Sustainable Water Systems for Batipa

Figure 1: Sunset at Batipa's Peninsula

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An Interactive Qualifying Project submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the degree of Bachelor of Science

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Report Submitted to:

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Abstract

Comprehending the potential and abundance of rainfall in the Chiriqui providence, Batipa Field Institute (BFI), believes it would be beneficial to install a rainwater harvesting (RWH) system. This project focuses on proposing a RWH system for BFI, while creating an educational, cost-effective model applicable for the Panamanian public. This was accomplished through exploring Panama's relationship with the environment and sustainability, communication with other biological research stations, and finally formulating our findings into a model using AutoCAD 2019.

Acknowledgements

This project was only able to be completed thanks to the help of our sponsor, and all the people we met along the way. Our team would like to personally thank:

First, we would like to thank *Mr. Edmundo González,* Batipa Field Institute's Coordinator. Mr. González has a contagious passion for preserving our environment, which further inspired us to view this project holistically. Not only did he organize our stay at David, Chiriqui, but Mr. González provided us with great resources to understand Batipa's condition, as well as introducing us to many helpful individuals along the way. Mr. González was constantly in contact with us, giving us an unforgettable tour of Batipa and experience in Panama.

We would also like to thank *Dr. Francisco Ugel*, provost at Oteima University, for providing us with helpful feedback on the direction of our project. Dr. Ugel was always available for any questions we had and was very enthusiastic in our proposal.

Dr. Bruno Bosari was also present during our stay at David. As an agro-ecologist from Winona State University, he gave our team many suggestions regarding sustainability for Batipa. These suggestions were then further analyzed and reported in this project. Not only do we thank him for this, but also for his enthusiasm of our project.

Our thanks also go to Panama's Conservation International project coordinator, *Querube Fuenmayor.* Her presentation on how to effectively inform locals, taught us that we should be thinking in their perspective, rather than ours. Empathizing with the struggles of locals, allows us to create a helpful, practical model.

Last but not least, we would like to thank Professor James Chiarelli. His guidance in our completion of our project, including formatting, clarifying our ideas, and organization of this project will not go unappreciated.

Executive Summary

INTRODUCTION

Even though our world is covered with 70 percent water, millions of people cannot access a clean, secure supply of water. Of that 70 percent, only three percent of the world's water is freshwater. The importance of water is a key factor in our project and is displayed through our design of water conscious systems for Batipa.

We worked with Oteima University and the Batipa Field Research Institute (BFI) to implement a sustainable, holistic water system. BFI is challenged by the lack of a secure, reliable, and scalable water supply and faces droughts during the months of the dry season (January - April). BFI recognizes that global climate change is, and will, continue to threaten its water supply and wants to take action to mediate future issues. We prioritized solutions for the "Los Cabimos" area, the land inside Batipa Foundation that includes BFI, housing for ecotourism, and has future plans for the construction of dormitories and facilities for research. We considered various options of securing the water supply, including the use of rainwater harvesting (RWH), a water well, and existing spring water sources. Having a secure water supply in place would allow students, researchers, and developers in the area to have a reliable and consistent means of accessing water. Additionally, we curated a RWH system that is targeted at rural, low-income Panamanians which is simple, safe, and easy to teach.

Panama is one of many Central American countries that is dealing with water shortage issues. The well-known Panama Canal requires a large amount of water to function. According to the *New York Times,* the locks lose 50 million gallons of freshwater to the ocean for every ship that passes. The locks source water from two artificial lakes, Gatun and Alajuela, which also the source of drinking water of central Panama. The two lakes struggle to supply the growing number of Panamanian citizens.

The Panamanian government is working on issues of sustainable water control, water infrastructure, and teaching the public to conserve water. Panama has great potential to be a leading country in water management. Unfortunately, the regions outside of Panama City lack governmental aid and resources, when compared to the capital. It is important for Panama to fully incorporate the goals and vision for the entire country, not just the capital, in order to create a productive and inspiring environment for its citizens.

We had the privilege to work with Oteima University, located in the city of David in the Chiriquí Province, about 326 km from Panama City. To help reduce the severe inequality of wealth, the university aims to improve economic opportunities in rural Panama, where the profits from the capital city's international services industry do not reach. Oteima was founded by concerned Panamanians who studied in more developed areas like the United States and Europe, who wished to use their training to help develop their own country.

BFI is in a dense, flourishing ecological area; home to forests and a river delta, in which Oteima plans to monitor rainfall, sea, and air temperature parameters. By visiting and learning about successful biological research stations, such as the Smithsonian Tropical Research Station (STRI), located in the Bocas del Toro province, we have gained insight into what has been advantageous or disadvantageous in other settings. The goals of this project are to understand the natural environment within Chiriqui province, create a water harvesting design specifically for Batipa Field Research Institute, and finally, to provide sustainable, low-cost designs for Panamanian people to use in their homes.

RAINWATER HARVESTING AND OFF-THE-GRID WATER SYSTEMS

Rainwater harvesting (RWH) is a method of taking advantage of the abundance of rainfall in Panama. The harvested rainwater can be used for all domestic and gardening applications, including irrigation, lavatories, and direct consumption. There are five major components when it comes to RWH: Collection, Conveyance, Storage, Purification, Distribution.

Designing an effective off-the-grid water system requires having multiple water sources. Rainwater harvesting constitutes a renewable and highly sustainable source of water, but also has limited scale and natural unpredictability. As a result, an additional water source is necessary for most applications to ensure that the supply of water is secure and predictable. Water wells draw water from underground aquifers, and provide a stable, year-round water source. Due to their predictability, they are a great complement to rainwater systems.

WATER SOLUTIONS FOR BATIPA

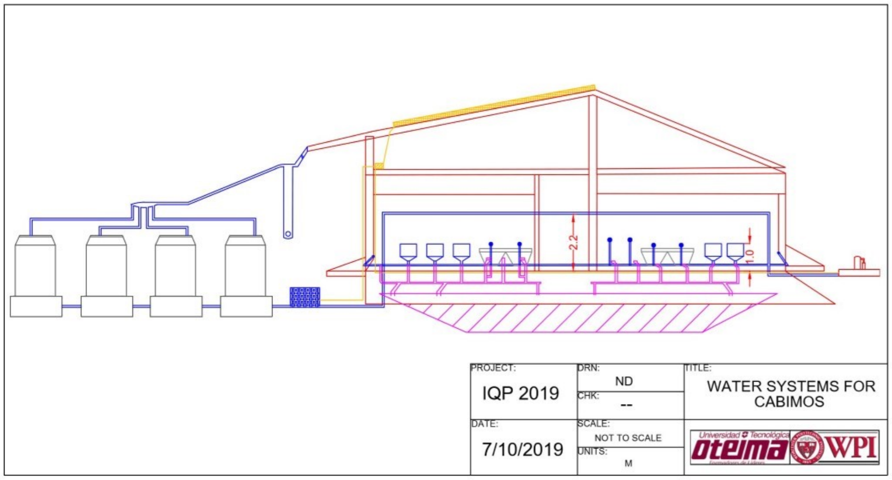

Figure 2: Water systems for Cabimos

Our CAD model for Batipa Field Institute's research station is based on a design called Aula Didáctica or more informally, Cabimos, is shown in the figure above. This was designed using AutoCAD and uses color layers to differentiate between electricity, water, and black water.

Our research indicates that BFI can support 10 people living there and 100 weekend visitors by using a combination of solar energy, rainwater harvesting and well water. Rainwater harvesting from the roof of the BFI building is enough to provide approximately 2,400 liters of water per day during the rainy season, with the remaining water being sourced from the water well. Storage should be enough to hold at least 150,000 L of water for use during a 3-day period to cover the needs of 100 visitors.

We propose that the well is the primary source of water, with the RWH system being utilized only when the tanks are full or when the well cannot accommodate present needs. In other words, the rainwater system would serve as a backup source to the well. Moreover, a scalable storage system of interconnected plastic cisterns will allow BFI to scale its water storage as needed. BFI can opt to initially deploy only a fraction of the total needed capacity and expand in the future.

Our rainwater harvesting design for BFI uses a combination of a tiled mesh and a first flush diverter for primary filtration. The tiled mesh will trap any large debris while the diverter will capture chemical contaminants washed off the roof by the first few liters of rain. We recommend 5000 Gallon Rhine water tanks for storage, due to their scalability and reliability. Distribution will be achieved by an on-demand DC pump powered by solar energy. A large-scale particulate and UV filtration system will treat the water for direct consumption.

EDUCATIONAL RAINWATER HARVESTING MODEL

One of our primary goals is to educate the public on how sustainability can benefit individuals as well as the entire country. Farmers are prime examples of people who need sufficient water access to be successful. Professions that use the land and its environment to succeed need to be mindful of the changing climate. Through our research and observation, we can help rural Panama to effectively use its resources like sunlight and rain to help sustain farming and other practices. Our simple do-it-yourself designs for rural Panamanian farms and households will demonstrate how to build and maintain a water harvesting system.

The educational rainwater harvesting model uses the simplest, most familiar and most widely available materials possible for every component of the system. Assuming a roof is already in place, we recommend CPVC piping for catchment and conveyance. For primary filtration, we recommend a fine tiled mesh capable of trapping leaves and biomass. For storage, we recommend dark-colored, sunlight-blocking rain barrels and for purification we recommend colloidal solver filters.

Even though this design is basic, it is the education portion that is the most important aspect of this design. We recommend this model to be distributed through the use of an easy-to-read/understand social media post. This post can show simple instructions and tips for safe water harvesting with this model. Local organizations, celebrities, and businesses can post these resources on social media and reach thousands of people.

FUTURE AREAS OF RESEARCH

We believe that the following ideas could be excellent opportunities for BFI to investigate and implement in the future.

I. Wastewater Treatment System

We believe that an aeration system at Batipa can be successful, not only because STRI has been successful, but also because it can be partnered with another method. The idea of a constructed wetland was highly encouraged by Dr. Bruno and is very environmentally rewarding. Wetlands are earth's natural sponge, filtering water while also providing an ecosystem that promotes biodiversity.

II. Solar Farm for Cabimos

We recommend that Batipa considers the creation of a solar farm. This solar farm would be located on the least desirable plot of grazing land and would only use 1-1.5 hectares of land. A solar farm of this size would be able to generate up to 1MW of electricity, enough to power up to 300 Panamanian homes. BFI would be able to provide plenty of electricity for the reserve and Cabimos area as well as be able to resell electricity to the grid.

III. Increase capacity of Cerro Batipa

Batipa currently uses a series of artificial dams and ponds in order to capture the water runoff from the mountain. These dams are sufficient for Batipa during the rainy seasons but do not contain the capacity to support the reserve during the dry season. We recommend that Batipa expands on these efforts by either increasing capacity or quantity of these reservoirs.

IV. Closely measure local climate change and weather patterns

In order to prevent further negative effects, we believe that Batipa should install a small weather station at the end of the existing dock as well as efforts to more closely follow weather patterns. This project would be very cost-efficient as well as extremely environmentally conscious. A simple DIY project with the inclusion of a Raspberry Pi computer can have great implications for BFI and spark the beginning of a long history of data collection at the research station.

Authorship

All team members contributed to the written work in Background, Methodology, and Findings and Analysis. Along with this, team members assisted in editing, formatting, taking photos, and were proactive in leading discussions regarding rainwater harvesting.

Panagiotis Argyrakis: Primary author of Site Assessment: Smithsonian Tropical Research Institute (STRI) at Bocas del Toro, Isla Colon in Background, Wells in Findings & Analysis, Conclusions, III: Increasing capacity of Cerro Batipa in Future Areas of Research. Co-author of the Executive Summary, Objective III: Develop a Holistic Water System for the Cabimos Area in Methodology, Objective IV: Create an Educational Rainwater Harvesting Model in Methodology. Co-Editor of the entire report.

Nathaniel DeSisto: Primary author of Water Scarcity in Introduction, Ecotourism and Biological Research Stations in Background, and Objective III in Methodology. Generated Batipa Rainwater Harvesting Model using AutoCAD, which is a portion of section III: Water Solutions for Batipa, Findings & Analysis. Took initiative in contacting local biological research stations.

Domenica Ferrero: Primary author of the Abstract, the Acknowledgements, Our Sponsor and Our Project in Introduction, Panama's Climate in Background, Objective I in Methodology, Water Harvesting Basics in Findings & Analysis, I: Wastewater Treatment System in Future Areas of Research. Contributed to Findings & Analysis in section III: Water Solutions for Batipa. Co-Editor of the entire report.

Marcelino Puente-Perez: Primary author of the Executive Summary, Fundación Batipa & Oteima University in Background, Objective II and IV in Methodology, Education Model in Findings & Analysis, II: Solar Farm for Cabimos in Future Areas of Research, III: Increasing capacity of Cerro Batipa in Future Areas of Research, III: Increasing capacity of Cerro Batipa and IV: Closely measure local climate change and weather patterns in Future Areas of Research.

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INTRODUCTION

WATER SCARCITY IN PANAMA

Water is essential to life on earth. Even though our world is covered with 70 percent water, we struggle using it efficiently. Of that 70 percent, only three percent of the world's water is freshwater. Only two thirds of that freshwater can be used, for the fact that the remaining third is stuck in glaciers. The increasing global population requires more and more water each year, which we are now experiencing its aftereffects on the environment. So much so, it is more difficult to effectively supply everyone. Across the globe, over one billion people lack access to water, over two and a half billion people find water scarce for at least one month out of the year, and over 2.4 billion have sanitation and water quality problems (WWF, 2018).

Panama is one of many Central American countries that is dealing with water shortage issues. Panama's well-known Panama Canal requires a large amount of water to function. Losing a "staggering 52 million gallons" of water from "each of the 35-45 ships that transit the canal daily", Panama has put effort in integrating new technology and techniques for sustainable water usage (Carse, 2012). Earlier this year, Carlos Vargas, the Panama Canal Authority's executive vice president for environment, water, and energy, has stated, "The last five months have been the driest dry season in the history of the canal" (Fountain, 2019). The significance of this drought is that it can be linked to El Niño, which occurs every 2 to 7 years and has been cited for centuries.

Warmer than normal surface waters in the equatorial Pacific affects weather patterns from Central and South America reaching to Asia, shown in figure 3.

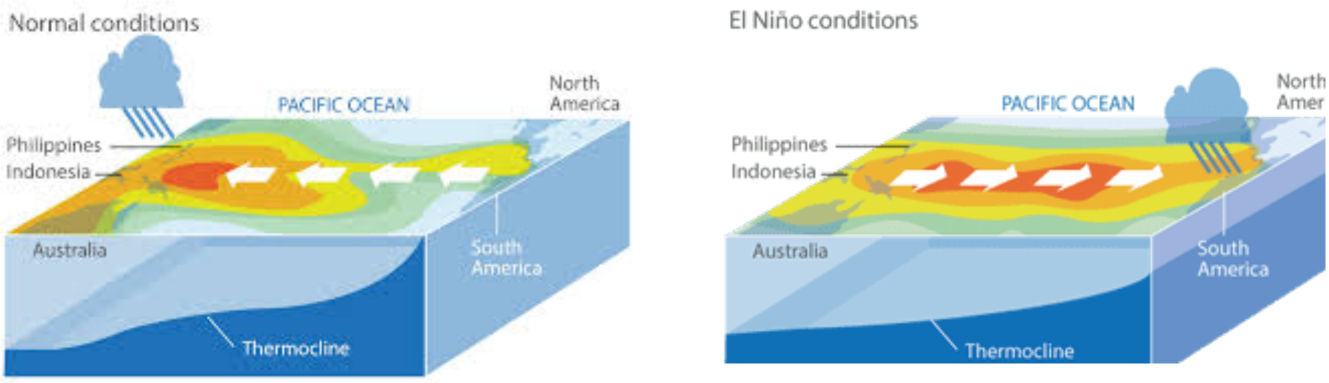


Figure 3: Normal and El Niño conditions of the Pacific Ocean

Over the past decade government officials of Panama have been working on the nation's water issue. Panama is focused on sustainable water control, water infrastructure, and teaching the public to conserve water. Panama has great potential to be a leading country in water management. Unfortunately, the regions outside of Panama City lack governmental aid and resources, in comparison to the capital. It is important for Panama to fully incorporate the goals and vision for the entire country, not just the capital, in order to create a productive and aspiring environment for its citizens.

OUR SPONSOR

Our WPI team has the privilege to work with Oteima University, located in the city of David in the Chiriquí Province, about 326 km from Panama City. Oteima University has grown from an educational training center into an officially recognized university twenty years after its founding in 1985. It now offers education for technical careers in computer science, English, business administration and tourism, aiming to train professional leaders and entrepreneurs with a commitment to Panama's goals of human and sustainability development (Oteima, 2017). To help reduce the severe inequality of wealth, the university aims to improve economic opportunities in rural Panama, where the profits from the capital city's international services industry do not reach. Oteima was founded by concerned individuals who studied in more developed areas like the United States and Europe, who wished to use their training to help develop their own country.

The mission statement of Oteima University is:

> "[to] develop professional leaders and entrepreneurs committed to the sustainable human development of the country through the generation, diffusion, and application of knowledge in areas of teaching, research, extension and production" (Oteima, 2017).

Oteima has established a biological research field station 40 km from David in western Panama on the Batipa peninsula. 2000 hectares of this peninsula has been divided into three main enterprises; "1000 hectares for the reforestation and harvesting of teak trees, 400 hectares for cattle pasture and a genetics laboratory, and 600 hectares dedicated to the preservation of biodiversity and wildlife" (Cloutier et al., 2017). Batipa Field Institute (BFI) is affiliated with Oteima University. Its mission statement is:

> "Applying the science and education for the conservation and sustainable management of natural resources." (Batipa Field Institute, 2014)

OUR PROJECT

We assisted Oteima University and the Batipa Field Research Institute (BFI) aiming to implement a sustainable, holistic water system. BFI is challenged by the lack of a secure, reliable, and scalable water supply and faces droughts during the months of the dry season (January - April). BFI recognizes that global climate change is, and will, continue to threaten its water supply and wants to take action to mediate future issues. We prioritized solutions for the "Los Cabimos" area, the land inside Batipa Foundation that includes BFI, housing for ecotourism, and has future plans of construction for dormitories and facilities for research. We considered various options of securing the water supply, including the use of rainwater harvesting (RWH), water well usage, and existing spring water sources. Having such a system in place would allow students, researchers, and developers in the area to have a reliable and consistent means of securing water.

BFI is in a dense, flourishing ecological area; home to forests and a river delta, in which Oteima plans to monitor rainfall, sea, and air temperature parameters. A close look at other successful biological research stations, such as the Smithsonian Tropical Research Station (STRI), located in the Bocas del Toro province, we have gained insight into what has been advantageous or disadvantageous in other settings. The main goals of this project are to understand the natural environment within Chiriqui province, create a water harvesting design specifically for Batipa Field Research Institute, and finally, to provide sustainable, low-cost designs for Panamanian people to use in their homes.

BACKGROUND

FUNDACIÓN BATIPA & OTEIMA

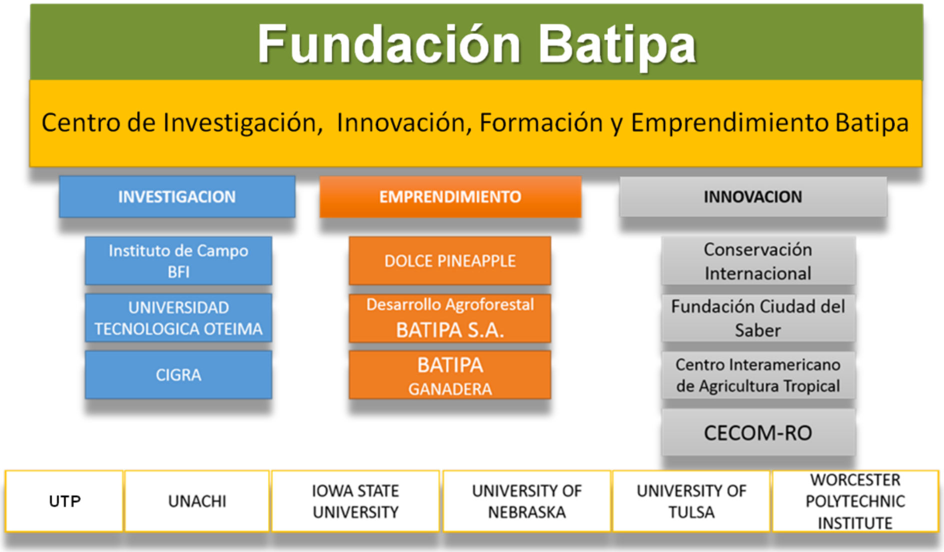


Figure 4: Batipa Foundation; Center of investigation, learning, and innovation

The Batipa Foundation is an organization devoted to sustainable development through the founding and investment in several companies that promote research, education, entrepreneurship, science, innovation as well as cultural and environmental awareness. It is structured as the parent organization of several companies in the research and education, farming and innovation areas.

Our sponsors, Oteima University and Batipa Field Institute, share Batipa Foundation as their parent organization and as a result also share their core values. Both are tasked with the goal of reducing wealth inequality in Panama through the use of education. We had the opportunity to work very closely with both entities in order to determine the best direction for our project.

Funding for BFI was provided by the Batipa Foundation. It is structured as a direct investment, with any profits being returned to the parent organization. According to stakeholders, the value of the investment is $200,000 and is aimed towards developing facilities and infrastructure for research and ecotourism.

This is where the capital for our project would come from, should BFI decide to implement it. Therefore, we are aiming to provide a scalable and cost-effective designs.

ECOTOURISM

Many countries depend on tourism as a significant portion of their economic output. Ecotourism exhibits similar economic potential but without the negative effects of traditional tourism and with sustainability and community awareness in mind. Ecotourism is defined as, "tourism of exotic, endangered environments usually to support conservation efforts and research developments." (Clayton, 2017). Ecotourism allows scientists to conduct research and, at the same time, to educate tourists as much as possible about ecosystems, environmental issues, conservation, and sustainability. Gaining a better understanding of the ecosystem and the species that inhabit it will only lead to more information on how to conserve it. To tourists, the first-hand experience of the importance of environmental sustainability can be interesting and educational. Typically, the ecosystems are a great distance from any human developed area, which allows the conserved area to be studied by scientists and also toured.

Ecotourism improves local economies much more than regular tourism. With ecotourism, local businesses reap the benefits. Average tourism doesn't allow local business to gain as much profits. Hotels, tour companies, and airlines take a large amount of the possible revenue.

Operations that are owned and run locally can take as much as ninety five percent of the profit while tourism only brings in about twenty percent to these local businesses (Lindberg et al., 1997).

"Ecotourism has a far greater potential for contributing to income and livelihoods in poor rural communities than what is realized," said Edgar Kaeslin, a Forestry Officer in Wildlife and Protected Area Management (Utkina, 2011). Some countries that utilize ecotourism include: Costa Rica, Ecuador, Nepal, and Madagascar. Regular tourists to these countries provide a great source of revenue and growth to their economies. The local business created through ecotourism will create more jobs for local citizens and even promote conservative efforts throughout the local town. Some of the benefits these local organizations and businesses receive go directly back into conservation efforts to maintain the ecosystems. Projects like reforestation and the repopulation of species can be expensive, ecotourism can help make these projects affordable.

THE CLIMATE OF PANAMA

Panama's climate consists of daylight lasting typically 12 hours as well as daily rainfall. The tropical rainforest climate provides multiple environments in which renewable energy, such as solar, can be taken advantage of.

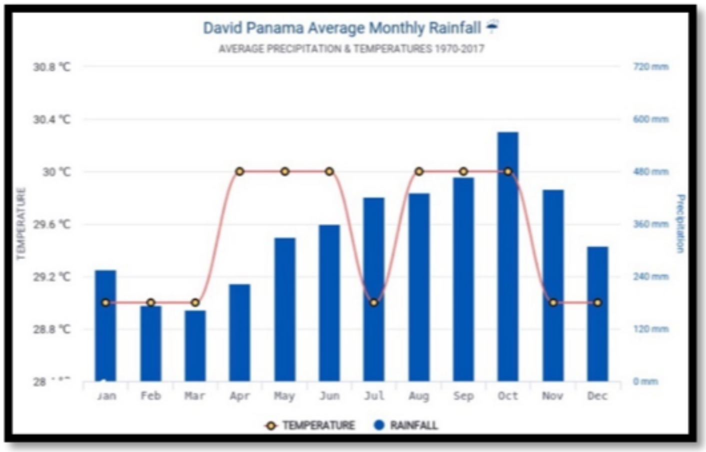


Figure 5: Accumulation of average precipitation and temperature at David, Panama from 1970-2017

With this data, the concept of water harvesting is further supported, considering the excess amount of water available, seen in figure 5. The water harvested could be used for drinking, residential, and/or facility use, especially during the dry season.

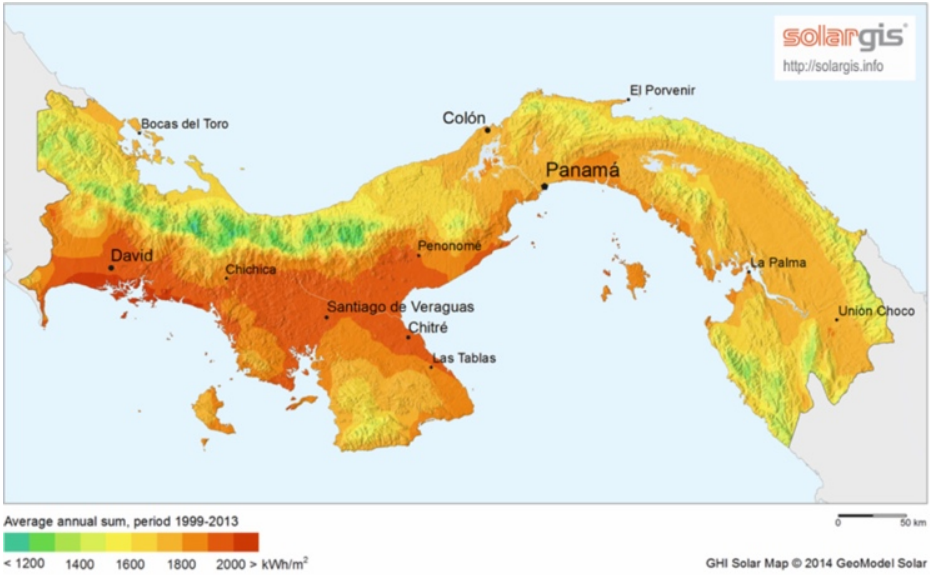


Figure 6: Solar irradiance in Panama from 1999-2013

Figure 6 demonstrates how much solar irradiation Panama receives over the course of 14 years. Panama receives an “average irradiance of 4.8kWh/m2/day”, having the strongest levels at the “south provinces of Chiriquí and Veraguas, with an average of over 5 kWh/m2/day” (SNE, 2015). This is significant, due to Batipa’s location being in Chiriquí Province. Knowing that there needs to be an input of energy into this system, Figure 6 suggests that a solar powered based energy source could be successful.

With this information in mind, our design will take advantage of Panama’s plentiful solar and water resources during peak time periods. Conservation and efficiency are key when it comes to taking advantage of these features.

The importance of taking advantage of implementing renewable resources is defined by the World Banks claims that, “around 2 million people are likely to be displace[d] from Central America by the year 2050 due to factors related to climate change” (World Bank Group, 2019). Emigration from Central America is observed to be done by the ones who rely more on the environment, such as farmers, young children, and even wildlife. Bringing attention to this issue can help prevent communities from leaving their homes, and can even encourage the concept on sustainability.

BIOLOGICAL FIELD STATIONS

Biological field stations provide an outdoor database for earth’s ecosystems. Scientists, students, general public, and even engineers travel to these stations to observe and learn from the environment. Research centers can be offshore laboratories or a land reserve, each having one goal in mind; protecting the surrounding ecosystem. There are 1268 contemporary biological field stations, located in 120 countries (Tydecks et al., 2016). Stations can be as little as a few acres or miles on end. Its facilities can differ from brand new laboratories to trail networks. However, each station shares a common view point, that every human should consider; “slowing the rate of human-induced climate change, protecting water and air quality, reducing the health impact of disasters, and minimizing…exposure to toxic chemicals,”(Keselman et al., 2013). Researchers have the opportunity to be the voice of the planet. More studies conducted on our environment will lead to a better understanding of how to maintain the ecosystems. These studies can have an impact upon how seriously government policy makers take environmental considerations.

The use of biological research stations is an effective way to protect the land while also learning about it. The impact of field station studies affect the world far more than just conservation efforts. These stations can teach the public about the land and get a better understanding of the ecosystem. The Batipa Field Institute is needed by Panama as a means of protection for the environment.

Site Assessment: Smithsonian Tropical Research Institute (STRI) at Bocas del Toro, Isla Colon

Figure 7: Entrance to Smithsonian Tropical Research Institute in Isla Colon, Bocas Del Toro

The Smithsonian Tropical Research Institute (STRI) is a non-profit organization that operates many research stations across Panama, for the purpose of researching tropical ecosystems and their relevance to the environment and human welfare. One of STRI's stations is located in Bocas Del Toro province, Isla Colon. STRI has been operating for decades and has developed a robust and extensive eco-friendly infrastructure including rainwater harvesting and solar power systems. We contacted and visited the station to learn about their RWH technology, how it is implemented and what challenges are associated with it.

At STRI, the rainwater harvesting system is comprised of three major parts. First, the gutter system collects all the water from the roof and channels it to the basement of the main building through a series of large diameter pipes. The second part, the storage, is a series of sediment-style tanks all connected to operate as a single storage medium with a total capacity of approximately 50,000 gallons. There is no filtration prior to the water entering the storage system because the first tank is being used as a sedimentation tank. Sedimentation tanks are tanks that allow sentiment, or large debris, to sink to the bottom of the tank, collecting the water from the top. Regular cleaning of the bottom is performed to ensure the water is not contaminated from the biomass. The output of the system is fitted with a floating extractor so that no sediment flows out. It is then connected to an industrial-scale particulate filter in series with a UV filter, needed for the elimination of any contaminates such as harmful bacteria. The filtration system operates at an on-demand basis and connects straight to the station for human consumption. The designated drinking tap on the first floor has an additional UV filter attached to it to prevent recontamination in the piping compromising the quality of the water.

Despite the extensive water harvesting infrastructure, STRI uses town water as its main water supply and the rainwater as backup. The staff stressed the importance of backups, especially since increasing tourist activities are putting pressure on the municipal infrastructure, leading to “raw water” getting introduced to the system when treatment facilities cannot keep up with demand. Staff said: “if we only used rainwater and got no rain, we would have no water”, (STRI staff member, personal communication, 2019). To maintain readiness, the rainwater system is always circulated. If the storage tanks get full, rainwater is used as the main source thus continuously introducing new water to the tanks.

Rainwater is also used for the fire suppression system, comprised of two large-scale storage tanks outside the main building of the research station. There is also a separate water tank for supplying the dormitory building, which stores chlorinated water. Chlorination is necessary in this case because it provides residual protection thus ensuring more thorough protection for the primary living facilities which are especially vulnerable.

In conclusion, our main takeaways from the visit to the Smithsonian Tropical Research Institute are:

I. Rainwater harvesting systems should be combined with at least one additional water source to ensure long-term stability and reliability.
II. UV treatment is the standard for large-scale, on-demand filtration but should have short pipe runs when used for drinking.
III. Chlorination is required if the water is to be stored in a tank and then directly consumed from that tank.

METHODOLOGY

To understand the needs of our sponsors, Oteima University and Batipa Field Institute, we must:

I. Understand Batipa’s sustainability challenges.
II. Survey and record critical information and infrastructure data about Batipa.
III. Develop a holistic water system for the Cabimos area.
IV. Create an educational rainwater harvesting model.

OBJECTIVE I: UNDERSTAND BATIPA’S SUSTAINABILITY CHALLENGES

Comprehending the effects of abundant rainwater in the tropics was attained once we arrived at Batipa. With consistent rainfall, it is crucial that the nutrients within the soil don’t wash away, which is beginning to be a problem at Batipa. Soil erosion was noted throughout the entire reserve, in which practices were put in place to prevent the rapid decline of topsoil. Batipa’s effort to combat these weather challenges were to introduce vetiver, seen in figure 8. Vetiver is a unique plant, the roots of which bind deeply in the soil, preventing rainwater from washing away the soil. Batipa’s planting of vetiver not only is an environmentally conscious solution, but also a sustainable one.

Figure 8: Vetiver at BatipaFigure 3: Vetiver plant observed at Batipa

It would be unjust to solely blame rainwater for the damage to the soil at Batipa. The harvesting and production of teak and cattle greatly affect the condition of the soil. The non-native teak trees in Panama are harvested in multiple monocultures. A monoculture is the harvesting of solely one species, which aside from damaging biodiversity, is known to damage soil due to the intense demand of a specific nutrient for that particular species. Along with that, the ranching of cattle that Batipa is a part of, exploits the environment, starting from the production of methane to the vast amount of land needed to raise these animals. What was once a forest has been wiped away and is now an area for cattle grazing.

OBJECTIVE II: SURVEY AND RECORD CRITICAL INFORMATION AND INFRASTRUCTURE DATA ABOUT BATIPA

During our time at Batipa, we were able to explore the many parts of the reserve. Batipa sits beneath Cerro Batipa, a nearby mountain peak on about 1,400 hectares of land. The uses of this land range from large-scale, sustainable teak-wood farming to natural flora and fauna reserves. However, the use of land that applies the most to our problem is the cattle raising and ranching.

In recent years, Batipa has struggled to find a reliable source of freshwater during the dry season (January-April), and has even resorted to leading the animals to brackish water as a supplement. This works in small quantities and for small periods of time, but it was still enough to cause the loss of over 30 animals and resulted in lower fertility rates across the board. This goes to show that Batipa's current water harvesting infrastructure, while viable during the rainy season, is not enough to support Batipa's humans and animals during the dry season.

In order to properly survey Batipa we needed a very resourceful sponsor. We were able to use a 4x4 vehicles and horses to properly traverse the hilly area. The local workers were able to show us where most of the livestock water is collected. Batipa relies on 3 main aspects of water management. These aspects are artificial ponds; tanks; pumps; and PVC piping, seen in figure 9.

Figure 9: Existing water tank at Batipa

Near the top of Cerro Batipa is a man-made reservoir, this is their largest storage source of water. This water is then channeled downwards into three smaller ponds spread along Batipa. These serve as the distribution points for most water usage in the reserve. It is from these ponds that the water is pumped to livestock, tanks, and small worker residences. In addition to Cerro Batipa, there are a small number of natural springs that have been used to supplement the human usage of water.

Figure 10: Cattle in gate with water source (blue cistern) in background

As of today, human water usage at Batipa is relatively low vs. usage for livestock. However, in the master plan of the Batipa Field Institute, there are plans to scale the tourist and researcher populations up to almost 100 people on weekends. The current system would not be able to sustain the population, even during the rainy season.

OBJECTIVE III: DEVELOP A HOLISTIC WATER SYSTEM FOR THE CABIMOS AREA

The next step in our process was to develop a water system for the Cabimos area at Batipa. After gaining a complete understanding of Batipa's stakeholders, natural challenges and future plans for its development, we had to research water management, best practices for rainwater harvesting and waste management. Our strategy was to speak with local experts, understand precedent in the region but also learn best practices from the international community. We started by speaking with Dr. Bruno Borsari, a biologist from Winona State University in Minnesota, who was conducting research at Oteima under the auspices of the Fulbright program. He connected us with important sources such as the Humanure Handbook by Joseph Jenkins, a book on sustainable waste management, and the Potters for Peace foundation, an organization that manufactures and provides education on low-cost ceramic filters for potable water treatment. He characteristically pointed out that “Waste is a human concept” regarding the cyclical nature of ecosystems (Dr. Bruno Borsari, personal communication, 2019). In addition, he introduced the idea of constructed wetlands as an effective alternative to septic tanks and municipal water treatment. Next, we visited the Bocas Del Toro research station of the Smithsonian Tropical Research Institute. There, we learned various practical aspects of deploying water management systems and different considerations we must investigate.

During our secondary research, we focused on understanding best practices of water management, availability of different products as well as case studies of rainwater harvesting systems worldwide. US government agencies like the Environmental Protection Agency and the Centers for Disease Control and Prevention were a significant source of reliable information on water filtration and treatment. We also consulted Do-It-Yourself (DIY) websites and examined proposals and setup tours of various online individuals.

OBJECTIVE IV: CREATE AN EDUCATIONAL RAINWATER HARVESTING MODEL

The last step for our project was to create an educational model, so Oteima University can spread knowledge about safe rainwater harvesting to communities outside Batipa who may be struggling to meet their water needs. To achieve this goal, our strategy consisted of three basic pillars. First, we had to learn about the local population, their culture, land and challenges they are facing. Then, we had to understand how Oteima University itself is planning on spreading knowledge and last, we had to evaluate the availability of various materials and construct a basic rainwater harvesting model using them.

We achieved the first pillar by spending a week traveling around Chiriquí and speaking with various locals affiliated with Oteima. It was important for us to understand that citizens of Chiriqui indeed do practice water harvesting, however, with bad practices. If water harvesting is not done in a safe and clean way, public health issues arise. Finding ways to educate proper techniques on water harvesting to locals was our focus. Then, through our work with Oteima University and the various presentations we participated in, we achieved our second objective and met different individuals driving Oteima's strategy and decision-making, including hands-on personnel and outside organizations and NGO's that conduct part of the effort. For our last goal we observed what kinds of materials are available within the farmlands of Batipa and in the city of David.

Figure 11: CPVC piping being used as a conveyance system at a household in David

This educational design is not specific to locals in David, but for everyone who wants to water harvest. Visiting San Blas, we had the privilege of observing how the Kunas, an indigenous group of Panama and Colombia, harvested rainwater. Without access to modern technology, the Kunas still have ways of collecting water. However, practices seen in figures 11 and 12 could be improved on and monitored closer for a more effective way to collect rainwater. The primary issues with these types of systems are, arguably, filtration and capacity of storage, which we discuss further in our findings and analysis II.

Figure 12: Water harvesting practices of indigenous people of Chichime Island, San Blas

Findings & Analysis

WATER HARVESTING BASICS

Rainwater harvesting (RWH) is an excellent method of taking advantage of the abundance of rainfall in Panama. It is important to realize that with high levels of rain, a system must adjust in response to how much water it can collect. The harvested rainwater can be used for all domestic and gardening applications, including irrigation, lavatories, and direct consumption.

There are five major components when it comes to RWH; catchment, conveyance, storage, purification, and distribution:

I. Catchment is taking into consideration the roof style of a building and if it is suitable to collect water. An ideal roof for water collection would be built with non-toxic, non-corrosive material. This is important, because lead sheeting or paint can leach dangerous chemicals into the water which are harmful if consumed. The size of the roof determines the volume of water that can be collected.

II. Conveyance of rainwater refers to the use of a gutter system. The system must be consistently clean and non-toxic, to ensure safe water flow. The rate of precipitation determines the size of the piping to be use, as pipes of insufficient diameter can cause overflow and blockage.

III. The type and scale of rainwater storage tanks depends on the indented use. Size, upfront cost, ease of maintenance and material properties are all factors in deciding what type of storage is appropriate.

IV. The purification process is the most adaptable step. Primary, secondary, and tertiary filtrations all depend on the use with irrigation being the least demanding and direct consumption the most. There are both DIY and industrial scale filtration systems available for all steps with flow rate versus cost being the main tradeoff.

V. Finally, there is distribution; how the water will travel from the storage tank to an outlet for use. This step is heavily influenced by where the storage tanks are located. The system may take advantage of gravity, which would work if the storage component is above the source of withdrawal. If not, the use of pumps is required.

WELLS

As we learned from visiting the Smithsonian Tropical Research Institute, designing an effective off-the-grid water system requires having multiple water sources. Rainwater harvesting constitutes a renewable and highly sustainable source of water, but also has limited scale and natural unpredictability. Even though the rainy season in Panama is high in precipitation, there are days with no or little rainfall. Increasing the storage capacity to account for short-term shortages is effective for small household applications but requires a disproportionate amount of area as the scale increases. As a result, an additional water source is necessary for most applications to unsure that the supply of water is secure and predictable.

Water wells have significant advantages over RWH and can become a valuable complement to rainwater systems. Wells draw water from underground aquifers, which are more stable and predictable than rainfall. In addition, they can provide water year-round and are a industry-proven, with more than 43 million people relying on private wells as their primary source of drinking water in the United States alone (Ayotte, J.D., 2017).

Water Solutions for Batipa

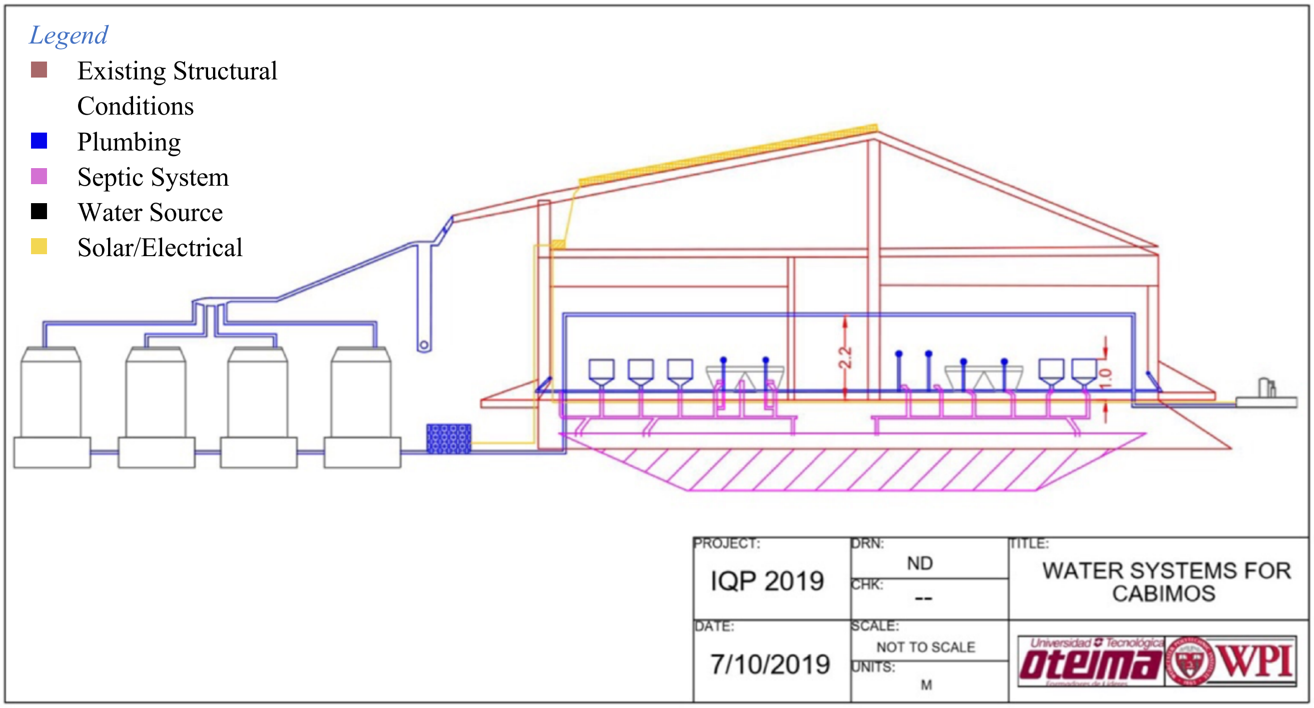


Figure 13: Water systems for Cabimos

Our model for Batipa Field Institute's research station is based on a design called *Aula Didáctica* or more informally, *Cabimos,* is shown in figure 13. This model was drawn in 'AutoCad 2019', a technical program especially used for civil and architectural engineering, along with mechanical systems like heat, ventilation, and plumbing. In AutoCad, there are layers that represent different components of the drawing. This means that, the plumbing is going to be on a different layer than the structural portion. Here, we used layers to conveniently show the different components of *Cabimos* and the systems it contains. The structural layer is represented by the dark red lines, the piping for water flow is blue, water storage is black, the septic system is pink, and lastly the solar energy system is yellow.

We started the model off by referring to the engineering plans of *Cabimos.* Our sponsor, Mr. González, gave us these plans so we could see exactly what this building contained. This was very helpful for us because we were able to see the existing conditions of the building. This includes the structural, electrical, and plumbing plans. Because we are adding on to a building, it is important for us to consider where certain pipes, beams, and other integral components of the building are.

The engineering drawing that was most helpful for us is “ESQUEMA DE TUBERIAS DEL AULA DIDÁCTICA BATIPA” figure 13, which translates as ‘Batipa Didactic Classroom Pipe Scheme’. This drawing was drawn by Daiselys D. Torrealba S with a scale of 1:20. A drawing at that scale means everything on the page is twenty times smaller than in real life. The reason this specific page is helpful to us is because it shows the water pipe connections in relation to the building. It has the basic structural components of the building while showing where the water is traveling. To make sure we drew the correct connections of our system we cross referenced (xref) the drawing into my drawing file. This was done by uploading the pipe scheme drawing, tracing it over the structural outline and the water pipe scheme, then deleting the cross reference. Left over was the outline of the pipe scheme proportional to the structure. That allowed us to make our system with connections of pipes exactly where they would be on the real building. The shower line is 2.2 meters in the air while the sink lines are 1 meter high. The drainage of these pipes is shown through the septic system, as those were cross referenced as well.

Our sustainable water ideas are based on current resources at Batipa and the future goals Batipa has in mind. According to our sponsor, the director of research at Batipa Field Institute, the vision for *Cabimos* is to have 10 people living at BFI and be able to accommodate up to 100 people staying there for a 1-to-2-day period. We calculated water consumption per person to be about 500 liters per day (IDAAN, 2019) and a worst-case of 1,000 liter per day. The following table shows the basic specifications of the needed water system along with an average and worst-case scenario.

	Sustained daily consumption (10 people)	**Peak daily consumption (100 people)**	**Peak Storage Needed for a 3-day period**
Average case (500L/day/person)	5,000 L/day	50,000 L/day	150,000 L
Worst case (1000L/day/person)	10,000 L/day	100,000 L/day	300,000 L

Table 1: RWH water supply

Table 1, above, shows that an RWH system with a water supply of 2,400 L/day would not meet the minimum needed flow of 5,000 L/day that is required to support 10 people. Moreover, the peak water flow of 10,000 L/day is also far greater that the supply of RWH.

We know that Batipa already has at least one working well. Implementing another one would be an effective and future-proof solution BFI because it would be a secure, year-round source of water. The well, because of its predictability, should be used as the primary source of water. That being said, the rainwater system will still be utilized to the maximum extent possible thus ensuring sustainability and low environmental impact. The system can work in the following way: The rainwater system fills up the tanks. Once the tanks are full, the excess rainwater is used normally, with the well serving as a buffer for any needs beyond the capacity of daily rainfall. If the tanks start draining, only the well should be used leaving the rainwater to replenish the tanks. The water in the tanks should only be accessed if the well runs dry. In this way, rainwater is utilized to its full potential while also serving as a backup source in case the well fails to supply water. This system is directly inspired by STRI, where the rainwater is used only if tanks are full, need to be cycled through, or, if the main water source is bad or not functioning.

At BFI, the catchment and conveyance steps have already been taken into consideration during the construction period, therefore we will not be looking at potential products for that design. Figure 14 is an overview of our design for Batipa.

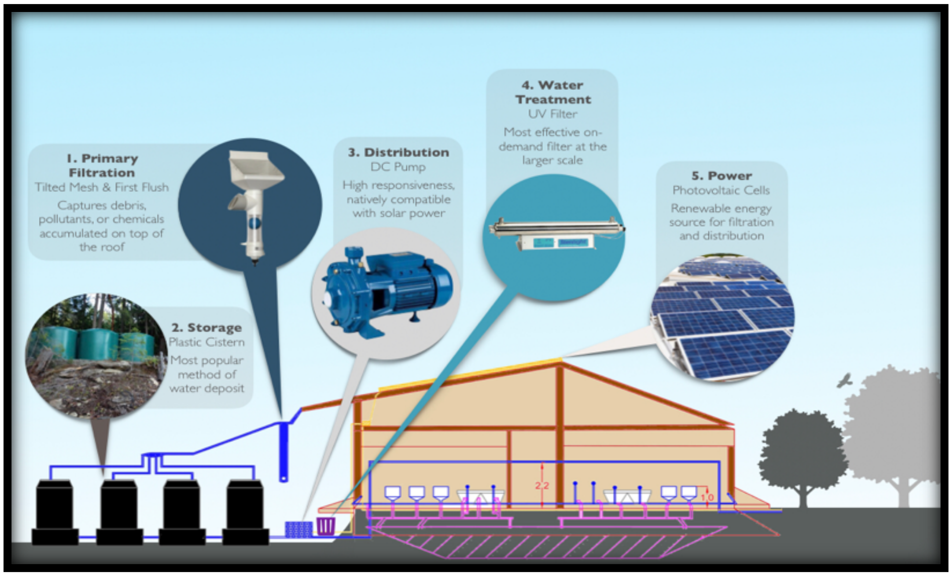


Figure 14: Summary of components in Batipa RWH model

First, we have the primary filtration which is going to be a tilted mesh filter. This is perfect for separating large debris that has accumulated on the roof, or gutters, since the last heavy rainfall. We believe that a tilted mesh is a fitting method of primary filtration, because it is an easy to implement, inexpensive solution. Table 2 summarizes why we decided a tilted mesh filter would be appropriate for this design.

PRODUCT	**TILED MESH**	 Figure 15: Leaf-eater available for purchase at most hardware stores
COST	$20+	
ENVIRONMENTAL FOOTPRINT	PLASTIC	
ADVANTAGES	• EASY TO INSTALL • CHEAP • FILTERS OUT LARGE DEBRIS • SELF CLEANING	
DISADVANTAGES	• NEEDS DAILY MAINTENANCE	
ADDITIONAL INFO	DUE TO THE ADVANTAGES OUTWEIGHING THE DISADVANTAGES	

Table 2: Product review: Tilted mesh

After the water seeps through the tilted mesh, there is a secondary filtration called a first flush divergent tube. The first flush divergent tube collects whatever the tilted mesh cannot. The initial rainwater collected from the roof is most likely contaminated water, due to any biomass accumulated from wildlife. Therefore, it is important to separate water out. Once the divergent tube fills up, a ball will close off the tube, allowing cleaner water to travel to the storage tanks. We believe that by adding a first flush divergent tube, in addition to the tilted mesh, will remove any chemical contaminants from the water and improve the quality of the harvested water. Table 3 summarizes key facts that helped us determine that a first flush divergent tube would be appropriate for this design.

Product	**First Flush Divergent Tube**	 *Figure 16: Buyable first flush system*
Cost	$50	
Environmental Footprint	Trivial	
Advantages	• Protects water • Easy to install	
Disadvantages	• Need to replace ball occasionally* • Consistent maintenance for longer use	
Additional Info	The placement of BFI puts them in a vulnerable situation for large debris to accumulate in the conveyance step.	

Table 3: Product review: First flush divergent tube

Following the primary and secondary filtration, the water moves to the storage compartment. The storage compartment in this design for Batipa will be plastic cisterns. Batipa has visions of scaling up their capacity for housing and taking that into consideration we believe the 5,000-gallon (G) Rhino plastic cisterns are the most practical option. The 5,000 G Rhino plastic cistern seemed to be the most fitting, after we learned how successful it has been at STRI. These cisterns can be connected with one another and behave as one unified container. A major advantage of this approach is the storage system to be expanded on-demand and tanks can be serviced individually. Fundacion Batipa is experienced with using dark colored plastic cisterns, utilizing them on grazing land for the cattle. This being said, we believe that the adoption of cisterns in this design for Batipa will be advantageous, knowing that it has previously been implemented, and thus workers are already familiar with dealing with this type of equipment. Table 4 summarizes our reasonings why we decided plastic cisterns would be appropriate for this design.

So, to start we can suggest anywhere from 30,000 to 60,000 liters for 10 to 20 people over a three-day period. The absolute peak would be 300,000 liters for a 3-day period. That level of storage is similar to the Smithsonian Tropical Research Institute at Bocas del Toro.

Product	**5,000 G Rhino Plastic Cistern**	*Figure 17: Cistern system at Smithsonian Tropical Research Institute* 
Cost	$2,000+	
Environmental Footprint	Plastic	
Advantages	• Batipa is familiar with handling cisterns • Can increase capacity size simply • Dark colored cisterns block sunlight, thus algae growth • Can place above ground	
Disadvantages	• Not as robust as metal	
Additional Info	Placing cisterns above ground would be the least invasive way to use cisterns, as opposed to in the ground.	

Table 4: Product review: 5,000 G Rhino plastic cistern

The next step is about distribution. The storage tanks are located at an elevation lower than the building itself. And even if they were next to the building, they would need to reach 2.2 meters high, the height of the shower heads. The only way for water to travel against gravity is with some type of pump. The pump we chose is a DC pump. Specifically, a 40 gallon per minute (GPM) DC pump, due to factors like average rate of rainfall and roof catchment size. The main reason, however, was the promising use of a combination with a renewable energy source, solar energy. Photovoltaic pumps, we believe, not only will be environmentally rewarding, but also encourage the view that solar energy can be taken advantage of in Panama. Batipa will greatly benefit from investing in solar panels, due to their vision of hosting more individuals. Hosting more individuals requires more energy, and we think that Batipa will get their investment worth out of a photovoltaic pump. Table 5 summarizes our reasonings why we decided a photovoltaic pump would be appropriate for this design for Batipa.

Table 5: Product review: Photovoltaic pump system

	Photovoltaic Pump System		
Product	**40 GPM DC Pump**	**Solar panels**	 Figure 18 : 40 GPM DC Motor *Figure 19: Example of roof solar array* 
Cost	$1,000+	large upfront cost, may receive state incentives	
Environmental Footprint	Mechanical,	source of renewable energy	
Advantages	• Rate of ability is consistent to Batipa's needs • Batipa knows how to use solar run power	• helps regulate roof temperature • Encourages use of solar power	
Disadvantages	• If no sun is out, possibility of gasoline use.	• Cloudy days can prevent the collection of energy	
Additional Info	Although it is more industrial than a rope pump, a DC pump is the most practical option for Batipa	See Recommendation II	

Once the water is looped back by the pump it will be treated. The water will be filtered through a UV filter in this design. This is the most effective on-demand filter at a larger scale, creating potable water, also seeing it in action at STRI. Using UV filtration is dictated to be the most effective method to eliminate bacteria from water. Table 6 summarizes our reasonings why we decided UV filtration would be appropriate for this design for Batipa.

Table 6: Product review: UV filter

Product	**UV Filtration**	Figure 20: High flow-rate UV filter 
Cost	$2,500+	
Environmental Footprint	• No chemicals • Emits no by-products	
Advantages	• Better alternative than chlorinating the water, environmentally wise • No chemical taste • Reliable	
Disadvantages	• Electricity needed	
Additional Info	It is crucial for the water inputted into this filtration to be free of particles. Large particles can create shadows, reducing the effectiveness of the UV light.	

Educational Rainwater Harvesting Model

One of our primary goals for this project is to educate the public on how sustainability can benefit individuals as well as the entire country. Farmers are prime examples of people who need sufficient water access to be successful. Their crops and livestock need plenty of water to become and stay healthy. A simple water harvesting system may end up saving these crops and animals during the dry season and random droughts. Professions that use the land and its environment to succeed need to be mindful of the changing climate. Through our research and observation, we can help rural Panama to effectively use its resources like sunlight and rain to help sustain farming and other practices. Our simple do-it-yourself designs for rural Panamanian farms and households will demonstrate how to build and maintain a water harvesting system. We suspect there is a vast number of citizens in Panama who would benefit from this simple system to collect water.

Now that we have a good understanding of water harvesting and its benefits, it is part of our goal to have as many people understand our perspective on water sustainability. A large portion of impoverished Panamanian citizens live in areas that are off the grid. They have their own way of looking at things, their own traditions, and their own ways of using land. Ideally, we could give them information about sustainability, and they would try their best to conform to those ideas. Unfortunately, that is not possible, as indigenous groups and Panamanian citizens who live off the grid have had generations of knowledge passed down to them leading them to be more resistant to learning new methods.

During a presentation from project coordinator, Querube Fuenmayor, explained how it would be difficult to express that what we are doing will benefit them. Communication would need to start with the owners of the land or the governments of the indigenous tribes. Unfortunately, each tribe has their own ideals and system of government. The hope would be to come up with an agreement to set aside land for growth in exchange for something else. For example, Mrs. Fuenmayor mentioned an agreement in Ecuador that benefited both parties and sustainability. Local fishermen and restaurant owners came up with a solution in which the restaurants only would buy from the local fisherman, reducing the prices of fish while giving the fishermen more business (Ouerube Euenmayor, personal communication, 2019).

We aim to provide an easy to teach model that will prove to all groups in the Panamanian countryside that rainwater harvesting can substantially increase their quality of living. This model can be easily conveyed through classes, short videos on social media, or a brochure.

Here we will breakdown the technical specifications, designs, and purposes of each component.

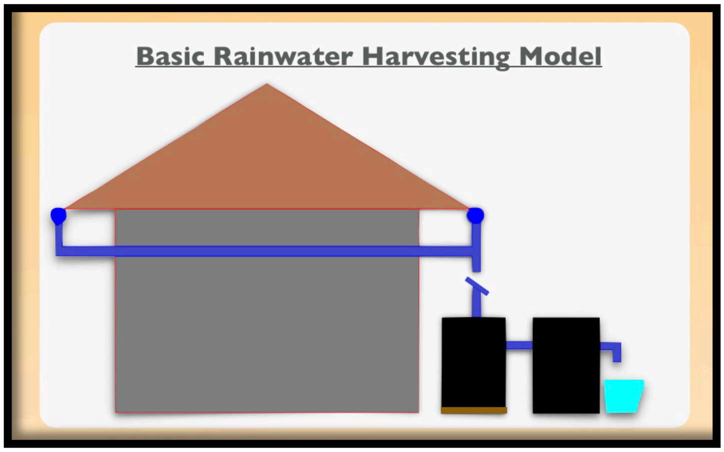


Figure 21: Basic rainwater harvesting model for local adoption

Our basic rainwater harvesting model, figure 21, consists of 4 main components. Component #1 represents catchment and conveyance. This component collects water from small to medium sized buildings for a very lost cost. Efficient water catchment is important, especially when collecting rainwater during the dry season. Therefore, it is crucial to take advantage as often as possible. Having the correct conveyance system will allow you to harvest as much water, for how long it rains for. Chlorinated polyvinyl chloride (CPVC) is our component #1 in figure #15.

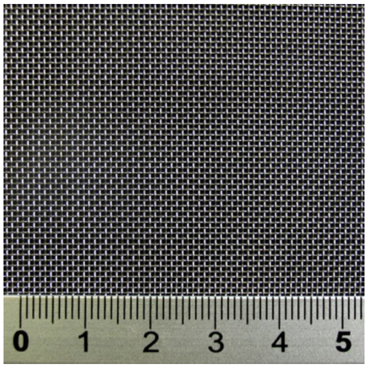
We chose CPVC piping primarily due to cost, which will hopefully encourage locals to take the first step in committing to a rainwater harvesting system. Table 7 summarizes why CPVC piping is appropriate for this design.

Table 7: Basic RWH: CPVC piping

Product	**CPVC Piping**	Figure 22: Example of installed CPVC piping 
Cost	Depends on length needed	
Environmental Footprint	Plastic	
Advantages	• Cheap • Common • Safe for drinking • Easy to install	
Disadvantages	• Toxic when improperly disposed • Fragile over time	

Feature #2 represents primary filtration. The first level of filtration sets the standard for the quality of water by reducing the amount of work needed by 2nd and 3rd level filtration. Additionally, 1st level filtration reduces the need for maintenance on all underlying structures by taking the initial hit. In this design we use a titled mesh. Building a tilted mesh filtration is evidently just a tilted section of conveyance piping covered with a layer of wire mesh. The particle and mesh size are customizable, but depending on flow of water, the smaller the particle size the better. Table 8 further summaries why we chose tilted mesh as our primary filtration.

Table 8: Basic RWH: Tilted mesh

Product	**Tilted Mesh**	 Figure 23: 40 unit mesh
Cost	Very low	
Environmental Footprint	Very small	
Advantages	• Durable • Minimal • Maintenance besides cleaning • Easy to use	
Disadvantages	• Can be overloaded without cleaning	
Additional Info	A 45-degree angle is prime for water collection and debris disposal	

Storage of water harvesting is represented in feature #3, in figure #15. For this component, we felt that safe and sanitary water storage is one of the most important parts of this system. It is unfortunately very common to find very basic RWH systems that do not take sanitation into consideration. The rain barrels we recommend are darkly colored ones, in order to inhibit sunlight, and thus mold and algae growth. In addition, it is good practice to regularly circulate the water, to prevent any reproduction grounds for mosquitos. Table 9 summaries why we decided to choose rain barrels in this design.

Table 9: Basic RWH: Rain barrels

Product	**Rain Barrels**	Figure 24: Barrel examples with sediment tanks 
Cost	Low	
Environmental Footprint	Plastic	
Advantages	• Not a separate system from water source • Can use as a settlement tank • Cost effective	
Disadvantages	• Short-Term Storage	
Additional Info	Can be treated for long-term storage with difficulty	

Feature #4 represents the purification step. Having any effective, low-cost appliance that is able to treat water for human consumption was the objective. Depending on how filtered the harvested rainwater can get defines its usefulness. We aimed to provide a solution that is very easy to use and replicate. The Colloidal Silver Filter (CSF) is a basic ceramic-based filter, lined with silver, that provides drinkable water. The porous material of the ceramic pot allows for any water-born pathogen to get stuck while moving through the filter, while the colloidal silver prevents the growth of bacteria. In our observations of local Panamanians, we found that most did not use much more than a particulate filter for the entire system. While this is suitable for sinks and toilets, it is not safe enough for drinking water. Table 10 summaries why we decided that CSF will be successful in this design.

Table 10: Basic RWH: Colloidal silver filter

PRODUCT	**COLLOIDAL SILVER FILTER**	*Figure 25: Potters for Peace design of filter* 
COST	$7-$30 (CDC, 2008)	
ENVIRONMENTAL FOOTPRINT	VERY SMALL	
ADVANTAGES	• Reports show high level of filtration • Opportunity for local production (Oyanedel-Craver VA, 2008) • Silver prevents the growth of bacteria • Portable container • Can be combined with another filtration	
DISADVANTAGES	• SLOW THROUGHPUT OF WATER • NEEDS TO BE CLEANED REGULARLY • CANNOT FILTER CHEMICAL POLLUTANTS	
ADDITIONAL INFO	USA BASED NON-PROFIT, POTTERS FOR PEACE, PROVIDES OPPORTUNITIES FOR LOCAL COMMUNITIES TO PRODUCE COLLOIDAL SILVER FILTERS. SEE APPENDIX B	

Even though this design is basic, it is the education portion that is the most important aspect of this design. We recommend this model to be distributed through the use of an easy-to-read/understand social media post. This post can show simple instructions and tips for safe water harvesting with this model. Local organizations, celebrities, and businesses can post these resources on social media and reach thousands of people. 57% of Panamanians are connected to the internet in some way. Some social media sites even allow for sponsored posts that can reach very specific target audiences by means of location, age, sex, and income for very low prices. We hope that Batipa can be the leader of safe water usage in Chiriqui and western Panama.

CONCLUSIONS

WATER HARVESTING AT BATIPA

The data and concept designs so far have indicated that BFI can support 10 people living there and 100 weekend visitors by using a combination of solar energy, rainwater harvesting and well water. Rainwater harvesting from the roof of the BFI building is enough to provide approximately 2,400 liters of water per day during the rainy season, with the remaining water being sourced from the water well. Storage should be enough to hold at least 150,000 L of water for use during a 3-day period to cover the needs of 100 visitors.

We propose that the well water should be the primary source of water, with the RWH system being utilized only when the tanks are full or when the well cannot accommodate present needs. In other words, the rainwater system would serve as a backup source to the well. Moreover, a scalable storage system of interconnected plastic cisterns will allow BFI to scale its water storage as needed. BFI can opt to initially deploy only a fraction of the total needed capacity and expand in the future.

EVALUATION OF SUSTAINABILITY

The water system concept for Batipa Field Institute utilized both a well and rainwater as sources of water. While water wells could cause environmental harm by depleting their aquifers, we believe our design mitigates this issue in two ways. First, the scale of well water consumption is limited, given that no water is used for livestock or irrigation, which are the main ways aquafers are depleted around the world. Second, the rainwater harvesting system is utilized to the maximum extent possible. The supply of 2,400 L/day could mean that no well water is used during the rainy season if fewer than 5 people live on-site. Moreover, the new buildings outlined in the Batipa Master Plan could also be used for water collection, potentially fulfilling one hundred percent of the water needed.

Wastewater management, despite not being the main focus of our project, was also an important consideration because it affects the environmental footprint of the system. Grey water, meaning water from sinks and showers, can be used directly for irrigation. BFI can deploy a system of pipes that directs said water into a septic field. However, the existing septic system could serve the same purpose, due to the way it works. Black water, meaning water from lavatories, needs to be treated first. We propose using the existing septic tank as a sufficient solution. The septic tank ensures that treated liquid waste safely seeps to the ground and solid waste gets treated and disposed of. A potential alternative is an aeration tank, with the main advantage being better water quality to the septic field. However, we do not believe BFI should change the existing system now that it is in place. Another alternative waste management method is a constructed wetland, which needs to be researched further, as discussed in the next section.

FUTURE AREAS OF RESEARCH

To ensure the success of the project, the expected productivity of the water well should be investigated by industry experts. The existing water wells at the industrial area could serve as a helpful reference point in making that determination. Moreover, the feasibility of a constructed wetland could be investigated as an alternative way of waste management to the septic system.

EDUCATIONAL RAINWATER HARVESTING MODEL

Our research indicated that rainwater harvesting has the potential to be an excellent source of water for many Panamanians and is already in use by some. However, knowledge of how to effectively deploy a rainwater system is not as ubiquitous as the need to do so. Our simple, do-it-yourself design aims to bridge that gap and demonstrate how to build and maintain a water harvesting system.

We identified social media as an excellent distribution channel for the educational model. That way, anyone with a smartphone can access the information they need. Infographic brochures can also be distributed to people who may not readily have access to the internet. QR codes can be used to link the physical and electronic resources together. Moreover, social media can foster a community where members can ask questions, help each other and collectively solve challenges.

Future Areas of Study

After immersing ourselves in the culture of Batipa, we have come up with four recommendations that could inspire stakeholders, donors, or even further IQP project groups. Even though all share the same theme of sustainability, each recommendation has distinct properties.

Our additional ideas, regarding this project, are:

I. Wastewater Treatment System
II. Solar Farm for Cabimos
III. Increasing capacity of Cerro Batipa
IV. Closely measure local climate change and weather patterns

I: WASTEWATER TREATMENT SYSTEM

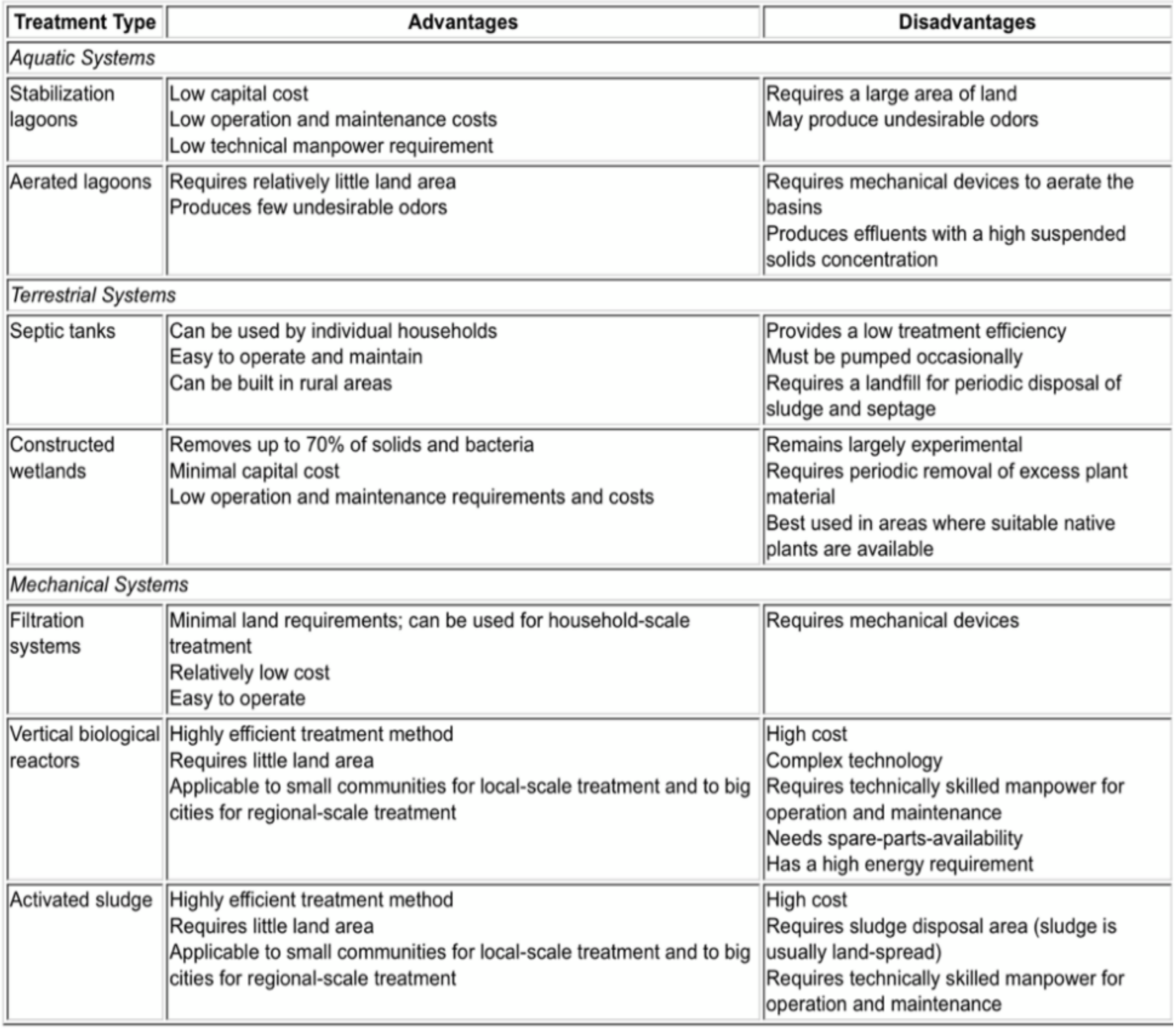
After visiting STRI in Bocas del Toro, we believe that Batipa can benefit from the same waste management system; which is an aerated aquatic system, figure 26.

Figure 26: Aeration waste management system located at STRI, Bocas del Toro

There are three different treatment types for wastewater; aquatic, terrestrial, and mechanical systems (UNEP, 1997). Like any system, the land size available, pricing, and environmental impact will influence what type of arrangement is implemented at Batipa. An aeration waste management system is when “the water layer near the surface is aerobic while the bottom layer, which includes sludge deposits, is anaerobic” (UNEP, 1997). The water layer that is in-between is more aerobic near the top and less towards the bottom, also known as the “facultative zone”. The aeration input can be mechanical, by the movement of water, or a diffused air system. Aerating wastewater encourages the breakdown of organic material.

We believe that an aeration system at Batipa can be successful, not only because its use at STRI has been successful, but also because of its ability to be partnered with another method. After the wastewater is aerated, it must be recycled back into the ecosystem. The idea of a constructed wetland was highly encouraged by Dr. Bruno Borsari and is very environmentally rewarding. Wetlands are earth’s natural sponge, filtering water while also providing an ecosystem that promotes biodiversity. Considering that there is a great system of mangroves along the peninsula, incorporating them into Batipa’s wastewater treatment system can be beneficial. Table 11, credit to Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean, 1997 describes the advantages and disadvantages of each type of wastewater treatment, which we believe could be an inspiration to future IQP project and for Oteima University to explore more in depth.

Table 11: Advantages and Disadvantages of Conventional & Non-conventional Wastewater Treatment Technologies



Treatment Type	Advantages	Disadvantages
Aquatic Systems		
Stabilization lagoons	Low capital cost Low operation and maintenance costs Low technical manpower requirement	Requires a large area of land May produce undesirable odors
Aerated lagoons	Requires relatively little land area Produces few undesirable odors	Requires mechanical devices to aerate the basins Produces effluents with a high suspended solids concentration
Terrestrial Systems		
Septic tanks	Can be used by individual households Easy to operate and maintain Can be built in rural areas	Provides a low treatment efficiency Must be pumped occasionally Requires a landfill for periodic disposal of sludge and septage
Constructed wetlands	Removes up to 70% of solids and bacteria Minimal capital cost Low operation and maintenance requirements and costs	Remains largely experimental Requires periodic removal of excess plant material Best used in areas where suitable native plants are available
Mechanical Systems		
Filtration systems	Minimal land requirements; can be used for household-scale treatment Relatively low cost Easy to operate	Requires mechanical devices
Vertical biological reactors	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Complex technology Requires technically skilled manpower for operation and maintenance Needs spare-parts-availability Has a high energy requirement
Activated sludge	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Requires sludge disposal area (sludge is usually land-spread) Requires technically skilled manpower for operation and maintenance

II: SOLAR FARM FOR CABIMOS

As of this report, Cabimos is equipped with a gas generator that powers an array of lights spread across the facilities. Our IQP team visited Cabimos and stayed overnight. The generator was used throughout the night, for lighting, as well as during the day during mealtimes. The generator was sufficient for the 15-20 people that were visiting overnight, but despite that fact, we believe Batipa needs to move away from fossil fuels as its primary energy source and serve its vision for sustainability better by switching to renewable energy. Additionally, the multi-year plan for BFI aims to expand its facilities and host up 100 people at once, which cannot be supported by the electrical system currently in place.

We recommend that Batipa consider the creation of a solar farm. This solar farm would be located on the least desirable plot of grazing land and would use approximately 1 to 1.5 hectares of land. (Vickey, 2018) A solar farm of this scale would be able to generate up to 1MW of electricity, enough to power up to 300 Panamanian homes. (Tisheva, 2016) BFI would be able to satisfy one hundred percent of its own energy needs and also sell electricity to the national grid.

A prime example of a design suitable BFI is the Matahar Kencana Solar Farm as shown in figure 27. (BSL, 2019) It features a lofted solar array that allows for the growing of fruit trees and certain vegetables. The Huerta, land where workers grow their own crops, used in Batipa would be a possible candidate for this design.

Figure 27: Bird's eye view of Matachari Kencana Solar Farm, Tanjung Malim ,a part of BSL Eco Energy Projects

The cost of this solar farm would be about $1M USD, however the Panamanian government's interaction with the International Renewable Energy Agency has sparked incentives for renewable energy efforts. (IRENA, 2018) This may mean a considerable amount of the cost of a solar farm could be reimbursed or rewarded elsewhere. Additionally, the system would provide about 20 years of guaranteed revenue. (BSL, 2019)

III: INCREASE CAPACITY OF CERRO BATIPA RESERVOIR

Batipa currently uses a water reservoir at the top of Cerro Batipa as well as series of artificial ponds to capture water from the mountain and provide drinking water for livestock. This system is sufficient during the rainy season, but a drought last year resulted in livestock dying, demonstrating increasing insecurity over the water supply potentially due to climate change. We recommend Batipa to expand on these efforts by increasing the capacity of the main reservoir. During our research, we learned that the reservoir could sometimes be rendered useless because recent decreases in average river flow led to saltwater getting introduced to the system. We recommend that BFI installs salinity sensors on the water intake to monitor salinity levels of the water getting pumped up to Cerro Batipa, so that pumping only occurs when salinity levels are sufficiently low.

IV: CLOSELY MEASURE LOCAL CLIMATE CHANGE AND WEATHER PATTERNS

During our time at Batipa, we experienced firsthand the effects of climate change. We decided to look closer into the reasons why the last two dry seasons have been so difficult for the reserve.

We discovered that this previous year was an “El Niño”. This is a periodic warming of Pacific waters that greatly affects weather patterns. The most recent event caused a very long drought in addition to seasonally low rainfall patterns, seen back in chapter 1; figure 3. As a result, Batipa was forced to lead livestock to brackish waters, this indirectly caused the death of 30 animals and infertility of many more.

In order to further understand the negative effects of climate change, we believe that Batipa should install a small weather station at the end of the existing dock as well as efforts to more closely monitor weather patterns. This project would be very cost-efficient and extremely environmentally conscious. A simple DIY project with the inclusion of a Raspberry Pi computer can spark the beginning of a long history of data collection at the research station. Similar initiatives could also spark the interest of a wider range of scientists, like computer scientists, to conduct research at Batipa in the fields of hardware design, software design and data science.

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Appendix A: Design Model for Batipa

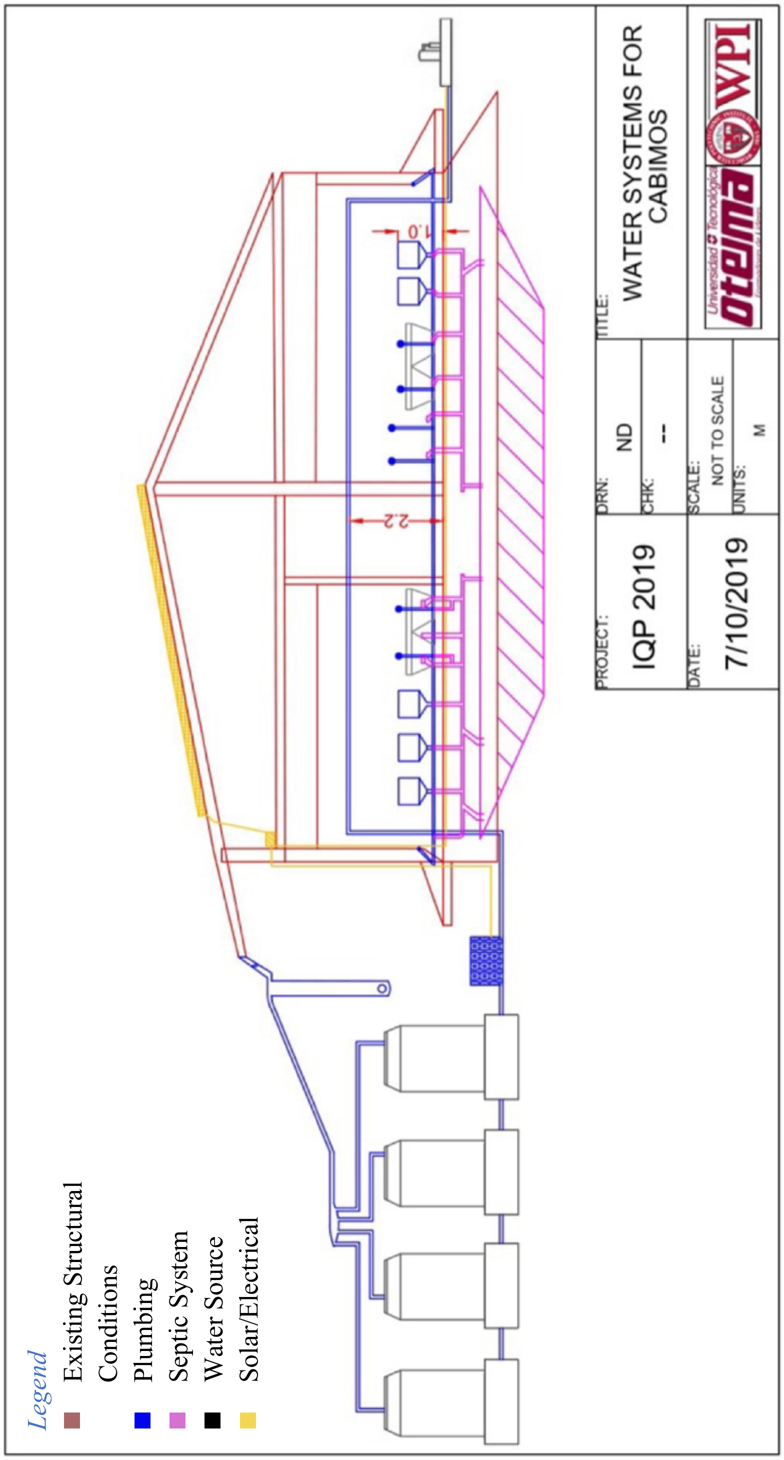
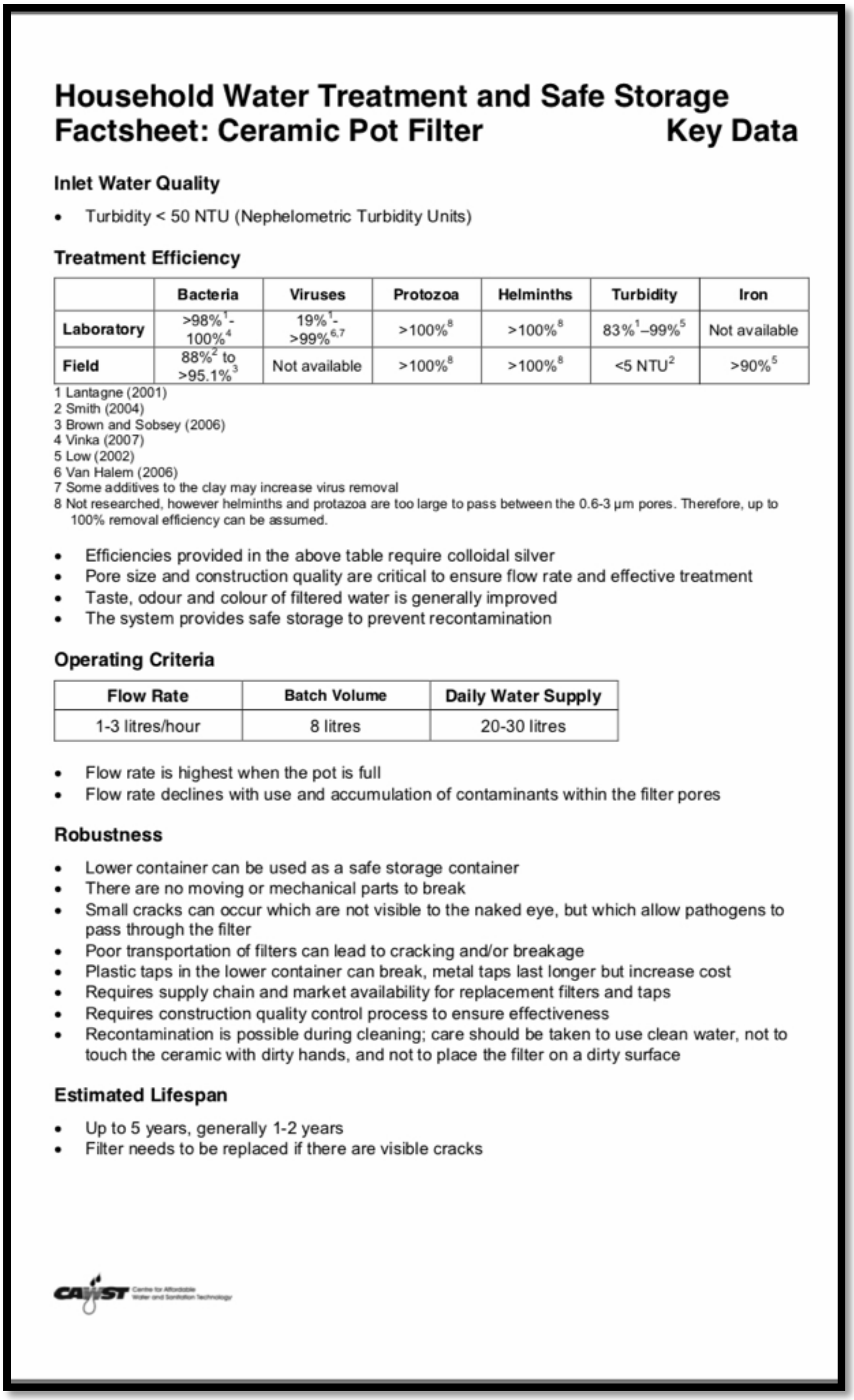


Figure 13: Water systems for Cabimos

Appendix B: Fact Sheet on Ceramic Pot Filter



Household Water Treatment and Safe Storage Factsheet: Ceramic Pot Filter

Key Data

Inlet Water Quality

- Turbidity < 50 NTU (Nephelometric Turbidity Units)

Treatment Efficiency

	Bacteria	Viruses	Protozoa	Helminths	Turbidity	Iron
Laboratory	>98%[1]-100%[4]	19%[1]->99%[6,7]	>100%[8]	>100%[8]	83%[1]–99%[5]	Not available
Field	88%[2] to >95.1%[3]	Not available	>100%[8]	>100%[8]	<5 NTU[2]	>90%[5]

1 Lantagne (2001)
2 Smith (2004)
3 Brown and Sobsey (2006)
4 Vinka (2007)
5 Low (2002)
6 Van Halem (2006)
7 Some additives to the clay may increase virus removal
8 Not researched, however helminths and protazoa are too large to pass between the 0.6-3 μm pores. Therefore, up to 100% removal efficiency can be assumed.

- Efficiencies provided in the above table require colloidal silver
- Pore size and construction quality are critical to ensure flow rate and effective treatment
- Taste, odour and colour of filtered water is generally improved
- The system provides safe storage to prevent recontamination

Operating Criteria

Flow Rate	Batch Volume	Daily Water Supply
1-3 litres/hour	8 litres	20-30 litres

- Flow rate is highest when the pot is full
- Flow rate declines with use and accumulation of contaminants within the filter pores

Robustness

- Lower container can be used as a safe storage container
- There are no moving or mechanical parts to break
- Small cracks can occur which are not visible to the naked eye, but which allow pathogens to pass through the filter
- Poor transportation of filters can lead to cracking and/or breakage
- Plastic taps in the lower container can break, metal taps last longer but increase cost
- Requires supply chain and market availability for replacement filters and taps
- Requires construction quality control process to ensure effectiveness
- Recontamination is possible during cleaning; care should be taken to use clean water, not to touch the ceramic with dirty hands, and not to place the filter on a dirty surface

Estimated Lifespan

- Up to 5 years, generally 1-2 years
- Filter needs to be replaced if there are visible cracks

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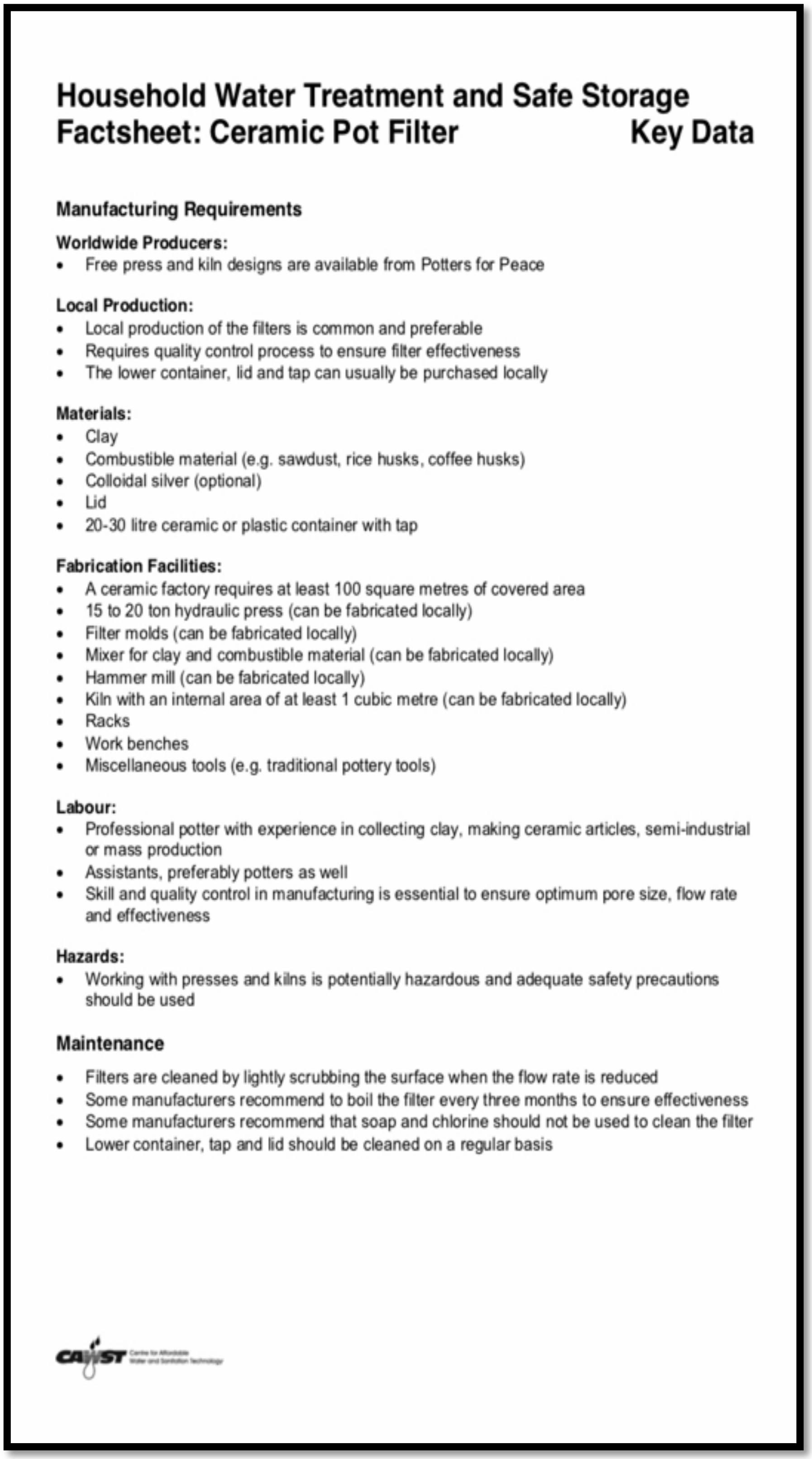

Household Water Treatment and Safe Storage Factsheet: Ceramic Pot Filter Key Data

Manufacturing Requirements

Worldwide Producers:

- Free press and kiln designs are available from Potters for Peace

Local Production:

- Local production of the filters is common and preferable
- Requires quality control process to ensure filter effectiveness
- The lower container, lid and tap can usually be purchased locally

Materials:

- Clay
- Combustible material (e.g. sawdust, rice husks, coffee husks)
- Colloidal silver (optional)
- Lid
- 20-30 litre ceramic or plastic container with tap

Fabrication Facilities:

- A ceramic factory requires at least 100 square metres of covered area
- 15 to 20 ton hydraulic press (can be fabricated locally)
- Filter molds (can be fabricated locally)
- Mixer for clay and combustible material (can be fabricated locally)
- Hammer mill (can be fabricated locally)
- Kiln with an internal area of at least 1 cubic metre (can be fabricated locally)
- Racks
- Work benches
- Miscellaneous tools (e.g. traditional pottery tools)

Labour:

- Professional potter with experience in collecting clay, making ceramic articles, semi-industrial or mass production
- Assistants, preferably potters as well
- Skill and quality control in manufacturing is essential to ensure optimum pore size, flow rate and effectiveness

Hazards:

- Working with presses and kilns is potentially hazardous and adequate safety precautions should be used

Maintenance

- Filters are cleaned by lightly scrubbing the surface when the flow rate is reduced
- Some manufacturers recommend to boil the filter every three months to ensure effectiveness
- Some manufacturers recommend that soap and chlorine should not be used to clean the filter
- Lower container, tap and lid should be cleaned on a regular basis

Household Water Treatment and Safe Storage Factsheet: Ceramic Pot Filter

Key Data

Direct Cost

Capital Cost	Operating Cost	Replacement Cost
US$12-25	US$0	~US$4[1]

Note: Program, transportation and education costs are not included. Costs will vary depending on location.

[1] Filter pots generally need to be replaced every 1-2 years

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Further Information

Centers for Disease Control and Prevention: www.cdc.gov/safewater/publications_pages/options-ceramic.pdf

Filter Pure, Inc: www.filterpurefilters.org

International Development Enterprises:
www.ideorg.org/OurTechnologies/CeramicWaterPurifier.aspx

Potters for Peace: www.pottersforpeace.org

Resource Development International Cambodia: www.rdic.org/water-ceramic-filtration.html

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