positioned properly (see section 4.1).

2. Check operation switch is in the 'on' position.

3. Make sure the pump is on and primed.
4.6.3 Back Flush

I am trying to back flush the system but nothing is coming out the back flush valve

1. Check valve configurations. For illustrations, see section 4.4. The first yellow valve (on the left) needs to be pointing left. The second yellow valve (on the right) should be pointing up. The grey three way valve should be pointing either up or down.

2. Water level in clean tank may be too low, tripping the float switch. Stop back flush attempt and run system on normal operation until water level in clean tank rises at least 14 gallons (about one minute of normal operation).

3. Check that the pump labeled “back flush” is working (i.e. it is vibrating and buzzing).

4. Check that the blower is working (i.e. it is making noise).

5. If none of the above, contact a service technician.

I am back flushing the system but dirty water is going into the sediment filter/ sediment filter pressure gauge is showing a pressure change while back flushing

1. Check valve configurations. For illustrations, see section 4.4.

2. There should not be any activity on the pressure gauge for the sediment filter while back flushing. If there is, then the check valve may be broken. Stop operation and contact service technician.
5 Maintenance Schedule and Log
## Maintenance Log

<table>
<thead>
<tr>
<th>Time &amp; Date</th>
<th>Maintenance Performed</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
## 6 Technical Specifications

### Embry-Riddle 2012 Haiti Water Purification System

### Technical Specifications

<table>
<thead>
<tr>
<th><strong>Pumps</strong></th>
<th><strong>UF Filters</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>AMT 388A-95</td>
<td>0.1 micron ultra-flow filters</td>
</tr>
<tr>
<td>1/3 Horsepower</td>
<td>14 max PSI, 10-12 GPM each</td>
</tr>
<tr>
<td>Inlet .75&quot;</td>
<td>OPERATING AT PRESSURE HIGHER THAN</td>
</tr>
<tr>
<td>Outlet 0.5&quot; FNPT</td>
<td>14 PSI WILL CAUSE PERMANENT DAMAGE</td>
</tr>
<tr>
<td>1 phase 230V</td>
<td></td>
</tr>
<tr>
<td>Max psi at 0 GPM 19 psi, 23 GPM @ 20ft. of head</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Sediment Filter</strong></th>
<th><strong>Blower</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Helix HD Sediment filter</td>
<td>600W</td>
</tr>
<tr>
<td>100 GPM Max</td>
<td>110/220V</td>
</tr>
<tr>
<td>125 PSI Max</td>
<td>50/60 Hz</td>
</tr>
<tr>
<td>Blue disc: 50 micron, Red disc: 130 micron</td>
<td>&gt;0.015 MPA</td>
</tr>
<tr>
<td></td>
<td>46.51 CFM</td>
</tr>
<tr>
<td></td>
<td>46.3 lbs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Ultraviolet Light</strong></th>
<th><strong>Battery Bank</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterilight Cobalt Series SC-600</td>
<td>8 Deep Cycle Batteries</td>
</tr>
<tr>
<td>73W Power consumption</td>
<td>6V, 225 Amp Hours each</td>
</tr>
<tr>
<td>UV dosage of 30mJ/cm² at 35 GPM</td>
<td>Linked in series to create a 48V system</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Solar Panel</strong></th>
<th><strong>Solar Panel Configuration</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Six 235W panels</td>
<td>Two parallel banks of three panels in series</td>
</tr>
<tr>
<td>29.4V Max power voltage (V_{mp})</td>
<td>Individual banks are nominally</td>
</tr>
<tr>
<td>7.65A Max power current (I_{mp})</td>
<td>V_{bank}: 110.7V, I_{bank}: 8.5A</td>
</tr>
<tr>
<td>36.7V Open-circuit voltage (V_{oc})</td>
<td>Both banks combined (in parallel)</td>
</tr>
<tr>
<td>8.25A Short-circuit Current (I_{sc})</td>
<td>V_{total}: 110.7V, I_{total}: 17A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Charge Controller</strong></th>
<th><strong>Inverter</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Morningstar TS-MPPT-60</td>
<td>Samlex SE001R-148 Inverter</td>
</tr>
<tr>
<td>Max Current 60 Amps</td>
<td>True sine wave output</td>
</tr>
<tr>
<td>At 48V, Max Power 3200W</td>
<td>Rated power: 600W</td>
</tr>
<tr>
<td>Max solar DC voltage: 150 V DC</td>
<td>Surge power: 800W</td>
</tr>
<tr>
<td>Battery operating voltage range: 8-72V DC</td>
<td>DC Voltage: 48V_{DC}</td>
</tr>
<tr>
<td></td>
<td>AC Voltage: 100/110/120V_{AC}</td>
</tr>
</tbody>
</table>

## 7 Glossary

| **AC** | Alternating current |
| **CFM** | Cubic feet per minute |
| **Cm²** | Centimeters squared |
| **DC** | Direct current |
| **FNPT** | Female national pipe thread |
| **GPM** | Gallons per minute |
| **I_{mp}** | Current at max power |
| **I_{oc}** | Short Circuit Current |
| **Lbs.** | Pounds |
| **mJ** | Millijoules |
| **MNPT** | Male national pipe thread |
MPa  MegaPascals
Psi  Pounds per square inch
SOC State of charge
UF  Ultrafiltration membrane. There are two UF filters on this system. They are the tall white cylinders. Can block spores, bacteria, and other pathogens from passing through. Ensures turbidity is below 5 NTU (nephelometric turbidity units).
UV  Ultraviolet light. Deactivates viruses and bacteria when applied in the precise dosage. UF Ultrafiltration membrane. Can block spores, bacteria, and other pathogens from passing through. There are two UF filters on this system. They are the tall white cylinders.
V_{mp}  Voltage at max power
V_{oc}  Open Circuit Voltage
W  Watts

8  Liability Information

Embry-Riddle Aeronautical University is not responsible for consequential system damages resulting from misuse of this water purification system or any components delivered or installed by the ERAU team. Reproduction of this manual is prohibited without permission from Embry-Riddle Aeronautical University.
9 Contact Information

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Drawings
<table>
<thead>
<tr>
<th>Part #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow Meter( sheet 7)</td>
</tr>
<tr>
<td>2</td>
<td>Sediment Filter(sheet 4)</td>
</tr>
<tr>
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Right View
Left View

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<td>1&quot; PVC Typ</td>
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Isometric view
Isometric view

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<td>1&quot; Male Adaptor X Female Threads</td>
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<td>0.5&quot; MNPT Brass Nipple</td>
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Isometric view
Appendix E

2014 Purifier Control Circuit