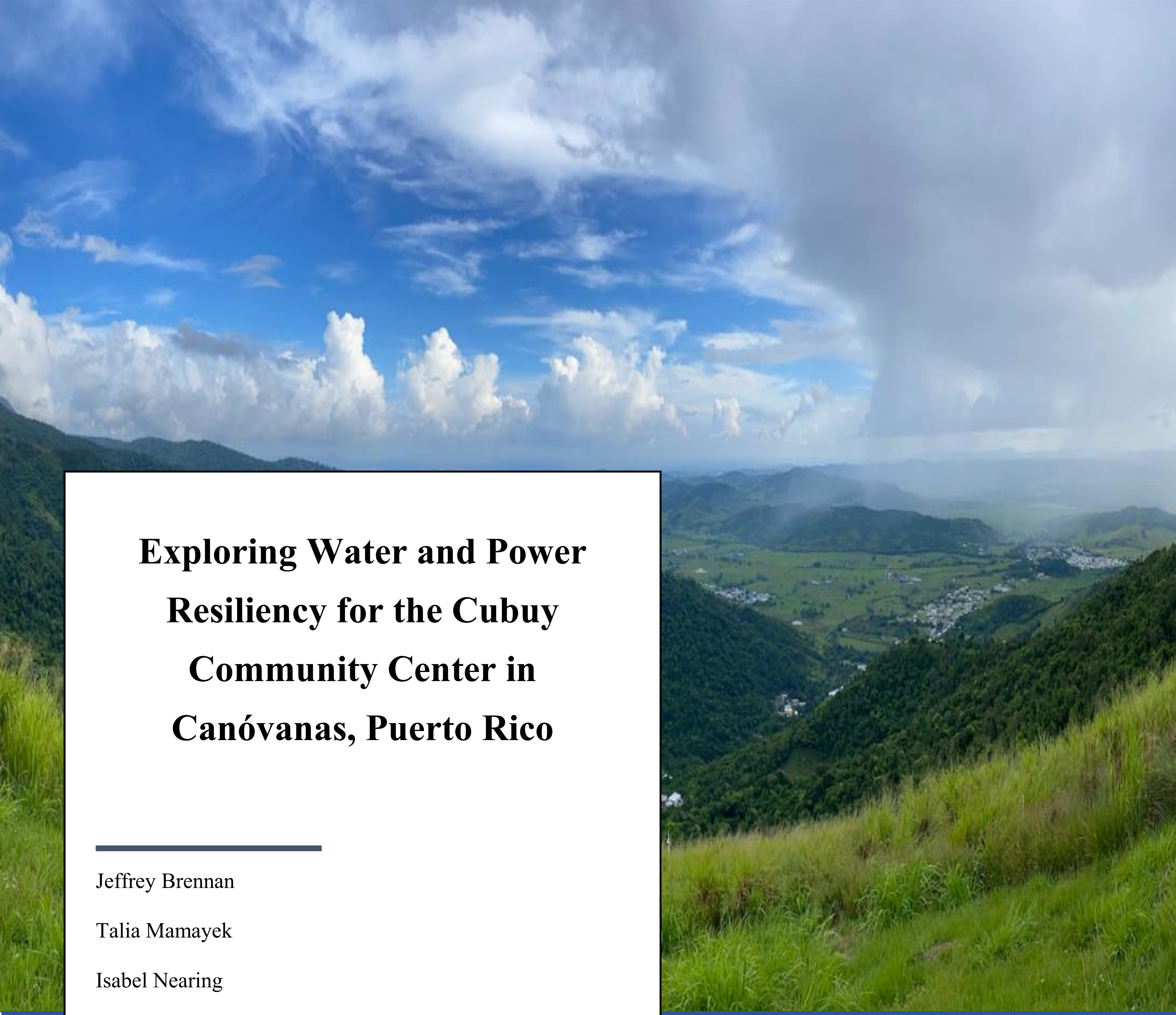

Exploring Water and Power Resiliency for the Cubuy Community Center in Canóvanas, Puerto Rico

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ABSTRACT

Cubuy, a rural community in Cańovanas, Puerto Rico, lacked sufficient water and power for months following Hurricanes Irma and Maria. Working alongside ID Shaliah and the Karma Honey Project, this project was intended to explore various methods of providing a renewable source of water and power for Cubuy during emergencies. Community interaction and focus groups helped gauge the extent of the community's resources. Interviews with engineers, organization leaders, and consultants provided insight into the best method of ensuring potable water and the specifications of a donated photovoltaic system. The resulting report can be referenced to supplement the further development of drilling a well and supplying sustainable solar energy to support Cubuy with water and power resiliency.

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- Our Sponsors Javier Valedon and Johnny Williams for working with us and providing us with resources to succeed in our project
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EXECUTIVE SUMMARY

Introduction

Small island developing states (SIDS), such as Puerto Rico, are islands and coastal regions facilitated by the United Nations that endure uneven challenges for sustainable development. SIDS experience elevated risks to natural disasters due to isolating geographic and geologic features which forces these states to be self-sustaining during the immediate aftermath of a disaster (Shultz, 2016). Building resilience in regions disproportionately impacted by natural hazards is paramount for communities' emergency preparedness. A common way to build resilience in communities is to establish and promote access to stable sources of power and water; two things that are sought after in emergencies. Different systems can be installed to provide power and water, such as photovoltaic (PV) arrays, rainwater harvesting (RWH) systems, and drilling a well.

Located in remote mountains near El Yunque National Forest, Cubuy is often cut off from the distribution network of Puerto Rico Aqueduct and Sewer Authority (PRASA) and Puerto Rico Electric Power Authority (PREPA). In this project, Worcester Polytechnic Institute students worked with ID Shaliah, the Karma Honey Project, and members of Cubuy, Puerto Rico to take steps towards providing a reliable power and potable water source for the Cubuy Community Center. The once abandoned school building is being retrofitted to become a community resiliency center. Providing vital resources to this building is imperative for it to function as a resiliency center during emergency events. The main priority is establishing a source of potable water, whether that be a RWH system or a drilled well, along with a PV system for power generation.

Goals and Objectives

This project was intended to assist the Cubuy Community Center in implementing a sustainable, reliable power and potable water source. To achieve this goal, our team followed these objectives:

- Identify the Vision and Rationale for the Power and Water Source from Sponsors and Community Members
- Analyze the Existing Roof Structure and Identify Potential Systems
- Establish a Network of Organizations to Aid in the Selection of Each System Considered and Weigh Social Impact
- Create a Library of Documents for Future Improvements to the Community Center

Generating and Evaluating Potential Solutions

Through our interviews with community members and communication with our sponsors we learned about the greatest needs of the Community Center. Many, if not all the people we talked to were without water and power for months following Hurricanes Irma and Maria. They all stressed how important it would be to the community if there was a potable water source to provide water in times of emergency.

An assessment of the existing infrastructure at the site was completed to evaluate possible systems and where they could be installed. We could not acquire the construction documents from the Public Buildings Authority, so we collected all necessary data on site. Each building was numbered for ease of reference and information was noted such as rooftop area, surface condition, roofing material, obstructions, and drainage points. This analysis helped determine which roofs were best suited for the various systems being considered.

Location Labeled	Name of Location	Rooftop Area (sq.ft.)
1	Cafe and Multipurpose Building	1661
2	Beekeeping Room	484
3	Medical Clinic Building	1283
4	Classroom	288
5	Refugee Building	1542
6	Bathrooms	463
7	Workshops	1652
8	Technology and Learning Building	821
9	Storage Building	
10	Pavilion	394
11	Office	435
- - - - - -	Property Line	

Figure 1: Map of Cubuy Community Center and Roof Surfaces Adapted from Google Maps (2021)

We then compared options for various potable water systems at the community center: drilling a well and harvesting rainwater. We researched the demand for water during emergencies and determined that a drilled well has potential to provide a large quantity of potable water to the community. Well water does not require extensive water filtration to make it drinkable compared to collected rainwater. However, wells are expensive; one company offered a $60,000 quote to drill one. A rainwater harvesting system may be cheaper but would supply potable water to significantly fewer people than a well. Overall, we recommend continuing to research the implementation of a well while understanding the financial and physical limitations such as contaminants in the water (Laskow, 2018). A rainwater harvesting system could be utilized for solely non-potable uses.

We found that installing a PV system would fulfil the need for a reliable source of power at the community center. We secured a donation of a PV system from ProSolar, which has the potential to grow to 221 panels. The system donated has battery capacity to provide the center with electricity 24/7, and the excess stored power can even be sold back to PREPA. To maximize system efficiency, it is important to consider the panel mounting angle, material of solar cells, reflectiveness of roof surface, and sun exposure. Fortunately, Puerto Rico has proven to be an optimal location for PV systems due to its geographical location.

The success of this project was reliant on networking with organizations throughout Puerto Rico which has proven to be a time sensitive process requiring a lot of patience and persistence. Interviews with professionals in the corresponding fields informed us about design and construction considerations for each system. We maintained contact with representatives of similar organizations that support community resiliency centers in Puerto Rico. Another major result of networking was to secure monetary and material donations considering both sponsors are non-profit organizations.

Large amounts of funding from grants and private companies would be beneficial for the community center to fulfill long-term plans. Similar projects in Puerto Rico have received millions of dollars in federal funding from agencies like FEMA and the USDA. The difficulty in securing such funding is due to the complicated and lengthy application process. Numerous documents and information are required about the project and may take up to a year to complete.

After completing field work, we were able to address questions regarding PV systems, potable water usage, and expanding the network of engineering and funding professionals. Our research led to the creation of a digital library with guides, models, and useful documents for the continuation of this project by our sponsors or future IQP groups.

Deliverables

A major outcome of this project was the development of a handoff guide, entitled "Building Resiliency for the Cubuy Community Center". This guide contains all our findings regarding PV systems, water usage analysis, networking, and funding opportunities, while also describing how we advanced the initial state of these aspects since our time in Puerto Rico.

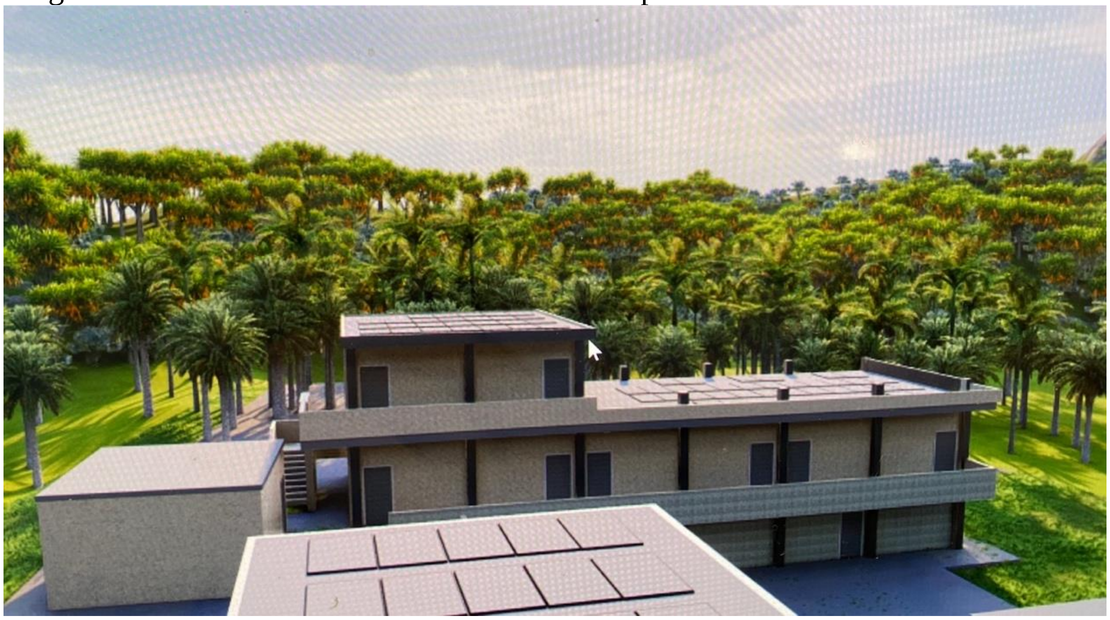

Image 1: Render of Future Solar Powered Cubuy Community Center

A model of the community center was also developed using building information modeling software to visualize the potential placement for PV panels. The visuals generated from the model can be used for marketing, sharing progress work with the community, and securing funding as well.

A contact sheet was developed to organize all the companies and organizations that we reached out to. This sheet contains the emails, phone numbers, and websites of our contacts, while also listing details of the interactions we had for them. This sheet will be passed on to future IQP groups so that they can maintain the relationships we developed.

This project was the first in the community of Cubuy, and much of our work related to establishing a working relationship with the community, ID Shaliah, and the Karma Honey Project. The documents we created will aid in the continuation of work in Cubuy. They are intended to serve as living documents to be edited with each group that works in the community. Pioneering IQP work in Cubuy was an exciting learning experience, and we are proud of the work we accomplished to set the stage for the continuation of IQPs in this caring community.

1. INTRODUCTION

Building resilience in regions disproportionately impacted by natural hazards is paramount for communities' emergency preparedness. A common way to build resilience in communities is to establish and promote access to stable sources of power and water; two things that are sought after in emergencies. Different systems can be installed to provide power and water, such as photovoltaic (PV) arrays, rainwater harvesting (RWH) systems, and drilling a well. These elements have many societal, environmental, and economic benefits for the area in which they are installed. These systems provide access to essential resources and offer long-term operation to a facility after a natural disaster. Groups and individuals who install these systems for their buildings often find that they are less vulnerable, decrease their risk, and improve their quality of life. These systems also provide many jobs for both skilled and unskilled workers through the installation and maintenance process. Research and awareness of the benefits of varied systems will encourage implementation on a larger scale.

The community of Cubuy, in the municipality of Canóvanas, Puerto Rico is an area that has been devastated by natural disasters. After Hurricane Maria struck in 2017, the citizens lacked access to water and power for up to eight months. They could not wash their clothes, flush their toilets, or use any electronics. This area is located up in the mountains on the back of El Yunque National Forest and was effectively isolated from not only the rest of the island, but the rest of the world as well. The installation of reliable power and potable water systems can drastically reduce the effects of weather disasters in the area. Installing a PV array and a reliable potable water source, such as a rainwater harvesting system or drilling a well, could help prevent total power outage and water loss in the event of a weather emergency. PV power has become increasingly popular and effective in Puerto Rico for these reasons and is encouraged by the Puerto Rican government.

One of the main options for reliable, sustainable power is a PV array. PV panels can operate on different systems depending on what type of energy they need. The system can be connected to the utility grid or can operate independent from the grid (Energy.gov, n.d.). PV panels can be mounted in a fixed position or at different angles to optimize their energy generation. PV panels work well in tandem with cool roofs. Cool roofs reflect more sunlight and absorb less heat, which helps to naturally cool buildings and their surrounding area (Office of Energy Efficiency & Renewable Energy, 2021). There are several types of cool roofs such as reflective paints and sheets that reflect sunlight and help reduce energy costs. PV panels that were at 45-degree angles on a cool roof were found to produce more power than those on a regular roof (Atlan, et al., 2019). Rainwater harvesting systems are a sustainable way to provide water to a community. Water catchment systems vary based on the sizes of the collection bins. Types of systems can be chosen based on the amount of rainfall in the area. The harvested water can be used in different applications. Potable water is used for drinking and bathing, while non-potable water is used for flushing toilets and washing clothes ("Rainwater Harvesting 101 | Your How-To Collect Rainwater Guide," n.d.). Potable water catchment systems are typically more expensive due to the need for quality filtration so that the water is of acceptable quality to drink, cook with, and bathe in. Wells are another great source of reliable, potable water. Wells consist of a hole drilled into the ground so that water in aquifers can be accessed. To get the water out of the ground, a system consisting of pipes and pumps are utilized (*The Groundwater Foundation : Get Informed : The Basics : Wells*, 2021). There are several types of wells that can be drilled. One is a bored well, which is a shallow hole (ranging from 10-30 feet deep) that is lined with stones or brick to increase its structural integrity. Another is a driven well, which is deeper than a bored well. Driven wells tend to be 30 to 50 feet deep and are made by directing a pipe into the ground. Lastly, drilled wells are another option. They are drilled using professional machines which can reach upwards of 1,000 feet into the ground, and require casing (*Learn About Private Water Wells*, 2020). Wells can provide a very large amount of clean, potable water for use in a variety of applications.

While there are many benefits to these systems, there are several challenges and gaps that may present themselves. During the placement of any PV system a few considerations must be accounted for. They should be installed on a surface with maximum sun exposure, little to no physical obstructions, and properly sealed cracks or seams. PV systems also need to be anchored onto roofs to prevent damage from storms. When considering RWH systems, extensive filtration and treatment is needed to make the collected water acceptable to drink. Another concern with RWH systems is that they lack stability against a hurricane. Many of the pipes in a RWH system are exposed above ground and are typically PVC pipes. Hurricane Maria recorded wind speeds upwards of 150 miles per hour, and these systems are unlikely to resist such high winds. Some RWH systems have underground piping which only complicates the maintenance. Wells are a great source of potable water, but they are extremely expensive to install. Wells can cost tens of thousands of dollars, which is not economically feasible for many. There are also tedious processes that must be done before a well can even be dug. A contamination test needs to be performed to ensure that there are no potential water contaminants in the area. A yield test needs to be done as well to ensure the groundwater table would not be affected by the well.

This project is intended to assist the community of Cubuy, Puerto Rico to become more resilient by providing the Cubuy Community Center with a reliable power and potable water source. The sponsors of this project, ID Shaliah and Karma Honey Project bought an abandoned school building and are retrofitting it to be a community resiliency center. This is a place where residents can find food, water, and shelter in times of need, but also take finance classes, self-defense classes, and learn personal development skills. Providing a reliable source of power and water to this building is imperative for it to function as a resiliency center. The sponsors envision the building as a place where community members can go daily, but more importantly as a resilient shelter to seek out during emergency events. They prioritize having a source of potable water, whether that be a RWH system or a well on site, and a PV system for power generation. We completed this project by first researching the different types of systems, how they function, and estimate the costs of each. Then, we identified the vision and rationale for the power and potable water source from the sponsors and community members. Within the first week of being in Puerto Rico, we got to know the "main players" of the project by listening to stories shared by the residents of Cubuy to understand their needs and befriending the people we worked with for the duration of the project. We assessed the existing roof structure and subsequent infrastructure connections at the Cubuy Community Center. This included an analysis of each roof on site, buildings, and the surrounding infrastructure that could impact the roofs. The results of the analysis heavily influenced the choice of systems compatible with the site. We expanded our network in the interest of obtaining donations, establishing connections with organizations doing similar work to ID Shaliah, and obtaining quotes associated with roof repairs and potential systems, such as a drilled well. This was a key step in the process of completing the project because our sponsors' organizations rely heavily on outside donations for funding. After talking to companies, identified which systems were feasible at the community center and aligned with the visions of our sponsors. The deliverables of this project were a Revit model of the site with placements of the PV panels, a handoff report for future IQP groups as well as our sponsors, and a contact list. We envision these three documents as useful information for our sponsors, those interested in our work, and individuals who want to further the project.

2. BACKGROUND

This chapter provides a discussion of the Cubuy community in Puerto Rico and information on constructing an off-grid potable water source and a solar photovoltaic system. There are numerous factors that contribute to a sustainable water supply and photovoltaic system, but we narrowed our research to areas that are vital to the function of these systems. we considered the time of implementation, the technical and social implications, as well as the economic feasibility of each system.

2.1. Puerto Rican Economy Overview

The economic state of Puerto Rico heavily influences the feasibility of implementing a sustainable water supply and photovoltaic system for the community center of Cubuy. Understanding the economy of Puerto Rico will determine which systems can be put into place at the community center. Within the past two decades, Puerto Rico has experienced a period of early growth followed by a period (2006 to 2020) of economic contraction (Bond, Strong & Smith, 2020, p.16). Therefore, we must consider the extent of funding as we develop our list of recommendations for the community center.

The history of economic development in Puerto Rico can be characterized by the major changes associated with Puerto Rico becoming a territory of the United States and the time after World War II. During the 1950-1960s, the U.S. instilled a program to transform Puerto Rico's economy from agricultural to industrial called Operation Bootstrap. This program involved a series of economic incentives aimed at creating jobs quickly and efficiently and establishing an export-based economy. During this shift, Puerto Rico heavily relied on the United States' corporations and welfare assistance. Operation Bootstrap ultimately failed to sustain the growth of Puerto Rico's economy. In 2006, economic growth was generally negative, with low labor-force participation and high unemployment relative to the CONUS, (Continental United States) (Bond, Strong & Smith, 2020, p.17).

2.1.1. Current Economy in Puerto Rico

Today, the multilayered economic and social crisis on the island of Puerto Rico is rooted in long-standing policy. As a U.S. territory, Puerto Rico still endures the legacy of colonialism without the proper representation in political affairs. The economy is now suffering due to the loss of federal tax provisions, the accumulation of massive debt, the ill effects of natural disasters, the coronavirus pandemic, government mismanagement, and population decline (Cheatham, 2020). The island declared bankruptcy in 2017 as the amount of debt hit $123 billion, which is equivalent to 188% of Puerto Rico's gross domestic product (GDP). The Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) established a financial oversight board for the debt reconstruction process. The effectiveness of this act is controversial, but some believe more can be done to reduce the territory's debt burden. Disaster preparedness, disaster relief, recovery education, and renewable energy are all areas that would benefit from more federal funding. The gap in funding creates challenges in providing capacity-building opportunities and in developing resiliency for the region.

2.1.2. The Community of Canóvanas, Puerto Rico

The population of Canóvanas has grown due to the economic development in the area, which can be attributed to its close location to the city of San Juan. In the municipality, there are factories that produce shoes and clothing, as well as electrical products, chemicals, and food. The main agricultural products of Canóvanas are coffee, sugar cane, fruits, and vegetables, as well as dairy farming and fowl. (Boricna Online, 2021).

As of 2019, Canóvanas has a population of 45,588 people with a median household income of $21,267. The employed population of the municipality is 14,554 people, who is about 32% of the total population. The three main industries of employment on the island are Retail Trade, Care & Social Assistance, and Administrative & Support & Waste Management services, which employ a total of 5,525 people (Data USA, n/d). It is key to note that the Administrative & Support & Waste Management may contain many employees that are unskilled. A reason for this is that citizens of Canóvanas may not have access to educational opportunities beyond high school. One goal of this project is to generate jobs for both skilled and unskilled workers.

Figure 2: Map of Canóvanas Municipality (Boricna Online, 2021)

The community center, formerly known as La Escuela Elemental Manuel Agosto Lebron, is in the municipality of Canóvanas, specifically in the Cubuy-Lomas region, shown in Figure 2. The elementary school served students from kindergarten through 6th grade and was funded by the Puerto Rico Department of Education. The site of the school shown in Image 2 below is the site of our proposed off-grid, emergency water supply and photovoltaic system.

Image 2: Cubuy Community Center

2.2. Stakeholder Analysis

This project is sponsored by two organizations: ID Shaliah and Karma Honey Project. ID Shaliah is a social and humanitarian project that serves communities in Puerto Rico. Their project leadership team is composed of a group of community leaders, notably Javier Valedon. ID Shaliah is committed to "serving others without distinction of person." ID Shaliah continuously works towards creating absolute autonomy to supply needs to communities and citizens. They provide many different programs to citizens of Puerto Rico, such as delivering hot food to over five hundred people monthly, delivering medicine and medical equipment such as wheelchairs, walkers, and blood glucose testing kits to participants, providing essential items for emergencies, as well as home rescue programs. ID Shaliah is a small, church-based volunteer organization. This non-profit organization was developed in early 2021, thus still getting itself off the ground. Since this is a non-profit organization, ID Shaliah receives funds from the public, government, and private foundations. They ask for donations online regularly, and even have an online merchandise store to help raise funds. ID Shaliah has created alliances with Canóvanas Municipality, Doctor Mecanico, Karma Honey Project, Bodymaker Fitness, and Hospicio San Lucas, who are all contributing help to the community center. The Karma Honey Project teamed up with ID Shaliah to help purchase The Manuel Agosto Lebron Elementary School. The site of the school will be the premises for our proposed ecological design.

Karma Honey Project is another major sponsor of this project. The Karma Honey Project was created in 2018 with the mission to increase the population of honeybees in Puerto Rico while spreading awareness of the species and creating local jobs in ecotourism and beekeeping. The Karma Honey Project was created by entrepreneur Candice Galek and her team, Carol Solowsky, Nandi Mulira, Pep Menendez, and Bert Rivera Marchand, who are all on the Board of Directors. Johnny Williams is our main contact to the Karma Honey Project, and we worked closely with him to complete the project. The Karma Honey Project is a great sponsor for this project due to its vast knowledge of environmental issues in Puerto Rico. The Karma Honey Project has several current developments, including the Dorado Bee Club, where they worked with the TASIS school in Dorado. After Hurricane Maria, the school suffered and so did the wildlife around it. Recovery of the bee population would be beneficial to the recovery of the wildlife, and so a Bee Club was formed with middle and high school students who were passionate about wildlife recovery. Students were able to learn all about bees and beekeeping, as well as social and economic responsibility (Karma Honey Project, 2021). In the community center, they have their own building, and will have a room for honey spinning, an area to keep beehives, and several classrooms so that community members can learn about the benefits of bees to the environment, and even learn to make their own honey! They will then buy back the honey from community members and create their own brand within the community center. The Karma Honey Project is a non-profit organization, where one hundred percent of the profits go to the repopulation of the honeybees, helping small farmers pollinate organic crops, donating to university-based research to help find solutions to the problems affecting bees, educating people on the importance of pollinators, and planting bee friendly fields of wildflowers. Like ID Shaliah, this organization is funded by the government, private foundations, and the public. You can also buy raw honey from the organization, which assists them in raising funds.

The Cubuy community, as well as the greater community of the Canóvanas municipality, has a large stake in this project. This project aims to serve them and cater to their needs in everyday and emergency situations. The community is vital in recognizing what resources need to be implemented in the community center. We conducted interviews with several members of the community so that they can get to know the people they are working with, as well as to get a sense of what their most important needs are. Through interviews, power and water have been identified as their most urgent needs. The community in Cubuy is extremely close-knit; during Maria they banded together to truly embody the spirit of "help thy neighbor". They gave up their own precious food and water to help those who had less than them. The community center will be able to bring them closer to a pharmacy and clinic, as well as a place to use computers, learn about beekeeping, but also to provide them with shelter, food, water, and power in emergencies. The community center will be able to improve the lives of all of those who live near it, so it is critical that when it opens, it is the best it can be.

All donors to this project also have a stake in it. No matter if they donated $1 or $100,000, their money is going towards ensuring this community center is getting the supplies it needs and functioning as ID Shaliah promised. Donors believe in the project and trust the project leaders to use their donations responsibly in a way that will advance the project. Therefore, when asking for donations, project leaders must be extremely transparent with how they will utilize funds. Large scale donors, such as ProSolar and Warner Records, have a larger stake in the project, and much of the center's success relies on them. For example, ProSolar has chosen to donate a PV system to the center, and many people will rely on the power generated from the system to survive and function in times of emergency.

2.3. The Effects of Hurricane Maria on Puerto Rico

When Hurricane Maria first devastated Puerto Rico on September 20, 2017, no one was ready for the toll the storm would take on the island. As a category 4 hurricane, it was the worst to hit the island in nearly 80 years. With wind speeds upwards of 155 mph, trees were uprooted, electrical wires and cell phone towers were damaged, and roofs of people's homes were blown off. Electricity was cut off to the entire island, leading to clean water and food becoming a scarcity. Before Maria struck, nearly half of the 3.4 million residents of Puerto Rico were living below the poverty line, and Maria added to that total. Puerto Rico had never seen a humanitarian crisis quite like this (Mercy Corps, 2020). The effects of Maria are still seen around the island today.

Hurricane Maria caused nearly $94.4 billion in damages. About 80% of Puerto Rico's crop value was eliminated, which was estimated to be $780 million in losses. Nearly a quarter of the island’s total land is dedicated to farms. It was not just crops that were destroyed, livestock were killed as well. Landslides and flooding caused by the storm killed farm animals and wiped-out dairy barns and large-scale chicken coops. The USDA (U.S. Department of Agriculture) worked closely with leaders in Puerto Rico to provide families with food while the store shelves were empty (Perroni, 2017). This decrease in food security was devastating for families who were already struggling and magnified the demand for reliable sources of food and water in the island-wide emergency.

Hurricane Maria also amplified the problem of abandoned schools. Due to political play and the complete overhaul of the school systems in Puerto Rico by Julia Keleher, the former education secretary of Puerto Rico, by the end of the 2016-17 school year 183 schools were closed. Parents, teachers’ union, and racial minorities alike were outraged by this decision. Their children had nowhere to go to school. After Maria, an estimated 160,000 people (5% of the total population) left Puerto Rico, and as a response Keleher closed more schools. Right before Maria, there were about 1,100 public schools left on the island, and after the storm over 250 of them did not open again. Many of these abandoned schools have been taken over by wildlife, the homeless, and even locals using them as horse stables. However, many of these schools are being retrofitted into community resilience centers so that families in need can find refuge, clean water, and food in emergencies (Katz & Alhindawi, 2019).

We had the opportunity to speak to members of the Cubuy community who were living there when Maria struck. We were able to have a heart-to-heart with local citizens to get a deeper understanding of the struggles they endured during this ongoing crisis. We sat down with four volunteers who live in Cubuy and work with ID Shaliah, a developing non-profit organization, and a sponsor of this project. The volunteers answered questions about what resources they would prioritize in an emergency, and what their personal experience with Hurricane Maria was like. One volunteer described the needs of the community by saying “I think this community needs help. Why? Because we are so far away from the hospitals, the clinics, and the help we need.” This statement was a theme of the day. As the conversation progressed, we learned just how desperately Cubuy needs vital resources localized within their community. We asked the volunteers, if they were comfortable, to share their personal experience during Maria. Each volunteer talked about how they were without power and water for months on end, and how those two commodities would be of great benefit if they were to be implemented in a community resilience center. One volunteer said “I had to wash my clothes and shower in the river with a gallon of water. Still, the power goes out randomly at my house.” Another added that he also bathed in the mountain water. Hearing how locals had to survive on such a limited supply of water was a shock. Without power or cell service, citizens had no way of contacting their family. One volunteer recalled how worried he was about his daughter, “I drove 3 hours to her house to see her.” This man had no other choice than to drive through downed power lines and trees just to ensure his daughter was alive. Even those who had generators as a backup power supply could not run them, because lines for gasoline were five to six hours long across the island. Maria wreaked havoc on the lives of Puerto Ricans, and these effects have lasted years. Driving up the narrow, winding roads into Cubuy, one can see water tanks and solar panels on the roofs of damaged homes. The volunteers that were interviewed seemed hopeful, knowing that the work their organization does is truly benefiting people.

Image 3: Destruction in the aftermath of Hurricane Maria (Kenneth Zapata, 2017)

2.4. Sustainable Water Supply Options

Alternative water sources can help reduce water risk and provide a reliable off-grid system that helps maintain operations of a facility during a water disruption. A sustainable water source addresses various needs for water without exhausting the water supply or economy and does not cause long-term detrimental effects on the environment. Providing a sustainable water supply is the highest priority of the community center. We explored the main methods of creating a sustainable water supply, which were implementing a rainwater harvesting system or drilling a well. The Advantages and disadvantages of these systems are laid out in this section, but a table summarizing these qualities is in *Appendix G*.

2.4.1. Rainwater Harvesting and Associated Benefits

Rainwater harvesting is a method of collecting and storing rainwater for human use from roof or land surfaces ("Rainwater Harvesting 101 | Your How-To Collect Rainwater Guide," n.d.). Rainwater harvesting (RWH) is particularly favorable in rural areas where a centralized water supply system is unreliable, which is the case for Cubuy. In times of a natural disaster such as Hurricane Maria, rural areas in Puerto Rico were cut off from the centralized water supply and were forced to find other means of obtaining clean water. The installation of a RWH system would provide an accessible water source even in the most desperate times.

Cubuy is located around regions that see an average annual rainfall, shown in Figure 2, ranging from 65 to 100 inches (CFWSC, n.d.). With the proper water catchment system in place, water could be collected for a variety of uses. Irrigation systems typically collect water for the purpose of watering the vegetation nearby. Non-potable use is more for flushing toilets and washing clothes, while potable water can be used for drinking, cooking, or bathing ("Rainwater Harvesting 101 | Your How-To Collect Rainwater Guide," n.d.).

There are numerous benefits to incorporating a system for capturing rainwater, as seen in Appendix F. The first and most important is that communities have a free source of water. While rainwater is not potable as soon as it is collected, it is generally clean. The general equation to calculate the amount of water harvested is catchment area (sq.ft.) x rainfall (in.) x 0.5 (gallons per ft) (*GrowNYC*, n.d.). Harvesting systems are also composed of simple technology, keeping them easy to maintain and inexpensive to build. Since the water collection process starts on the roof of a building, it allows gravity to do most of the work involved in directing the water towards a storage device. There are only a few technological parts involved, allowing for easy maintenance since one does not need to be specialized in the system to clean and maintain it. They can also be easily retrofitted to an existing building ("Rainwater Harvesting 101 | Your How-To Collect Rainwater Guide," n.d.). This is crucial since the chosen system can be easily integrated with the existing structure of the Cubuy Community Center. Lastly, a rainwater storage tank can provide water in case of an emergency, even if the water is non-potable. Having an extra supply of water that can be used for irrigation, toilet flushing, or clothes washing is better than having no water at all. Rainwater harvesting systems are great at providing an inexpensive, easily integrated, and maintainable storage device to provide water in times of need.

2.4.2. Types of Rainwater Collection Systems

There are three major types of rainwater collection systems. The first is rain barrels, which is a barrel at the bottom of a gutter that collects water runoff from the roof. This system is easy to install and typically does not take up much space. However, they have a small capacity of about 50-100 gallons and can easily overflow where valuable water may be lost ("Rainwater Harvesting 101 | Your How-To Collect Rainwater Guide," n.d.).

The second type is a "dry" system which is a variation of the rain barrel configuration, but with a larger storage capacity. It is also inexpensive to implement and less complicated to maintain ("Rainwater Harvesting 101 | Your How-To Collect Rainwater Guide," n.d.). This type of system must have the storage tank placed directly adjacent to the building since it collects water directly from the gutters. It is a non-pressurized system that uses gravity as its main way of collecting water inside of the tank. Due to the tank being large, this system is much better suited for an area with infrequent rainfall. The ability to hold a large amount of water would be essential for a building designed to help provide for the community in times of crisis and is a great balance between rainwater barrels and a "wet" system.

There are two types of "dry" systems. The first is called a direct system, where water is pumped directly to all required places from the storage tank. Direct systems only require one tank on the site and work by detecting when water pressure drops in any of the pipes (Davidson, n.d.). Water is then directly pumped to the pipes until the water pressure is back to normal. This system allows for higher water pressure and the need for only one tank due to the water pump. The downside is that the pump requires constant power to remain functional.

The other type is an indirect system. Indirect systems use gravity to their advantage to distribute water to wherever it must go. There are two tanks, one on the ground and another one at a high point on the roof above the building. Water is harvested and collected in the lower tank, then pumped into the tank located on the roof. After the water has been moved to the higher tank, gravity is used to distribute the water wherever it is needed (Davidson, n.d.). The benefits to this over a direct system is that the tank can be used without power if water has already been pumped up to the top tank, but the water pressure will be much less than one that uses a pump. The weight of the tank must also be considered. The roof must be able to support the weight of the tank and water, otherwise an indirect system is impossible.

Lastly, "wet" systems are very different from both barrels and dry systems. They can have the largest sized tank and the tank can also be located away from the collection system instead of right next to the roof. The gutters run into the ground and feed into the pipes that are connected to the storage tank. The system is typically pressurized to send the water to the tank and help ensure that no stagnant water remains in the pipe system (*Rainwater Harvesting System | Description, Uses, Quality, & Configurations*, n.d.). Underground pipes remain full of water (called charged lines) during periods without rainfall because they sit below the level of the tank inlets underground. Many people prefer wet systems over dry systems because they are more aesthetically pleasing since the pipes are not visible (BlueMountainCo., 2017). Since there is a need for an underground piping system, a wet system is the most expensive of the three. However, without proper management of a wet system, it can become a breeding ground for mosquitoes that carry diseases. Mosquitoes love stagnant water and may find a home in charged lines. Mosquitoes can spread deadly diseases and can easily contaminate the water that has been collected already. To prevent a mosquito infestation, metal screens are used to keep them out. Metal screens that are non-corrosive with hole sizes of one millimeter or less can keep mosquitos out of wet system pipes (BlueMountainCo, 2017). Anaerobic fermentation can also occur if the system is not well-managed. Anaerobic fermentation occurs when leaves and organic materials begin to decompose in an environment that is depleted of oxygen. Anaerobic fermentation releases thiols and hydrogen sulfide, which gives off a rotten egg smell. These products will contaminate the water, making it unusable. To prevent this process from occurring, the charged lines need to be drained in between rainfalls so there is no water for organic matter to decompose in. To accomplish this, a first flush diverter can be installed in the ground. A flow controller can also be programmed to drain water from the charged lines (BlueMountainCo, 2017).

2.4.3. Methods for Filtering Collected Rainwater

Since the water collected in the tanks can be easily contaminated, it must be cleaned and filtered unless the water is to be used for irrigation purposes only. The first step in the filtration process is prefiltration (Capeheart et al., 2021). This is when large sediment is removed from the water collected so it does not collect in the big tank. The three main methods to accomplish prefiltration are a first-flush diverter, roof washers, and cistern inlet strainer baskets. A first-flush diverter collects the first amount of rainwater in an area separate from the tank since most of the sediment collects in this space. It is then flushed out of the system back into the ground. Another type of first flush system is the roof washer. This system can be expensive and must be washed out after every heavy rain but would greatly benefit the system if it is an area where debris may be a problem. The last method of prefiltration is a cistern inlet strainer basket, which is a thin wire mesh screen that keeps debris and mosquitoes out of the storage tank (Capeheart et al., 2021). The baskets are a good method because they can be easily cleaned, however they require cleaning after each rainfall.

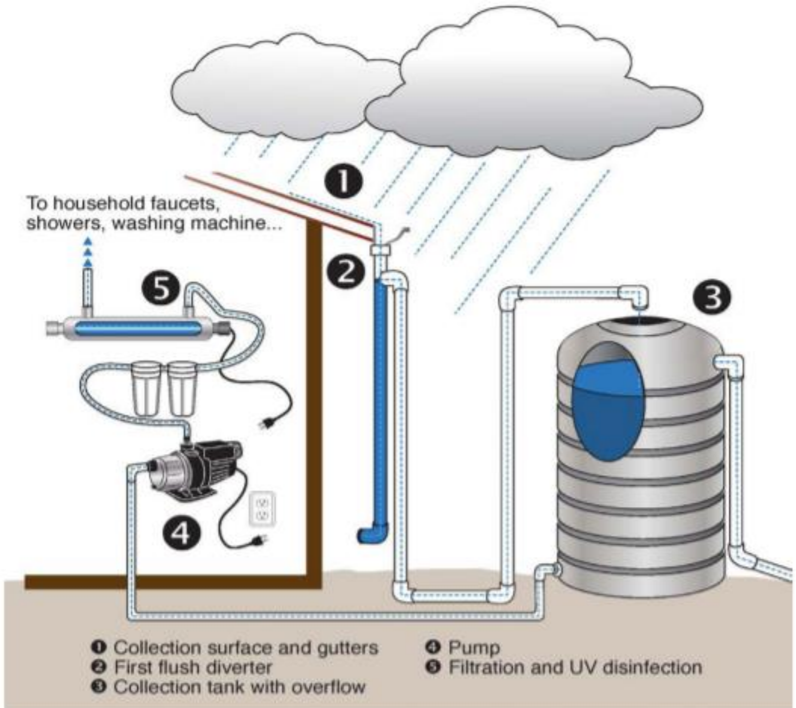

Figure 3: Image of the water filtration process (John Polle, Capeheart et al., 2021)

Following prefiltration, there needs to be some sort of in-tank protection to help deal with any remaining sediment in the water. The outlet tube should be placed just above the bottom of the tank to help with filtration. Any remaining sediment will sink to the bottom of the tank and any remaining contaminants will typically float to the top of the water (Capeheart et al., 2021). Therefore, keeping the outlet tube just above the sediment on the bottom of the tank will provide the cleanest water, free from as many contaminants as possible. An overflow pipe should also be installed at the top of the tank to allow for the removal of excess water. The pipe should still be screened to prevent animals or insects from entering the pipe from the outside to keep the tank as clean as possible.

The final step to ensure that water is safe to drink is water treatment. The most popular way to produce the cleanest water is a three-prong method. The first step in the three-step process is a five-micron cartridge sediment filter. This is a screen that is supposed to remove any sediment that is five microns or larger. Immediately following the five-micron filter is an activated carbon filter that filters out sediment above three microns and can remove some contaminants through absorption. The last step in this three-step process is disinfection. This is where the remaining contaminants in the water are eliminated and creates clean, potable water (Capeheart et al., 2021). There are several different ways to disinfect the water which include chlorination, UV light, ceramic filters, solar disinfection and ozonation. Each with their own benefits and drawbacks.

Chlorine is one of the main methods used to treat collected rainwater. It is placed in the tank in either a gas, liquid, or dry form to disinfect the water (*After-Storage Treatment | Rainwater Harvesting*, n.d.). Not only does the chlorine sufficiently disinfect the water, but it also leaves behind residuals that will continue to keep the tank clean even after the water has been used.

UV lights are another method that can be used to disinfect. Water is sent through a tube with a UV bulb which does not allow bacteria in the water to reproduce. However, UV light does not work as a filter and can be less effective unless the water is filtered out beforehand. Sediment in the water can block parts of the light and allow for bacteria to continue to reproduce if not properly filtered (*After-Storage Treatment | Rainwater Harvesting*, n.d.). However, since this operated with the use of a lightbulb, there needs to be some sort of electricity to continue to run the system.

Ceramic filters are a way to disinfect water while saving on power and energy use. They work by allowing water to flow through a convoluted pathway filled with millions of micron sized pores. The filter is also aligned with colloidal silver to help ensure that all bacteria is removed and to prevent the growth of new bacteria (Capeheart et al., 2021). This would be a beneficial filter in an area where a main power source can go out in a moment's notice.

Solar disinfection is another potential method that involves placing water in a glass box outside and allowing the sun to remove any remaining bacteria (Capeheart et al., 2021). While this method is effective, the water must sit outside for approximately six hours, making it very inefficient. This would be better for smaller systems that do not require a large amount of water to be disinfected on a day-to-day basis.

The last major method is ozonation. This process involved introducing ozone gas to the storage tank that allows for the gas to "disinfects, oxidizes, deodorizes and decolorizes" the water (*After-Storage Treatment | Rainwater Harvesting*, n.d.). While this is an effective method of treatment, it comes with its risks. Ozone gas is poisonous and requires the installation and maintenance of a licensed professional. This would be inconvenient as it would not allow a regular operator to maintain the system and is not the best option for this reason.

Biosand Filters as an Alternative Method of Filtration

Another possible alternative to providing potable water is a biosand filter. This type of filter is about one meter high and made from plastic or concrete. There are no electrical components that go along with the filter, so it can function without the need for a power source. Even without needing power, it can still produce around 12-18 liters of water per hour. There are five major components that the filter consists of, including the diffuser, biolayer, filtration sand, separation gravel, and drainage gravel (CAWST, n.d.). The diffuser is a layer that provides protection to the sand below the water being added into the top. The biolayer is the top portion of the sand that grows bacteria and microorganisms responsible for eating the pathogens in the water. After the filter has been built, it takes around 20-30 days of use for the biolayer to fully develop. The biolayer also develops with the type of water that is being used, so the water should ideally come from the same source for maximum efficiency of the biolayer (CAWST, 2009). The rest of the sand layer helps remove pathogens from the water and traps any solids that were in the water. Following the sand are two different types of gravel. Separation gravel serves the purpose of holding the sand in place and preventing it from slipping down into the drainage gravel and the outlet hose. The drainage gravel is to hold the separation gravel up and prevent that from slipping into the outlet hose. The water is then pushed out the outlet hose into a collection area using gravity (CAWST, n.d.).

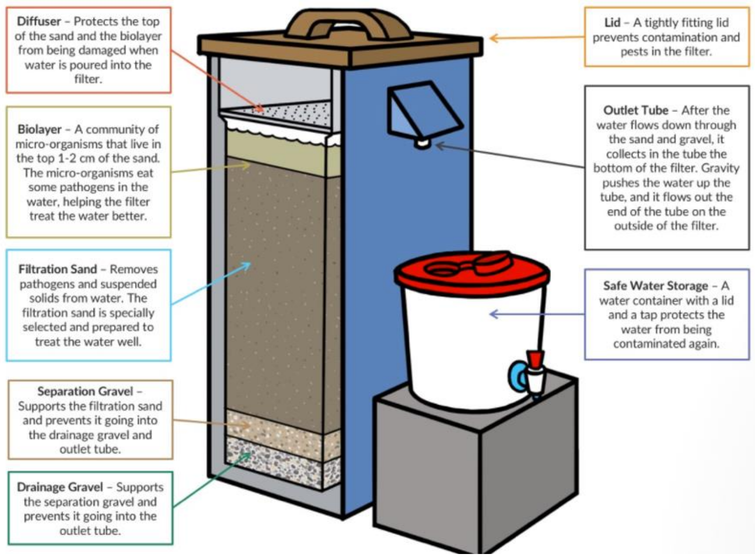

Figure 4: Components of biosand filter (CAWST, n.d.)

There are a few important aspects to note regarding biosand filters. They can remove up to 100% of helminths (worms) and protozoa, 98.5% of bacteria, and 70%-99% of viruses (CAWST, n.d.). However, as effective as a biosand filter is at filtering the water, it should still only be one step in a multi-step filtration system. Another method such as chlorine or iodine should be used to further purify the water to ensure it is completely safe for drinking. The amount of time when water has stopped flowing through the outlet is called the pause period. It is important to allow the water to sit in the filter for no less than one hour but no more than 48 hours. This allows for all the pathogens in the water to be killed and creates the maximum level of filtration (CAWST, 2009). A biosand filter could be a cheap alternative to other methods of producing potable water and would always be functional since it does not require any power.

2.4.4. Challenges Associated with Rainwater Harvesting

Although there are many benefits to rainwater harvesting, it has many challenges associated with it as well.

Irregular Rainfall

The irregularity of rainfall in many areas has made rainwater harvesting an unreliable option for recycling and consumption (Mwamila, Han, & Katambara, 2016). High-need areas cannot be expected to resort to conserving water until the next rainfall. There is a need for a constant supply of water for both potable and non-potable uses, so an irregular rainfall schedule would make it not worth investing in a rainwater harvesting system.

Lack of Awareness

Rainwater harvesting systems often are not prioritized as alternative water supply sources due to the lack of successful demonstration projects in underdeveloped areas around the world. In many areas, there are no policies or regulations surrounding rainwater harvesting systems. Without any sort of incentives or suggestions to install these systems, the awareness and education surrounding them are practically non-existent (Mwamila, Han, & Katambara, 2016). With a heightened sense of awareness about rainwater harvesting systems, change could be made for good.

Water Quality Related Issues

Pure rainwater in the atmosphere is generally low polluted, but pollutants such as particles, microorganisms, heavy metals can accumulate on catchment areas, but they can be easily washed away by rainfall (Goyal, 2014). Other pollutants such as bacteria and hazardous chemicals require rainwater to be treated more intensely to be used. (Goyal, 2014). Unfortunately, filtration systems can be very costly, especially for potable uses. It can be hard to obtain these systems in underdeveloped areas. Users of collection systems are encouraged to dispose of the "first flush" of rainwater, because this first collection picks up most of the contaminants from the roof and gutters. The vessel that collects the water also needs to be kept to a certain standard to minimize contamination from humans or animals, as well as preventing algal growth and breeding of mosquitoes (Goyal, 2014).

2.5. Wells as a Water Source

One possible solution for a sustainable water source at the community center is to drill a well. A well is a hole drilled into the ground to access water contained in an aquifer. To get the water out of the ground, a pipe and pump are used in conjunction with screen filters to remove unwanted particles that could clog the pipe. Depending on the location of the well and how much water is needed, they can vary in depth and diameter. Once constructed, wells provide a reliable and abundant amount of water. This water can then be used for various needs such as irrigation and domestic use (The Groundwater Foundation, n.d.).

2.5.1. Types of Wells

There are three basic types of wells which differ in how they are constructed. The first and simplest type is dug or bored wells. These are holes in the ground that are dug with either a shovel or a backhoe. They are then lined with stones, brick, tile, or a similar material to prevent it from collapsing. This type of well typically has a large diameter without much depth, approximately 10 to 30 feet. They are usually not lined entirely because of how shallow they are (Learn About Private Wells, 2020).

Another type is driven wells, which are constructed by driving a pipe into the ground. They tend to have more depth than bored wells, being approximately 30 to 50 feet deep. Even though this type of well is continuously cased, they can still be easily contaminated. This is because they draw water from aquifers so close to the surface (Learn About Private Wells, 2020).

The final and most sophisticated type are drilled wells. They are constructed by using percussion or rotary-drilling machines. This allows them to reach extreme depths around thousands of feet, much deeper than any other types of wells. Digging them that deep does require the installation of a casing but has a much lower risk of contamination (Learn About Private Wells, 2020). Since our team does not have the knowledge required to determine the optimal type of well at the community center, an expert will need to come on site for assessment.

2.5.2. Components of a Well

Generally, wells have the same basic components regardless of type. The casing of a well is a tube-shaped structure placed inside the well. It is used to keep the well opening from collapsing and provides a path to bring the groundwater to the surface. The casing also helps to keep dirt and contaminants from mixing with the drinking water. Common materials for well casing include carbon, steel, plastic, and stainless steel. The optimal choice typically depends on the geology in the area (Learn About Private Wells, 2020).

The next two components are used to help prevent contaminants out of the water being pumped. The first is a well cap that is placed on top of the well casing. This helps to prevent debris, insects, or small animals from getting into the well. They are typically made of aluminum or plastic and can include a vent to control the pressure while pumping. The second component is a well screen that is placed at the bottom of the casing. This helps prevent too much sediment from entering and can be a continuous slot, slotted pipe, or perforated pipe (Learn About Private Wells, 2020).

Pumps for wells come in two different types depending on the depth of the well. Jet pumps are the most common option for shallow wells at a depth of 25 feet or less. They are mounted above ground and use suction to draw the water from the well. For deep private wells the best option is a submersible pump. Submersible pumps are placed at the bottom of the well inside the casing and are powered from a source on the surface shown. Once it is determined how deep the well on site would need to be, we will know what the optimal pump to use is.

2.5.3. Testing Potability of Well Water

There are a lot of tests that go into determining the potability of well water. Basic water potability includes tests for coliform bacteria, nitrates, pH, sodium, chloride, fluoride, sulphate, iron, manganese, total dissolved solids, and hardness. If a particular contaminant is suspected in the water, then additional testing may be appropriate. Private wells should be tested at least once a year and even more frequently if it is shallow. When conducting testing, the drinking water at the tap and at the source should be tested. Testing should be done by a local certified laboratory at a local Health and Human Services Department (Groundwater Foundation, n.d.).

2.6. Photovoltaic Systems

Photovoltaic (PV) systems are composed of multiple components including solar panels, an inverter, racking for mounting, cabling, and other electrical devices (Energy Education, n.d.). The size of the system can vary from a small rooftop setup to massive industrial solar farms. They can be entirely independent, or a system connected to the utility grid depending on what is needed from the system. A diagram of a grid-tied system can be seen below in Figure 7. The amount of energy produced by a system depends on many factors including type of solar cell, tilt angle, temperature, level of sunlight, and weather conditions.

PV systems work by utilizing the photons from the sun as they fall onto the solar panels to produce electric current (Energy Education, n.d.). This process is called the photovoltaic effect. Each panel produces a small amount of electricity, but many can be linked together, forming a solar array to produce much higher rates.

The energy these panels produce is in the form of direct current which many small electronics utilize but are designed to be powered by an electrical utility grid. This means that to make the electricity useful, it needs to be converted from direct current (DC) to alternating current (AC) using an inverter. This AC electricity can then be used to power electronics locally or be sent back to the electrical grid if connected for use elsewhere (Energy Education, n.d.).

Storage of produced solar photovoltaic energy can be done using batteries. Having batteries connected to the system allows for the power to be used at night or when poor weather conditions keep sunlight from hitting the solar panels. Batteries are also important for utilities in grid connected systems. As solar energy is fed back into the grid, the batteries can store it to be given back to customers later (Energy.gov, n.d.).

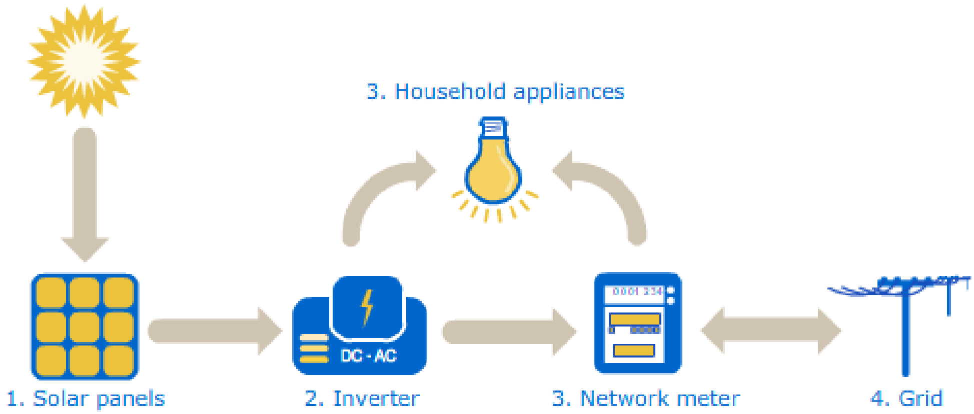

Figure 5: Grid-tied solar PV system diagram (AGL Solar Energy, 2014)

2.6.1. Types of Photovoltaic Systems

Photovoltaic systems vary depending on how they are mounted, the type of solar cells, and how they are connected for usage. PV arrays must be mounted in a stable area and able to withstand any weather over the years. The two mounting options are ground mounted systems and roof mounted systems.

Ground mounted PV systems are cheaper to install and service. Where the system is mounted on the ground is particularly important to assess beforehand to ensure it is in the best position for energy production. Checking to see if the area can be improved by removing obstructions that would shade the panels is a major step when installing this type of system. PV arrays mounted on the ground can be fixed axis for a cheaper upfront cost but will not generate as much energy as single axis tracking panels. Tracking mechanisms automatically move panels to follow the sun across the sky (Energy.gov, n.d.).

Roof mounted PV systems are usually the preferred option in many situations because they are unshaded and out of the way. They typically come in two variations: flat roof and pitched roof. For flat roofs it is common for the arrays to be held on using gravity, but pitched roofs need to have array racking anchored on (Energy Education, n.d.).

2.6.2. Factors of System Efficiency

There are many factors that determine the efficiency of a PV system. One factor is where the system is being installed because insolation varies based on location. Insolation is a measure of the solar energy that is incident on a specified area over a set period and is expressed in kWh/m^2 per day. Another factor is the angle that the solar panels are mounted at which is determined by the company installing them. When aiming to maximize efficiency it is also extremely important to install them in areas with the greatest sun exposure and no obstructions.

System efficiency also varies based on the type of solar cells it will have. Silicon solar cells are the most popular currently because they offer both reasonable prices and good efficiency (NREL.gov, n.d.). The cells are usually combined to make larger assemblies that can be installed on a roof or the ground. Thin-film solar cells are another commonly used option. They are made from very thin layers of semiconductor material such as cadmium telluride or copper indium gallium diselenide, making the thickness of the cell layers only a few micrometers. The advantage of these cells is that they are flexible and lightweight, making them easier to scale up compared to the manufacturing techniques required for silicon solar cells (NREL.gov, n.d.). Other types of solar cells exist that are more efficient than both silicon and thin-film solar cells. Even though they may be more efficient they are significantly more expensive, making them only useful for extremely specific applications.

2.6.3. Benefits of Photovoltaic Systems

There are quite a few reasons to move towards a PV system for power generation instead of fossil fuels. PV systems provide a source of renewable energy while oil is not sustainable. Burning fossil fuels also poses a threat to human health and the environment, unlike PV systems. There would also be limited dependence on the utility company PREPA, Puerto Rico Electric Power Authority, to provide electricity at excessive costs of about $0.22/kWh (Salasovich, J., & Mosey, G. 2011). Another benefit could come from connecting the system to the grid. This would enable any excess electricity produced to be sold back to the utility company at a reduced cost.

2.6.4. Cost of System Install

There is a wide range in costs associated with PV systems in Puerto Rico. The low range of costs is based on larger more modern systems. The high range of costs is based on older smaller-scale systems.

Looking at a fixed tilt ground mounted system, low range cost can be as low as $3.50/W for crystalline silicon solar cells and $3.20/W for thin film solar cells. If single-axis tracking was desirable in the system, the low range cost would be $5.00/W for crystalline silicon solar cells. The high range for these systems is assumed to be $7.00/W for crystalline silicon and $6.40/W for thin film with fixed tilt. Single-axis tracking is assumed to be $10.00/W for crystalline silicone (Salasovich, J., & Mosey, G. 2011).

For a fixed tilt roof mounted system, low range cost would be assumed to be $6.00/W for crystalline silicon and $5.40/W for thin film. The high range cost to install was assumed to be $9.33/W for crystalline silicon and $8.73/W for thin film (Salasovich, J., & Mosey, G. 2011).

All prices for the various systems include the cost of all components needed for the system. These components include the PV array, inverter, electrical equipment, and installation. The final cost and potential gain from a grid connected system depends on multiple factors such as available incentives, the cost of electricity, and the solar resource given panel orientation.

2.6.5. Sales of Excess Electricity

If a grid connected system is chosen, anything produced over the needs of the facility can be sold back to the utility. In Puerto Rico, the net-metering laws state that PREPA will buy 75% of anything not used by the customer at approximately $0.10/kWh. This applies to system sizes under 25kW for residential and 1 MW for commercial. This offer does not seem like a great option considering they pay less than half for electricity than what you can buy it for but setting up a power purchase agreement, PPA, can help.

A PPA is an agreement with PREPA having them buy back the power at a higher price that can be much more beneficial. One large-scale 20 MW PV project in Puerto Rico with a PPA is in Guyama. AES Ilumina entered a PPA with PREPA where they agreed to buy the power at a rate of $0.13/kWh.

2.7. Cool Roofs

Cool roofs are ones that have been specifically designed to reflect more sunlight and absorb less heat than the standard roof (U.S. Department of Energy, 2021). Cool roofs can be made from many different types of materials, such as highly reflective paint, sheet covering, or highly reflective tiles or shingles. In the heat of summer, standard roofs can reach temperatures upwards of 150°F. A cool roof in the same heat can stay more than 50°F cooler (U.S. Department of Energy, 2021).

There are many benefits of cool roofs, the main one being a drastic reduction in energy bills due to the decreased need for air conditioning. This lower demand for energy can help prevent power outages (U.S. Department of Energy, 2021). In the area of Cubuy, it is imperative that there are no unnecessary power outages; it may be extremely difficult to get back power after it is lost. Cool roofs can also prevent the urban heat island effect by reducing local air temperatures (U.S. Department of Energy, 2021).

There are several types of cool roofs which depend on the slope of the roof. Single-ply membranes are prefabricated sheets that are rolled onto the roof and are attached by an adhesive, fasteners, or held in place with gravel, stones, etc. Built-up roofs have a base sheet, several fabric reinforcements layers, and a dark protective surface layer (Office of Energy Efficiency & Renewable Energy, 2021). These types are recommended because they are less susceptible to mechanical, moisture, and UV damage (U.S. Department of Energy, 2021). For steep sloped roofs, shingle and tile roofs are recommended. Shingles can be made of several materials such as fiberglass asphalt, wood, polymers, or metals. Tiles can be made of clay, slate, or concrete. Some of these materials are naturally reflective, and others rely on surface treatment to become cool roof tiles (U.S. Department of Energy, 2021).

It was found that PV panels that were on a cool carpet (a sheet coated with a paint that allows for more reflection of sunlight), generated more power at a 45° angle than a PV panel on a black carpet (Atlan, et al., 2019). This study was completed on only mono-crystalline PV cells, which is important to take into consideration (Atlan, et al., 2019). From this study, applying a cool coating paint showed a 5-10% improvement with cool roof application (Atlan, et al., 2019).

3. OUR APPROACH

This project was intended to assist the Cubuy Community Center in implementing a sustainable, reliable power and potable water source. The project was broken down into the following objectives:

1. Identify the Vision and Rationale for the Power and Water Source from Sponsors and Community Members
2. Analyze the Existing Roof Structure and Identify Potential Systems
3. Establish a Network of Organizations to Aid in the Selection of Each System Considered and Weigh Social Impact
4. Create a Library of Documents for Future Improvements to the Community Center

3.1. Identify the Vision and Rationale for the Power and Water Source from Sponsors and Community Members

After arriving in San Juan, we had the opportunity to meet with our sponsors and residents of Cubuy who volunteer for ID Shaliah. To connect with them on a deeper level, we devoted the first week in Puerto Rico to learning about the community and getting to know the residents. We were passionate about collaborating with and learning from community members who volunteer for ID Shaliah and are directly impacted by the project. It was important for us to remember that the residents of Cubuy live very different lives than us. Some steps that we took to initiate these relationships were:

- Creating name tags for group members, community members, and sponsors to wear
- Having each group member introduce themselves to the community members on-site
- Conducting semi-structured interviews with the volunteers to learn more about their lives and their experiences with unreliable water and power
- Speaking with our sponsors, Johnny and Javier, in the first week to gain an understanding of what they believed was most necessary for the community center

To identify how residents were affected by Hurricanes Irma and Maria, we used interviews to elicit community members' memories of the storms. We were able to gain an understanding of how they responded and what they thought were current vulnerabilities within the community of Cubuy. Understanding the lives of the residents and forming sound relationships with community volunteers allowed us to gain a sense of what the community needed. It also offered insight as to how the sponsor's organizations operate. We asked several members of the Cubuy community, who also were ID Shaliah volunteers about the following topics: information on community strengths, desire for a reliable power source, challenges with water access, as well as their experiences during and after Hurricane Maria. We also focused on the social risks, economic effects and adverse psychological effects caused by natural disasters in Puerto Rico. The complete list of semi-structured interview questions we asked the participants are in the Appendix.

Some challenges and limitations that we encountered while completing this objective were:

- A language barrier was apparent during some discussions, as we were not proficient in Spanish and not all volunteers spoke English
- Finding a time where many community members were able to meet with us

- We were only able to meet with and interview community members that were already involved with the project

We were able to combat these issues by always including Javier and one other English speaker in the group to translate. Finding a time where the members could meet was easily resolved after we had Javier organize a date and time that everyone would be on-site. Even though we formally interviewed five residents, with the nature of the volunteer structure at ID Shaliah, we were constantly being introduced to more and more people, and got to learn their stories.

3.2. Analyze the Roof Structure and Identify Potential Power and Water Systems

An initial assessment of the existing structure included gathering data to help inform decisions regarding what systems to implement on the site. After the existing roof structure and other infrastructure related to the community center were examined in detail, we had a better understanding of what systems could be implemented on the roofs. Having a better understanding of the structure and completing the analysis was an integral part of the methodology. The project could not move forward without this step.

To assess the infrastructure, we:

- Measured each roof edge on-site to create a visual model of the site
- Determined the square footage of each roof based on the gathered measurements
- Used collected field data to determine the material of each roof and its condition
- Identified obstructions to each roof that would prevent systems from being implemented, such as piping, water tanks, and columns
- Took reference photos and video documentation of each roof and the surrounding infrastructure
- Evaluated which specific component options should be chosen for each roof given the assessment and collected data
- Calculated an estimate of gallons of rainwater that each roof on site could collect, and complied data to determine how many people rainwater harvesting could serve

Some challenges that we encountered while completing this objective were:

- Not having access to the as-built structural documents of the building
- Slight inaccuracies arising from available measuring tools

Due to delays in the process of getting the as-built structural documents for the site, we had to record all measurements manually. We could not do the structural analysis that we would have liked to do without the proper documentation. Since we had to take all our own measurements, they were slightly inaccurate. However, since the documents we created acted as estimations rather than definite placements of where systems should be located, the small inaccuracy was acceptable.

3.3. Establish a Network of Organizations to Aid in the Selection of Each System Considered and Weigh Social Impact

A major element of the project was building connections with suppliers, organizations, and contractors to consult with the implementation of a power and potable water supply. This was determined after talking with Javier and Johnny and discovering that this project relied on donations due to the nature of ID Shaliah and the Karma Honey Project's budgets. Through this network, we gathered donations (monetary and supplies), advice, and vital information that helped implement the system. Suppliers were contacted to ask for the donations of items such as roof sealant, components of water catchment systems, and photovoltaic arrays. Several organizations contributed supplies to this project. ProSolar donated a photovoltaic system, Warner Records donated $100,000, and DG Authority donated beekeeping equipment. Licensed engineering and construction firms were contacted to provide design and consulting services for the structural integrity of the roof and quotes for the project. Specifically, water engineers were contacted to help determine the best location for a potential rainwater harvesting system on the site, and to answer questions we had about drilling a well on site. Several companies were contacted to determine the cost to fix the roof, as well as to how the roof should be fixed. We had also researched several other organizations, such as ResilientSEE, that have retrofitted abandoned buildings and turned them into community resilience centers, just like the work ID Shaliah is doing. These organizations were contacted, and interviews were conducted with the leaders of them, to get advice on how to implement a power and potable water system. We were able to interview Yanel de Angel, a co-founder of ResilientSEE. Johnny and Javier have many connections to the community and experts in different fields that were contacted as well. For example, Kendall Lang from Fusion Farms, an aquaponics company, was close with Johnny and was a key informant for this project. He has already seen the facility and was able to advise us on the appropriate route to take when determining what type of water catchment system will be installed.

Each group member had been assigned a field of organizations to contact. The fields were roofing, PV systems, potable water systems, and organizations doing similar projects in Puerto Rico. Each group member continued to contact these organizations throughout the duration of the project to ensure maximum outreach.

To complete this objective, we:

- Created an email template to send out to companies explaining the basis of the project and introducing ourselves
- Researched different contractors, suppliers, and organizations that we could reach out to and organized them in a spreadsheet
- Found information about said contractors, suppliers, and organizations and attempt to initially connect with them through emails, phone calls, Facebook, and LinkedIn
- Sent the email to the companies that had responded to the initial message
- Followed up with the contacts to increase the chances of getting a response

Some challenges we encountered while completing this objective were:

- Not receiving responses from numerous contacts, even after several follow up messages
- Not receiving timely responses from contacts, even though it was explained that this is a very time sensitive project
- Trouble finding the current contact for the State Hazard Mitigation Officer (SHMO) which would help with FEMA grants

3.4. Create a Library of Documents for Future Improvements to the Community Center

- Designed a site layout and building model using Revit to visualize current infrastructure of the community center in addition to future improvements
- Created a handoff document containing our findings regarding PV systems, rainwater harvesting systems, well drilling, and expanding our network
- Composed a final contact list containing all key contact information for everyone we reached out to
    - Contains names, emails, phone numbers, interview notes, links to websites, and our initial outreach template

There are three main deliverables for this project: a 3D Revit model of the site, a handoff report, and a large-scale contact list. The 3D model visualizes where the PV system should be placed supported with dimensions and anticipated appearance of the finished project. This model can be used to show contractors and engineers where systems will be placed and is great for marketing as well. Our sponsors have shared that it is important to have a visual representation of what is coming to gain support and engage community excitement. The handoff document contains findings about PV systems, potable water systems, expanding our network, and funding opportunities. We discuss the status of each by three criteria; what existed at the site before we got there, how we advanced it, and recommendations for anyone who is looking to further our work. This document is intended for a broad audience including future IQP groups, our sponsors, and anyone who is interested in our project. The document is meant to be succinct and understandable, with visual aids. The contact sheet is mostly relevant for our sponsors and future IQP groups so that they can continue to nurture the relationships we started while we were in Puerto Rico. All the contact information for each member we contacted is listed in the sheet, including which organization they work for, how they can help the project, and notes on the conversations. Having our important documents and information organized in one accessible library will make our work easy to navigate and comprehend. Ideally, since we are not the only group working at the community center, the work of the community center planning group will be in the library as well.

4. FINDINGS AND ANALYSIS

This chapter outlines the qualitative and quantitative data collected over the course of the project. The sections below explain how we evaluated the motivation of the stakeholders and the potential impact of the project as well as how we documented the existing condition of the community center. A separate guide entitled "Building Resiliency at the Cubuy Community Center" contains findings on possible water supply options, the implementation of a PV system, networking with relevant contacts, funding from private companies, and possible grant opportunities. Pertinent project data is outlined below with references to specific appendices for full data and findings.

4.1. Findings Regarding Project Impact and Motivation of Stakeholders

One lesson that we learned was that understanding our sponsors' vision for our project was an ever-changing learning experience. Our sponsors are extremely hardworking, ambitious, and have high hopes for the community center. They are thinking of new ideas every day to implement on the site. The passion for this project is seen in everyone involved, from our sponsors all the way down to the volunteers. The progress being made is incredible, considering some of the setbacks they had. They were unable to get the as-built documents for the building, one of the buildings was vandalized, and the pandemic slowed down supply chains, so some equipment was delayed. Despite this, Javier and Johnny have kept their heads held high, and are still pushing for the clinic and pharmacy to open on January 15, 2022. With these challenges come change, and it took time and discussion for us to figure out how best to contribute.

During our preparation period in Worcester we had the opportunity to interview Javier. We were under the impression that water needed at the site would be used for non-potable uses only (for example, rainwater harvested from a roof that would only be used for washing clothes). We structured some of our background research around this. We did not do extremely in-depth research on the treatment or filtration of water. When we got to the project site, and initially asked Javier about what he saw our project accomplishing, he told us the water would be potable. We also thought this project was going to revolve around constructing a green roof on the site, but on our first day there, we found out that our sponsors did not want a green roof on site. We were now going to focus on implementing a reliable power and water source on-site. We had originally only considered rainwater harvesting systems to provide a potable water source, but soon we had considered several other systems, such as drilling a well on site or pumping water from a nearby river. We also expanded the scope of our project to include research grant opportunities to fund the implementation of the systems we envisioned. Another important aspect was reaching out to organizations that could provide us with donations, advice, and consultation. Our project did change quite a bit from the preparation period, but also during the first few weeks of being in Puerto Rico, but we adapted to change well and completed the project. We were ready to adapt to these changes and were excited to assist in maximizing the potential of the community center.

Another thing that we discovered quickly upon arrival at the project site is that open communication with our advisors, sponsors, and each other would be critical to the completion of the project. Being able to communicate with our sponsors and advisors when we felt like the project was going in a direction that we did not expect, had an idea we would like to express, or were confused about something was extremely important to us. The act of communication brought a sense of trust between all of us, which contributed to the success of the project. Communication was vital in the first week or two of the project when we were first getting to know Johnny and Javier. They were being introduced to what an IQP is, since this was WPI's first time working in Cubuy and with ID Shaliah and the Karma Honey Project, and our team and sponsors saw our project acting in different scopes. Each week at our sponsors and advisors meeting, we were able to have respectful conversations about the work we were doing, the expectations set for us, and how we were going to continue our collaboration moving forward. Having a time for open communication every week contributed to the success of the project and made us feel closer to both our sponsors and advisors.

4.2. Findings Regarding the Existing Infrastructure of the Community Center

The following section outlines how we documented the infrastructure at the Cubuy Community Center. This information was used to build a rationale for where each system should be placed.

We were limited to the data collected through on-site analysis since we were unable to confirm or obtain the original construction documents from the Public Buildings Authority. The most cost-effective and manageable design for the Cubuy Community Center is a design that utilizes the current infrastructure and suggests minimal infrastructural changes. For that reason, it was important to understand and document each existing structure on the site.

Location Labeled	Name of Location	Rooftop Area (sq.ft.)
1	Cafe and Multipurpose Building	1661
2	Beekeeping Room	484
3	Medical Clinic Building	1283
4	Classroom	288
5	Refugee Building	1542
6	Bathrooms	463
7	Workshops	1652
8	Technology and Learning Building	821
9	Storage Building	
10	Pavilion	394
11	Office	435
------	Property Line	

Figure 6: Map of Cubuy Community Center and roof surfaces adapted from Google Maps (2021)

We documented the site plan and layout of existing infrastructure of the Cubuy Community Center with a series of photos and sketches. For ease of reference and consistency, the buildings and associated rooftops were labeled to correspond with the aerial map of the site (Figure 6). The list of pictures in Appendix E documents the condition of each roof surface, the material of the roof, and the surface area. The surface area of each roof was calculated from measurements taken on-site. We also noted the slope of the roof, existing rainwater outlets, and any obstructions such as pipes, columns, and trees that would interfere with the placement of systems on the roof. This information along with sketches drawn on-site were synthesized within an AutoCAD diagram for visualization and technical purposes.

Image 4: Southern perspective of the existing infrastructure

The Cafe and Multipurpose Building has pre-existing infrastructure that aids in the drainage of water. There are three scupper PVC pipes used as rainwater outlets through the parapet of the flat roof. The water collected from these outlets is currently directed down the hillside away from the building, with no specific collection area. The group of buildings shown above do not have any established water collection system such as gutters, downspouts, and drains. From observations made during rainfall, we concluded that water tends to runoff the edges of the roofs with some water left as standing water. To properly collect rainfall for a water harvesting system, new gutters and downspouts should be installed around the chosen roof edges.

Image 5: Northern perspective of existing infrastructure

The Technology and Learning Building on the north side of the site has a small-scale gutter system on the highest rooftop. This system consists of two scupper PVC pipes with a diameter of 2 inches that directs water onto the walkway below. Currently, there are no gutters or conveyance systems that can be used for rainwater harvesting. The flat roofs should have gutters installed to collect and direct rainwater towards a storage tank. The roof of the storage building is made from corrugated steel and can only be considered for rainwater harvesting or photovoltaic panels if it is structurally reinforced.

The system implemented on the roof of each building is dependent on the material and construction of the roof. The roof area and the materials used heavily influence the efficiency of collection and the quality of water. Base materials like asphalt, concrete or tile roofs can be used in rainwater catchment, but steel roofing is the most suitable. This is because potential contaminants may grow on the base material itself and there are uneven surfaces and cracks that slow down the collection rate. The existing condition of the roofs of the Cubuy Community Center should be repaired before a rainwater catchment system or photovoltaic array is installed.

Image 6: Example of blistered and cracked roof at the Cubuy Community Center

We estimated which roofs are unfit to place a system before possible roof improvements are completed. Some roofs on the site have a built-up roof system, made from layered asphalt material and ply sheets. These roofs are currently in poor condition showing cracks and large areas of blistering shown in the image above. We found out that the downside of these materials is that they can slowly leach low levels of toxins into the water storage tank (Gardiner, 2015). The built-up roofing material should be significantly repaired, scraped, and power washed or completely replaced. These roofs may still be suitable to collect rainwater if they are properly repaired and the water supply system is protected from contamination and treated before use.

On the exposed concrete roofs, a roof primer and high strength roof sealant should be used to penetrate and seal porous surfaces. The current sealant used is Crosco 6500, a water-based 100% acrylic elastomeric sealer of a single component that waterproofs and protects the roof. This product also reflects sunlight and reduces interior temperature which creates a cool roof.

General considerations and repairs for the roof also include safety measures and maintenance. On all roof areas that are accessed frequently or are easily accessed by members of the community center, there should be safety precautions in place. Railings should be installed around the essential equipment on the roof that may be accessed for maintenance or routine cleaning. This is especially the case on the lower roof of the Technology and Learning Building to provide a critical form of fall prevention.

4.3. Findings Within the Building Resiliency Guide

The findings regarding PV systems, water usage analysis, expanding our network, and a list of funding opportunities can be found in "Building Resiliency at the Cubuy Community Center", the handoff document we created. This document is intended for future IQP groups, our sponsors, and anyone who is interested in our project. This document is meant to showcase our findings in a succinct, visually appealing way. This is the document that we would want someone who is interested in our project to read first. Each section is divided into three sections: what previously existed at the site, what we did to advance it, and then recommendations for our sponsors and future project groups. This guide is also intended to be a living document, for future IQP groups to edit and add to as they see fit to show the advancements of the work done at the community center. This guide contains the key information gathered from our research and is the most important outcome of this project.

5. OUTCOMES

Below we explain the work we did in Puerto Rico that led to us developing our final outcomes. For each outcome we provide explanations of what it is, why it was created, and recommendations on how it can be utilized. Given the building resiliency guide is the most important outcome of this project, we also cover what can be found in it. We believe each of these outcomes can be extremely useful in expanding upon the work we have started.

Through our interviews with community members and communication with our sponsors we learned about the greatest needs of the Community Center. Many, if not all the people we talked to were without water and power for months following Hurricanes Irma and Maria. They all stressed how important it would be to the community if there was a potable water source to provide water in times of emergency.

An assessment of the existing infrastructure at the site was completed to evaluate possible systems and where they could be installed. We could not acquire the construction documents from the Public Buildings Authority, so we collected all necessary data on site. Each building was numbered for ease of reference and information was noted such as rooftop area, surface condition, material of the roof, obstructions, and drainage points. This analysis helped determine which roofs were best suited for the various systems being considered.

We then compared options for various potable water systems at the community center: drilling a well and harvesting rainwater. We researched the demand for water during emergencies and determined that a drilled well has potential to provide a large quantity of potable water to the community. Well water does not require extensive water filtration to make it drinkable compared to collected rainwater. However, wells are expensive; one company offered a $60,000 quote to drill one. A rainwater harvesting system may be cheaper but would supply potable water to significantly fewer people than a well. Overall, we recommend continuing to research the implementation of a well while understanding the financial and physical limitations. A rainwater harvesting system could be utilized for solely non-potable uses.

We found that installing a PV system would fulfil the need for a reliable source of power at the community center. We secured a donation of a PV system from ProSolar, which has the potential to grow to 221 panels. The system donated has battery capacity to provide the center with electricity 24/7, and the excess stored power can even be sold back to PREPA. To maximize system efficiency, it is important to consider the panel mounting angle, material of solar cells, reflectiveness of roof surface, and sun exposure. Fortunately, Puerto Rico has proven to be an optimal location for PV systems due to its geographical location.

The success of this project was reliant on networking with organizations throughout Puerto Rico which has proven to be a time sensitive process requiring a lot of patience and persistence. Interviews with professionals in the corresponding fields informed us about design and construction considerations for each system. We maintained contact with representatives of similar organizations that support community resiliency centers in Puerto Rico. Another major result of networking was to secure monetary and material donations considering both sponsors are non-profit organizations.

Large amounts of funding from grants and private companies would be beneficial for the community center to fulfill long-term plans. Similar projects in Puerto Rico have received millions of dollars in federal funding from agencies like FEMA and the USDA. The difficulty in securing such funding is due to the complicated and lengthy application process. Numerous documents and information are required about the project and may take up to a year to complete.

After completing field work, we were able to address questions regarding PV systems, potable water usage, and expanding the network of engineering and funding professionals. Our research led to the creation of a digital library with guides, models, and useful documents for the continuation of this project by our sponsors or future IQP groups.

5.1. Building Resiliency Guide

We have created a hand-off guide titled "Building Resiliency at the Cubuy Community Center" intended for our sponsors, future IQP groups, and those interested in the project. We created the guide so that our main findings are communicated to all audiences in a succinct, understandable, and visually appealing manner. We wanted readers to easily access the content of our work in one location rather than navigating the IQP report to uncover the main findings. In the guide is an introduction to the document, explaining the motivation behind the creation of it, what it contains, a short overview of our project, and our vision for how it would be used. It also contains a brief acknowledgements section thanking our sponsors, advisors, and others that helped us complete our project. Then, as outlined in the table of contents, are sections on PV systems, water usage analysis, expanding our network, and funding opportunities. Each section is broken down into three sections (as they pertain to each subject): what existed prior to our arrival in Puerto Rico, advancements we made during our time in Puerto Rico, and recommendations for future groups. Organizing our content in this way makes the guide very easy to navigate and understand our work.

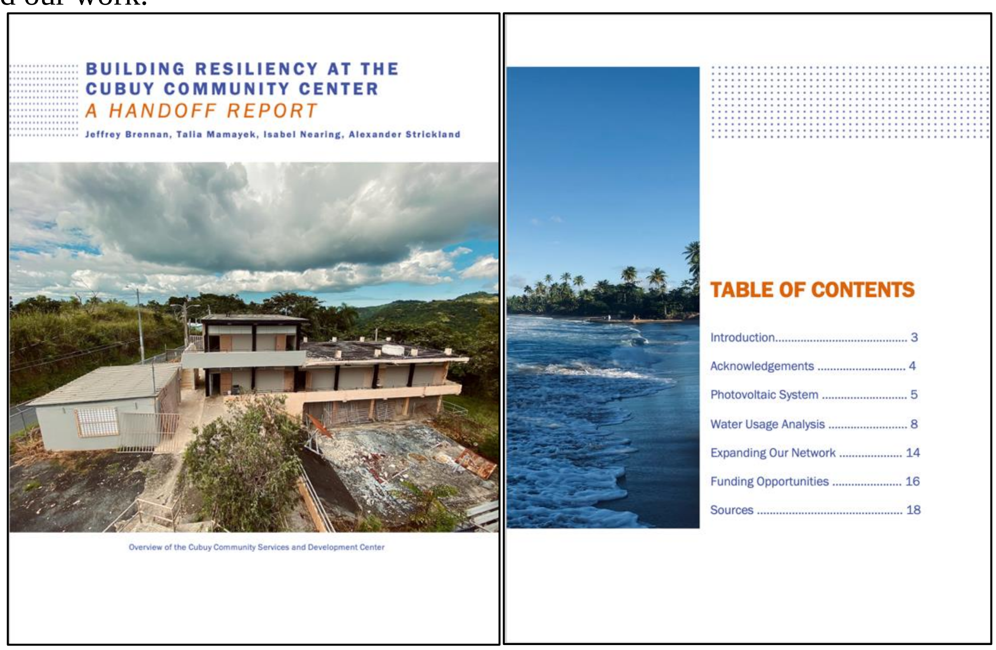

Figure 7: Cover of Building Resiliency Guide

In the section on PV systems, we inform the reader that there was no previous use of renewable energy at the site. We developed a relationship with ProSolar and discussed their donation of a large PV system. They asked us to provide measurements of each roof along with pictures of obstructions and surrounding infrastructure, so they could develop a plan for their donation. With the gathered roof edge measurements, we developed a two-dimensional layout of the site in AutoCAD. We secured a growing system from them. They initially donated a small system but will donate one panel to the site for every sale they make. We recommend that future groups focus on creating content to spread the word about ProSolar and how they are donating a panel per sale and research what could be useful at the community center that would utilize any excess electricity production from the system.

We describe the three uses of water at the community center in detail. At the site, water is used for normal operations, emergencies, and alternative uses. Normal operation is the daily water use at the community center, supplied by PRASA. Emergency use applies to water used for consumption and personal hygiene (domestic water) when normal operations are interrupted. Alternative use applies to non-essential, non-potable uses of water, such as watering gardens or washing clothes. This alternative use of water should supplement the other sources of water at the community center. The site currently relies on municipal water supplied by the Puerto Rico Aqueduct and Sewer Authority (PRASA) for normal operations. This system is proficient in supplying water to all buildings at the community center and providing water to the septic system. We researched the best systems to implement to supplement emergency use and decided that a well should be further researched because of its large potential to supply an abundance of clean water. Wells are also more resistant to storms, considering most of their infrastructure is underground. However, wells are expensive, costing $10,000+, and are not common in Cubuy, so information on contaminants and groundwater table disruption are unknown. RWH systems were considered for emergency use, but they do not supply water to enough people, and the rainwater collected is very hard to make drinkable. We determined a RWH system would be best utilized for alternative use rather than emergency use.

We take readers through our networking process as well. Prior to our arrival on-site, Johnny and Javier initiated two important connections that would help us throughout the project. We were informed that Greg Jones from ProSolar and Kendall Lang from Fusion Farms visited the site and had knowledge about both PV and RWH systems. Another important relationship already established was with the mayor of the Canóvanas region. She promised a donation of approximately $7,000 to fix the electrical system at the community center. Johnny and Javier are great at networking, which proved to be advantageous to our project. We had conversations with both Greg and Kendall that helped us advance our project regarding water usage analysis and alternative power, but we reached out to many more people to see how they could help as well. We emailed lots of companies involved in well drilling, RWH systems, and other organizations like ID Shaliah to seek guidance from them. We were able to establish a large, extensive network with some very useful contacts. We recommend that future groups reach out to their contacts early and often to get responses, they be persistent and send multiple follow up emails to obtain the information you are looking for and continue to reach out to new people and organizations.

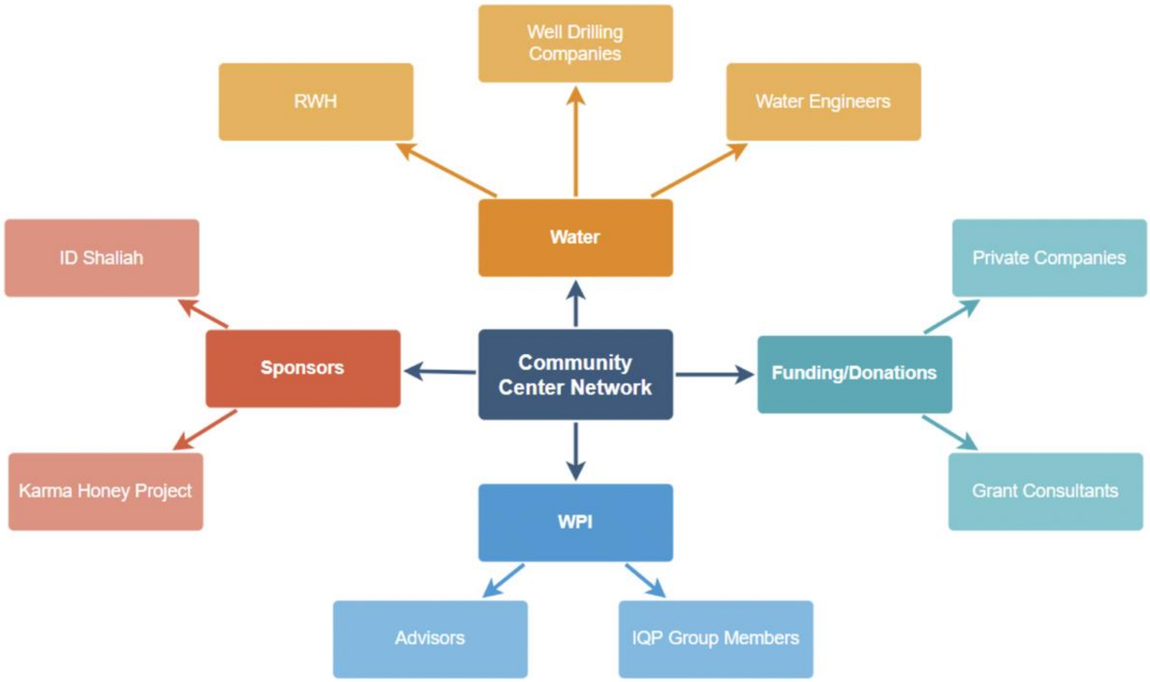

Figure 8: Graphic displaying the networking "web" from this project

Lastly, we detail potential funding opportunities for the community center, so that they can have long-term, large sources of funding. Due to the foundation of non-profits and grass root initiatives, finances can be a major challenge for these organizations, and ID Shaliah and the Karma Honey Project are no exceptions. When we spoke with Javier and Johnny there was a great interest in applying for grants because they can provide a significant amount of funding. Grants can provide valuable resources for organizations to carry out projects that they would not be able to complete otherwise. However, there were some concerns expressed about the unfamiliarity of formal grant writing as well as the unique documents required when applying. We researched various grant opportunities that are related to community development, energy, and water and waste disposal from organizations such as FEMA, USDA, and EPA. When approaching the search for funding, we targeted grants that had been awarded to projects in Puerto Rico with similar initiatives to ours. We have also researched, interviewed, and selected several agencies and organizations that could possibly assist in the application process. To aid in the longevity of the project, we compiled a list of grant opportunities that the Cubuy Community Center project aligns with in terms of eligibility and application window. For future groups, we recommend that they focus on organizing the finance structure and budget of the Cubuy Community Center, including both of our sponsors non-profits, and create a Volunteer Management System (VMS) as an organization tool.

This document should be used in conjunction with the other outcomes to expand on the project work. Many of the individual recommendations include needing to reach out to other companies and organizations, whom of which are listed in the contact sheet. It is recommended that future IQP groups edit the guide and add to it, as they complete IQP work in Cubuy. Having a collective account of previous work done in the area can show the progression of projects at the community center and allow students to continue building off each other’s work.

5.2. Model of the Cubuy Community Center Infrastructure

A model of the community center was developed using building information modeling software (BIM). The measurements and survey of the existing buildings allowed us to document and capture building data in one location. The visuals generated from the model can be used for marketing, sharing progress work with the community, and securing funding as well. The 3D model visualizes where the PV system should be placed supported with dimensions and anticipated appearance of the finished project. This model can be used to show professionals and engineers approximately where systems will be placed and is a working tool for project members. Our sponsors have shared that it is important to have a visual representation of what is coming to gain support and engage community excitement.

Image 7: Aerial view of the site rendered in Lumion and Revit

5.3. Network of Contacts

With a lot of our project revolving around reaching out to different people and organizations, it can become difficult keeping track of everyone that we talked to. To better organize all our contacts, we have created a spreadsheet that has all the important information relating to who we have been in contact with. The sheet contains names, organization names, what they do, contact information, and notes detailing our interactions with everyone on the list. It was a very easy way for all of us to place these names in one list that could be filtered and updated from anywhere. It was also created for future reference by our sponsors or future WPI IQP groups. It’s useful for our sponsors to know who we have already talked to and for future projects to have an idea of as well. Not only will they know who we have talked to, but the extent of our communications as well. Included in the notes are hyperlinks to all our interview notes and to our outreach email template. The contact sheet can be found in both the building resilience guide and the file library.

5.4. Digital File Library

With the expectation that our sponsors and potentially another IQP group will be continuing the work on our project, we created a file library to access everything we have done. This includes all written documents created for conducted research, interview questions with notes on responses, an outreach template, and the building resiliency guide. There are also many other types of files including slides for final presentations, relevant contact list, rainwater calculations, created Revit files of site layout with buildings, and AutoCAD drawings of accurately sized roofs. This file library exists in a Google Drive under an account created specifically for the community center. However, this library is restricted for use only by the community center staff and future IQP groups. Others may request access to the library via our Puerto Rico Project Center website or the Cubuy Community Center website We expect this library to be a valuable asset to future projects in various ways. A future IQP group will be able to pick up where we left off on our research, saving them unnecessary time and work. The information we gathered from interviews will also be good professional advice that is known to be reliable. Future networking for the project is expected so the outreach template will be a great outline to start with. If another group is continuing work at the community center it is strongly recommended that you go through all files in the library before conducting any other work. This will ensure they are well informed on what has been done also give them a good idea of where to start and how they can move forward.

6. CONCLUSION

Our team leaves ID Shaliah and The Karma Honey Project with several concrete deliverables to support their development of the Cubuy Community Center. We recommend that our sponsors and future IQP teams use the Building Resiliency Guide, building model, contact sheet and supplementary documents to facilitate the Cubuy Community Center design process and conversations with potential funders. To advance current relationships and the development of a drilled well and supplying sustainable solar energy, we suggest that major decisions are informed by the contents of our digital file library. The impressive efforts of our sponsors and community volunteers will promote emergency preparedness and community resilience. Pioneering work in Cubuy was an exciting learning experience and we look forward to seeing the center reach its maximum potential.

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8. APPENDICIES

Appendix A: Ethical Considerations

While conducting primary research involving interviews, focus groups, and other ways of interacting with members of a community, it was important to give the subjects a feeling of privacy and confidentiality. It must be remembered that no individual needs to tell us anything, and consent must be received by individuals who are interviewed. We investigated the ethics associated with conducting primary research and obtained the following important guidelines to follow (Halej, 2017).

- The goal of primary research should be to benefit the area and community you are working in
- Research participants should be provided with information on the purpose, methods, and what their answers will be used for
- All participants must provide their consent to relevant research being conducted
    - This can be in the form of a written statement, video, etc.
- The identity of all participants should be kept confidential and private unless specified otherwise
- All stages of the research process should be documented to create transparency about the whole process
- Consider any barriers that may stand between you and participants and how they can be resolved. This can include problems such as language barriers.
- Have methods of properly tracking and storing all data obtained throughout the research process
- Maintaining ethical data analysis practices by staying away from "Cherry-picking" quotes, using inconsistent information causing misleading data, and choosing to omit certain data that may not be favorable to your research

We will be dealing with many people in a range of formal interviews and focus groups to a more casual setting, such as creating icebreaker games and trying to get to know the community. Regardless of how research is being conducted, it is important to stick to the considerations above and ensure that all information gathered is with complete documented consent.

Consent is an extremely large element of conducting any study. Obtaining enthusiastic verbal consent is key to conducted studies. It is also crucial that participants know that they can withdraw consent at any point during the interview/focus group. We do not want participants to feel like they are being forced to do something. The interviews and focus groups should be a fun, enjoyable, and educational experience. These conditions will be outlined in a statement that is read to participants prior to an interview or a focus group, which can be found in Appendix B.

It is also of the utmost importance to remember that we are guests while completing research in Puerto Rico. We must always show respect to the native culture and not outstep any cultural boundaries.

Appendix B: Informed Consent Script

Hello, we are students from WPI working with ID Shaliah and the Karma Honey Project to explore resources such as a potable water and power source for the Cubuy Community Center. We would like to hear how your life was impacted by Hurricane Maria and how you would ideally utilize the community center so that we can address all major interests of the community. We may include some information you provide in our report that will be published online, if that's okay with you. You do not have to discuss anything that you would not like to and can stop at any time. May we speak with you for a few minutes? Do you have any questions for us before we begin?

Appendix C: Focus Group Questions

Questions from the focus group held with many of the ID Shaliah volunteers that are members of the Cubuy community

1. How did you get involved with the project and ID Shaliah?
2. How much time do you spend at the community center?
3. How close is the community here? What are the weaknesses & strengths of the community?
4. What are the priorities of the center?
5. Do you see yourself benefitting from services and is there anything else you think should be in the center?
6. What were some personal impacts from Hurricane Maria?
7. How much would you use the center daily/during an emergency?

Appendix D: Interview Questions for Grant Consultants

1. What is needed for a Nonprofit Security Grant Program?
2. Does one have to develop a COOP Plan to apply for a grant?
3. Looking at safe room funding FEMA grants, which one is this project eligible for?
    - Grants under hazard mitigation assistance (HMA)
    - Hazard mitigation grant program (HMGP)
    - Pre-disaster mitigation (PDM)
    - Flood mitigation assistance (FMA)
    - Building infrastructure and communities (BRIC)

4. Separate from HMA, do you think this project is eligible for community development block grant funds through housing and urban development (HUD)?
5. Can you explain the application process and how long does it typically take?
6. What information is needed about the project and organization?
7. Where can these application forms be found? FEMA Go?
8. What does a hazard mitigation plan entail?

Appendix E: On-Site Roof Analysis

Below is a numbered list of each roof at the Community Center site providing an image of the roof, the total square footage, and any obstructions on the roof. This was sent to ProSolar so they could do an analysis of which roofs would be suitable for solar panel placement.

	Roof #1 Area: 1661 sq.ft. Obstructions: Pipe, old water tank
	Roof #2 Area: 484 sq.ft. Obstructions: Heavily shaded

	Roof #3 Area: 1283 sq.ft. Obstructions: None
	Roof #4 Area: 288 sq.ft. Obstructions: Heavily shaded
	Roof #5 Area: 1542 sq.ft. Obstructions: Tree far corner

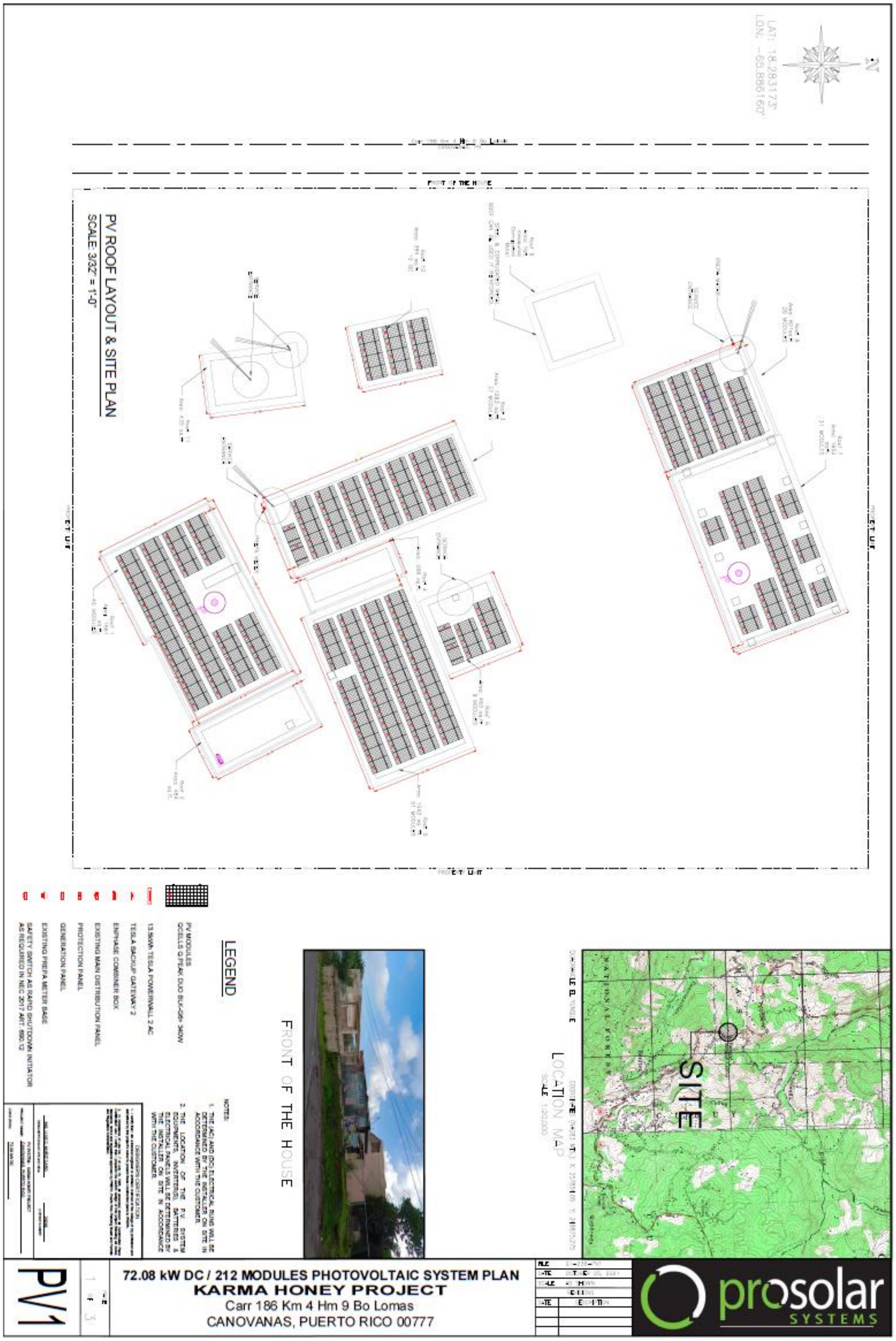
	Roof #6 Area: 463 sq.ft. Obstructions: Column, pipes
	Roof #7 Area: 1652 sq.ft. Obstructions: Columns, old water tank
	Roof #8 Area: 821 sq.ft. Obstructions: None

	Roof #9 Area: difficult access, did not measure Obstructions: None
	Roof #10 Area: 394 sq.ft. Obstructions: None
	Roof #11 Area: 435 sq.ft. Obstructions: Electrical service entrance

Appendix F: Rainwater Calculations for Roof 5, The Refugee Building

Month	Average Monthly Rainfall (in)	Estimated supply to collection tank (gal)	People Supported for Minimum Domestic Use	People Supported for Maximum Domestic Use
January	6.08	5,060	82	41
February	5.40	4,495	81	41
March	7.92	6,591	107	54
April	5.37	4,472	75	38
May	8.38	6,977	114	57
June	4.50	3,748	63	32
July	10.53	8,771	143	71
August	12.26	10,212	166	83
September	9.05	7,536	127	63
October	7.51	6,257	102	51
November	10.30	8,578	144	72
December	8.79	7,321	140	60
Average	8.01	6,668	112	55
Annual	96.10	80,019	1345	662

Appendix G: Site Plan and PV Roof Layout Provided by ProSolar



Appendix H: Advantages/Disadvantages of Proposed Potable Water Sources

Type of System	Advantages	Disadvantages
Dry RWH	• Cheapest RWH option • Simple maintenance • Large storage capacity • Free source of water	• Piping is above ground: not stable against hurricanes • Storage tank must be close to the collection building • Relies completely on weather • Needs extensive filtration and treatment to make potable
Wet RWH	• Better protected from hurricanes: piping is underground • Storage tank can be farther away from the collection building • Aesthetically pleasing • Free source of water	• More expensive RWH option • Maintenance is complex • Has a potential to be a mosquito breeding ground
Drilled Well	• Provides an abundance of clean water • Reliable source of water • System lasts a long time • Resistant to storms	• Most expensive potable water option • Many extensive tests must be done to determine if the well can be dug