Water for Small & Very Small Communities in Puerto Rico: Background and Framework for Thoughtful Implementation of Resilient Treatment Technology

A Project Paper Presented to the Faculty of the Graduate School of Cornell University in Partial Fulfillment of the Requirements for the Degree of Master of Professional Studies in Global Development with a Specialization in International Resource Management

by
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Abstract

Small towns and communities in under-resourced areas often struggle to build, maintain, fund, and operate resilient drinking water treatment infrastructure that meets their needs. Development practitioners often supply technology and infrastructure without addressing the need for community engagement and education, workforce training, secure funding sources, and long-term operation and maintenance plans. Often the infrastructure does not provide the level of service a community needs by not adequately treating the source water and having a short time between component failures. The AguaClara Cornell project team comprised of Cornell University's (CU) School of Civil and Environmental Engineering (CEE) and AguaClara Reach (ACR), a non-profit organization focused on bringing safe drinking water "on tap" to developing areas, are looking to implement their water treatment technology in Puerto Rico (PR) while keeping this holistic mindset for what true implementation of new technology looks like. **This report provides context for working in Puerto Rico, a summary of Puerto Rico relevant work conducted thus far by the Cornell AguaClara Program, and a prospective roadmap of next steps for implementation of ACR technology in Puerto Rico.** The summary includes the author's work on the application for a National Science Foundation (NSF) Convergence Accelerator grant that supports the development of a convergence framework to expedite the deployment of equitable water systems, especially for those most impacted by climate change. The grant application proposes a three-pronged approach for developing this framework that includes Governance & Finance, Resilient Treatment Technology, and Community Education & Workforce Training. ACR and its partners plan to follow this approach when implementing water treatment technology alongside a community.

Biographical Sketch

Alexandra Everhart Gearing grew up exploring and racing around the woods of her small town, Edinboro, Pennsylvania. It was during these times that her love of nature developed. Throughout Alexandra's life, she realized that when the environment is not thriving, it means people are not thriving. This led her to Pennsylvania State University, where she graduated with a B.S. in Environmental Resource Management with a water specialization and minor in Environmental Engineering. For five years after graduation, Alexandra worked as a water resource engineer in Buffalo, NY and Wellington, New Zealand. Alexandra's experiences showed her that the lack of water systems in underdeveloped areas leading to preventable sickness and disease weighs on her heart in a way other issues do not. This led to her moving to Ithaca, NY to pursue her MPS in Global Development at Cornell University, concentrating in International Resource Management with a focus on water and sanitation.

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Thank you to the staff at the InterAmerican University of Puerto Rico: Center for Environmental Education and Research for their insight into what it is like working on the ground in Puerto Rico, for connecting me to resources, and helping me to navigate San Juan during my visit! Thank you to the staff at Syracuse University's Environmental Finance Center: Center for Sustainable Community Solutions for collaborating and answering my questions about funding and financing for small vulnerable communities.

Dedication

This report is dedicated to my husband, Dillon, whose unwavering support, encouragement, and thoughtfulness made this project and my time at Cornell University possible.

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Abbreviations

Abbreviation	Meaning
AAA	Autoridad de Acueductos y Alcantarillados
AAFAF	Fiscal Agency and Financial Advisory Authority of Puerto Rico
AC	AguaClara
ACR	AguaClara Reach
APP	Agua Para el Pueblo
BIF	Bipartisan Infrastructure Funding
BIL	Bipartisan Infrastructure Law
CBDG	Community Block Development Grant
CECIA	Center for Environmental Education, Conservation, and Research
CEE	Civil and Environmental Engineering
CPA	Center for Public Administration
CSCS	Center for Sustainable Community Solutions
CU	Cornell University
CVOC	Chlorinated Volatile Organic Compound
CWA	Clean Water Act
CWS	Community Water System
DOH	Department of Health
EFC	Environmental Finance Center
EPA	Environmental Protection Agency
IAUPR	InterAmerican University of Puerto Rico
IL	Implementation Location
IP	Implementation Partner
MHI	Median Household Income
NGO	Non-Governmental Organization
NIEHS	National Institute of Environmental Health Sciences

NJIT	New Jersey Institute of Technology
NSF	National Science Foundation
NTU	Nephelometric Turbidity Units
O&M	Operation & Maintenance
OSAN	Non-PRASA Aqueduct Systems Organizations
OSU	Ohio State University
PR	Puerto Rico
PRASA	Puerto Rico Aqueduct & Sewer Authority
PWS	Public Water System
RCAPS	Rural Community Assistance Partnership Solutions
SAVerS	Small and Very Small Communities
SDWA	Safe Drinking Water Act
SRF	State Revolving Fund
SU	Syracuse University
UPRM	University of Puerto Rico at Mayaguez
UN	United Nations
US	United States
USDA	United States Department of Agriculture

1. Introduction

Small towns and communities in under-resourced areas often struggle to build, maintain, and operate effective drinking water treatment plants and distribution systems. They are frequently not included in non-governmental organization's (NGOs) or nonprofit's household-level treatment initiatives and yet they are not large enough to be managed by the government's city-wide water systems. **S**mall (1,000 - 10,000 persons) and **V**ery **S**mall (100 - 1,000 persons) communities (referred to herein as "**S**A**V**er**S**") fall into a difficult middle category, and because of their limited capacity, they encounter numerous obstacles to secure funding, implement projects, and operate water infrastructure that meets their needs. Exacerbating SAVerS abilities to meet their needs is climate change. Climate change is increasing the frequency and intensity of hurricanes, underpinning the necessity of resilient water systems (Tejeda R, 2023). During these storms, surface water used for drinking water becomes so turbid that it is unusable, and water systems which are reliant on electricity are rendered inoperable due to electricity outages. Technology that can operate without electricity, has minimal moving parts, and does not require a full-time operator not only helps SAVerS during normal times, but is especially valuable in the wake of natural disasters.

For this project, I worked alongside engineers from Cornell University's (CU) School of Civil and Environmental Engineering (CEE) and AguaClara Reach (ACR), a non-profit organization focused on bringing safe drinking water "on tap" to developing areas (ACR, 2023). Over the past 18 years, ACR has developed resilient water treatment technology, improved Community Water Systems (CWS), and built Water Treatment Plants (WTP) across Honduras and Nicaragua to supply clean drinking water for ~ 100,000 people. While working with the Cornell AguaClara Program, Puerto Rico (PR), a United States (US) territory, was identified as an area with several SAVerS that could benefit from ACR's technology. *This report summarizes my work to learn about the Puerto Rico water landscape, help strengthen connections with potential partners, and assist with a National Science Foundation (NSF) grant application to develop a convergence framework for expediting the implementation of* *equitable water systems. It is my goal that this work will not only benefit SAVerS in PR, but SAVerS everywhere, especially those most impacted by climate change.*

Regardless of whether the NSF grant application is funded, ACR and its partners plan to follow a three-pronged convergence approach when attempting to implement water treatment technology alongside a community. This three-pronged approach focuses on Governance & Finance, Resilient Treatment Technology, and Community Education & Workforce Training. It strives to ensure a community is supported on all fronts to operate and manage a CWS with a quality WTP for the long-term. It works to address the mistakes often made by development practitioners, who introduce technology without considering a community's understanding of their water situation, specific requirements, and willingness and capacity to sustain a CWS indefinitely. *This report provides context for working in PR, a summary of the PR relevant work completed thus far by the Cornell AguaClara Program, and a roadmap for collaborative work to continue for implementing an ACR Plant in PR.*

This report will be useful to any individual working with SAVerS in areas subject to increasing natural disasters due to climate change and looking for appropriate technology. It may be particularly beneficial for engineering students working with AguaClara at Cornell University (CU), Ohio State University (OSU), and the New Jersey Institute of Technology (NJIT) who are involved in optimizing ACR's plant design to comply with U.S. Environmental Protection Agency (EPA) regulations and seeking to be part of the implementation process. An extra implementation challenge present in PR, but not present in Central America, is ensuring technology is able to meet the stricter U.S. EPA Safe Drinking Water Act (SDWA) and Clean Water Act (CWA) regulations. As a former science and engineering student myself, we are often removed from how communities on the ground interact with the technology and the complexities involved in its successful implementation. This report aims to bridge that gap by emphasizing how important it is for communities to understand their water quality and have capacity to implement, operate, and manage a CWS.

2. Background of Water in Puerto Rico

2.1 Demographics & Colonial History

Puerto Rico has a population of 3.2 million people where 99% of the population is Hispanic (U.S. Census Bureau, 2022). Approximately 60% identify as white Hispanic, 11% as African American or Black Hispanic, 10% as multiracial Hispanic, and 19% identifying as “other Hispanic” heritage (U.S. Census Bureau, 2022; Data USA, 2020). PR became a U.S. Territory in 1898 after the Spanish-American war, and like many resource rich regions, it has not escaped the effects of colonialism (Cheatham & Roy, 2022). While PR is under U.S. federal government rule and part of the U.S. financial system, PR citizens do not have the right to vote in federal elections or the ability to file for bankruptcy like U.S. states (Bonillo, 2020). There has been broad racialized neglect of the U.S.’s occupied islands and since becoming a U.S. Territory, PR has been expected to follow U.S. regulations without the same level of support and social systems that U.S. States enjoy (Bonillo, 2020). The Puerto Rican government has been saddled with debt and has petitioned to declare bankruptcy like U.S. states, but instead Congress passed the 2016 Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) (Bonillo, 2020). This legislation authorized restructuring under supervision of a congressionally appointed Oversight Board. The goal of the restructure was to reduce the local government’s budget by initiating austerity measures and decreasing public services (Bonillo, 2020). It was written into the island’s new constitution that “repayment of public debt must take priority over financing public services” (Bonillo, 2020). This injustice results in the inability to allocate funds towards public service delivery and is one of the key hindrances preventing PR from building a robust and resilient water and wastewater network.

2.2 Water Governance & Coverage

The structure of the Puerto Rican government closely mirrors that of a U.S. state. The island is divided into 78 municipalities, each comprised of towns, surrounding areas, and small communities.

A municipality is similar to that of a state county, and every municipality has an “alcade”, a similar authority to a mayor in the mainland U.S. (Opitz-Stapleton, 2008).

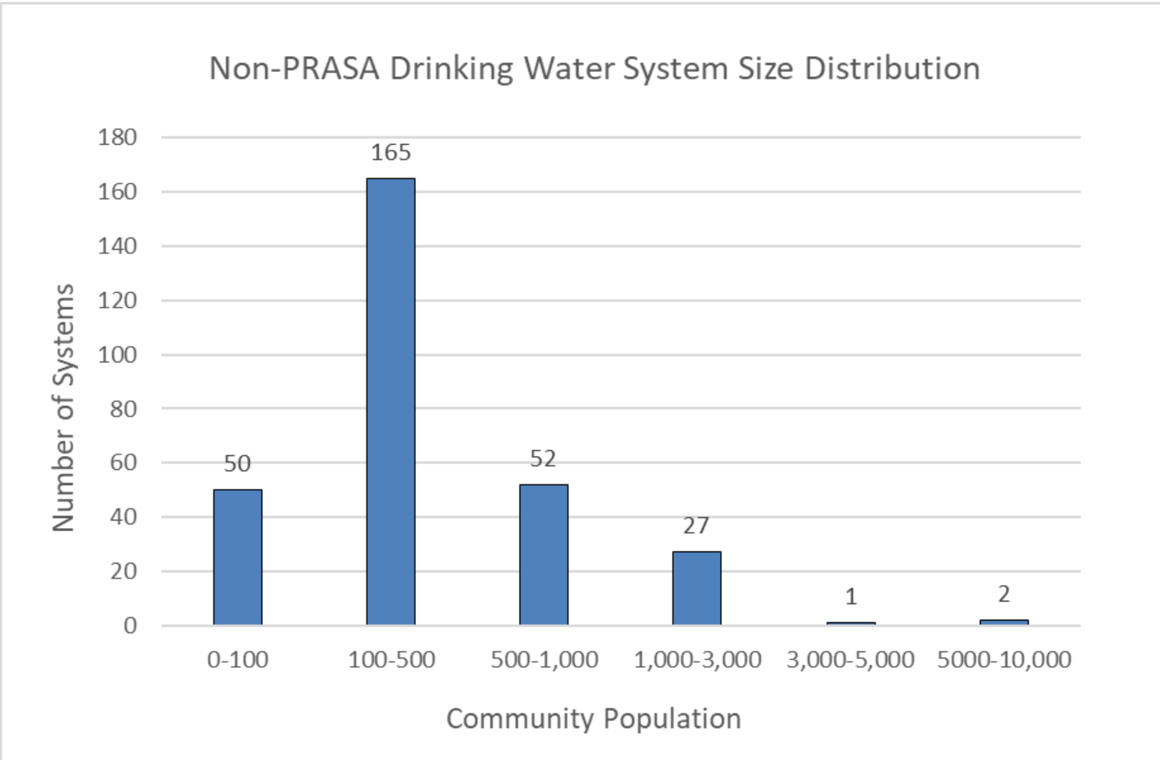
Puerto Rico’s Aqueduct and Sewer Authority (PRASA), previously called Autoridad de Acueductos y Alcantarillados (AAA), is the governmental agency founded in 1945 that manages most of Puerto Rico’s drinking and wastewater treatment (Fiscal Agency and Financial Advisory Authority of Puerto Rico (AAFAF), 2023). PRASA serves 97% of PR’s population with drinking water and almost 60% with wastewater services (AAFAF, 2023). This report predominantly focuses on the 3% of systems not managed by PRASA, commonly referred to as “non-PRASA” systems. All the non-PRASA systems fall under the SAVerS definition.

PR has approximately 413 small or very small drinking water systems (Keenum, 2021), approximately 297 of these are non-PRASA, according to an ongoing EPA Region II study, and serve 136,000 people (data provided through personal communication with Cristina Moldonado at the EPA Region II office). These numbers do not include any systems that have fewer than 15 connections or serve fewer than 25 people because the PR Department of Health (DOH) does not require them to be registered (SDWA, 1996). There are also some non-PRASA systems with over 15 connections that do not want government supervision and are therefore discreetly managed by the community (Arce-Nazario, 2018). Based on conversations with partners in PR, some communities choose not to join PRASA due to a distrust in the government and previous experiences where oversight did not result in needed support but rather fines for noncompliance. Table 1 and Figure 1 provide a data summary from the EPA Region II non-PRASA inventory study entitled “Puerto Rico Community Drinking Water Systems Capacity Assessment Project.” The primary objective of this inventory project is to perform a comprehensive evaluation of non-PRASA community drinking water systems to support potential infrastructure investments and capacity-building initiatives, aid community water systems in attaining and maintaining compliance with federal and state drinking water laws and regulations while enhancing resilience to natural disasters. The data below was provided through personal communication with Cristina Moldonado at the EPA Region II office and the project will not be fully completed until the end of 2023.

Table 1: Non-PRASA Size Inventory Summary

Item	Value	Unit
Total # of Systems Surveyed in EPA study	297	Systems
Total Population Served	135,952	Persons
Smallest Community	17	Persons
Largest Community	7,416	Persons
Greatest Number of Connections	2,767	Connections
Number of Systems using Groundwater	189 (64%)	Systems
Number of Systems using Surface water	105 (35%)	Systems
Number of Systems using Springwater	3 (1%)	Systems

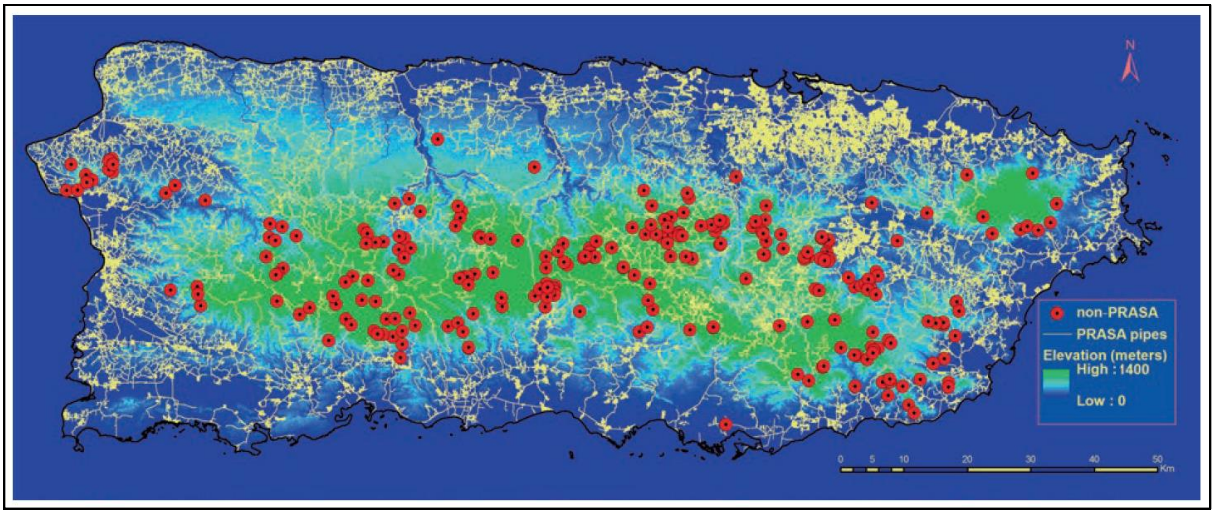
Figure 1: Non-PRASA Drinking Water System Size Distribution



The largest three systems above 3,000 persons are a private university, a U.S. Army base, and a veterans army base. All the non-PRASA systems are part of what the U.S. SDWA categorizes as small public water systems (PWS), those serving less than 10,000 customers (US EPA, 2006). The SWDA further divides PWSs into those providing water to 3,301 - 10,000 persons, 501 - 3,300 persons, and 500 persons or less (SDWA, 1996). This paper considers these systems part of the small (1,000 - 10,000 persons) and very small (100 - 1,000 persons) communities that make up the SAVerS demographic. A list of communities who would be top candidates for ACR treatment technology are listed in Section 5.3.

Many non-PRASA systems exist because the communities they serve are too far away to be easily connected to the PRASA water network (see Figure 2 below). The majority of non-PRASA systems are located in the rural, mountainous, and hard- to-reach areas of PR and operate under collective (community) management. There are other private systems that supply water to industries, hotels, etc. As PRASA infrastructure has grown, more communities have been connected. Some communities have been connected to PRASA and maintain their non-PRASA water supply as well. While others have shifted from PRASA to non-PRASA because they believe the shift will improve their water (Arce-Nazario, 2018). This shifting towards or away from PRASA is a window into the varying beliefs and perceptions Puerto Ricans hold of their government and water. The PRASA system has not been universally accepted. Some non-PRASA communities have chosen not to connect despite it being a relatively simple connection (Arce-Nazario, 2018). Based on discussions with PR water professionals, this hesitation is most likely due to the belief that non-PRASA water is purer than PRASA.

Figure 2: Non-PRASA Locations Vs. PRASA Pipe Networks (Arce-Nazario, 2018, p.468)



Note: "Non-PRASA systems (red dots) and the PRASA major pipe infrastructure (yellow lines). Note that the non-PRASA water systems are mostly located in the mountainous region (green areas in the map), and that many non-PRASA systems are contiguous to PRASA infrastructure. The precise location of non-PRASA points has been slightly altered to preserve the confidentiality of communities" (Arce-Nazario, 2018, p.468).

2.3 Climate Change & Resiliency

As an island territory in a tropical climate, PR has always been vulnerable to tropical storms and hurricanes. However, as hurricanes increase in frequency and intensity due to climate change, PR becomes especially vulnerable (Tejeda R, 2023). Furthermore, Puerto Ricans experience frequent power outages caused by the weak electrical grid regardless of the weather patterns (Bonillo, 2020). PR's climate risk is exacerbated by its 120-year-long colonial legacy. PR has been subject to exploitative practices and policies leading to deforestation, overfishing, pollution, wetland removal, solid waste mishandling, destruction of coastal ecosystems, input-intensive export-oriented agriculture, and mass tourism (Braveboy-Wagner, 2008; Lewis, 2013; Baver & Lynch, 2006). These exploitative practices substantially impact drinking water source quality.

It is important for individuals working on water issues on the island but not originally from PR to truly understand the destruction Hurricane Maria brought to PR in 2017. Hurricane Maria, a category four storm, landed in PR on September 20th, 2017, and "devastated Puerto Rico, causing loss of life, severe flooding, damage to infrastructure, widespread electricity outages, and interruptions in water and wastewater treatment" (Keenum et al, 2021). Over 90% of electrical systems were destroyed, leaving some communities without electricity for more than six months and 80% of the agricultural areas (where SAVerS tend to be located) were left without communication, healthcare, and water. (Lin, 2020; Keenum et al, 2021). The below excerpt is from a study conducted at the Interamerican University of Puerto Rico (IAUPR) that gives a window into the challenges small communities were facing trying to have clean water in their homes post Hurricane Maria.

"System SB1's roughing filters clogged because of increased runoff during the storm, and the source pipeline to the filter site was damaged by the hurricane, preventing use of the slow sand filter ….as the demand increased throughout the day, the water level in the tank dropped below the level of the tablet chlorinator, resulting in distribution of unchlorinated water. System SB2 experienced damage to electrical lines, resulting in the package plant filters being backwashed with source water instead of filtered water…. System GC2…switched to a surface water source when power was lost. After a fatal case of leptospirosis was identified in the community…, support was received from the EPA for a generator to convert it back to solely utilizing groundwater" (Keenum et al, 2021).

This reality emphasizes the need for resiliency in design. After a natural disaster, systems still need to operate to prevent sickness, ideally with as little management, maintenance, and outside materials and labor as possible.

2.4 Funding & Environmental Justice

The poverty rate in Puerto Rico has hovered around 40% for the past several years with the territory's Median Household Income (MHI) being $21,967. Based on census blocks, the MHI of rural non-PRASA system members is $15,085, while the neighboring PRASA system members is $15,946 suggesting that there may not be as much of an environmental justice issue between non-PRASA systems and *neighboring* PRASA systems as some research suggests (U.S. Census Bureau, 2014; Arce-Nazario, 2018). However, the poverty rate in the mainland U.S. is 12% and the median household income is $69,021 which highlights the inequitable distribution of resources and support U.S. mainland states receive versus U.S. Territories. (U.S. Census Bureau, 2022), over double that of PR (U.S. Census Bureau, 2022). The high poverty rates Puerto Ricans experience coupled with the history of disinvestment across the water, solid waste, and power infrastructure sectors impacts communities' abilities to build and fund their own water treatment systems or fix their treatment systems post damage (EPA, 2021). This presents an environmental justice issue where U.S. territories receive less funding and support than U.S. states and yet are required to meet the same standards and regulations for public services like water delivery.

For example, one study highlighting two PR communities (referred to as community A and B for their privacy) found that Community A faced fines for their water not meeting regulations, yet their struggle to comply was due to financial constraints. Community B was told by the DOH that to receive funding to improve their water system, they must first demonstrate their system's effectiveness, which required costly tests. Paradoxically, they lacked the funds to conduct these tests, creating a frustrating loop of financial barriers (Opitz-Stapleton, 2008). This vicious cycle exemplifies the challenges and injustice many communities experience.

During a Small Water System Needs Assessment in February 2019 in PR with non-PRASA community leaders (run by Syracuse University's Environmental Finance Center: Center for Sustainable Community Solutions (SU-EFC: CSCS) found that since Hurricane Maria, participants felt "government agencies have become more aware of the existence of the community aqueducts and instead of providing much-needed assistance, they are more concerned with following regulations and there has been an increase of fines levied" (CSCS, 2019). Most of the money, if not all, to operate non-PRASA CWSs comes from paying community members. This money is often only enough to pay for maintenance and not enough to make any long-term improvements to the system

(Opitz-Stapleton, 2008) and suggests that these fines are another example of injustice. Funding is one of the first and biggest hurdles SAVerS encounter. During the Small Water System Needs Assessment, several issues were identified for SAVerS when trying to access financial resources. The more significant hurdles are listed below; (CSCS, 2019)

- Language (Spanish speaking and writing, rather than English)
- Technology (access to internet and computers)
- Grant writing experience
- Capacity and time to research grant opportunities
- Meeting eligibility requirements of a federal nonprofit 501(c)(3)
- Not holding the land title where the system is located

These issues are compounded by lack of proper dissemination of information by federal agencies. Many federal agencies have programs for low-income communities but make little to no effort to ensure knowledge of these programs. The burden of ensuring this information makes it to the right groups often falls on nonprofits and NGOs.

2.5 Water Quality

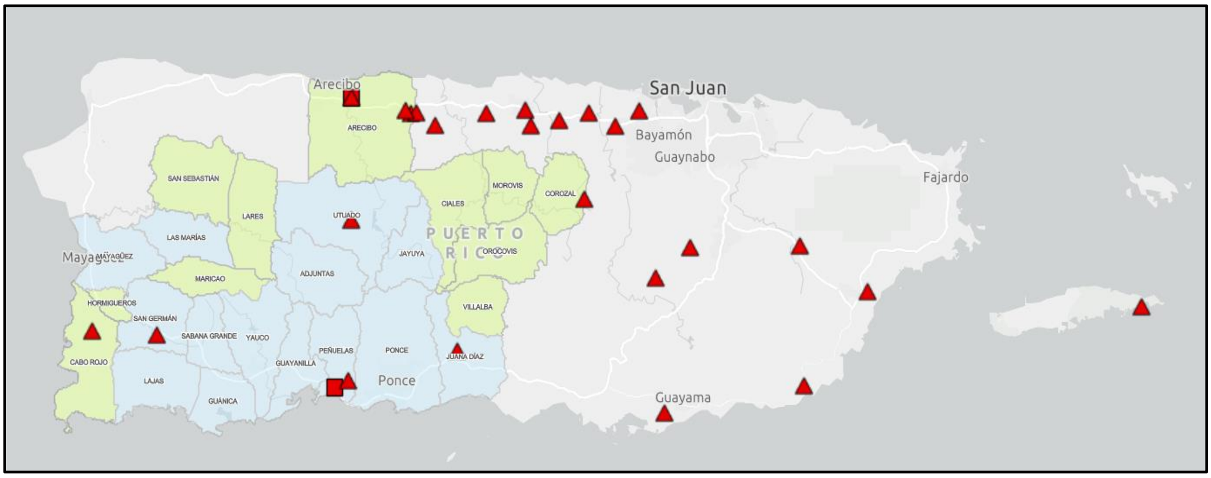
2.5.1 Chemical Contamination

The National Institute for Environmental Health Sciences (NIEHS) PR Test Site for Exploring Contamination Threats program (PROTECT) identified that after Hurricane Maria there were increased levels of turbidity, bacteria count, and concentrations of chlorinated volatile organic compounds (CVOCs) in tap water across PR. These elevated levels suggest potential long-term risks to both the environment and human health (Lin, 2020).

> *"Environmental pollution in PR was extensive even prior to Hurricane Maria, with over 200 hazardous waste sites including 18 active superfund sites primarily contaminated by pesticides, CVOCs, and heavy metals." (Lin, 2020).*

Naturally, this contamination means numerous chemicals are impacting water quality, and the chemicals can spread quite far from the source given PR's several karst aquifers (Warren et al, 2023). It is important to test multiple sources when selecting a community's source water for a treatment facility as standard water treatment often does not remove heavy chemical and metal contamination. Figure 3 below shows the locations of PR's superfund sites. Most of the sites are along the coastlines and most of the non-PRASA systems are inland. However, there are still several sites in the mountains that could be influencing the water quality of non-PRASA systems. When looking for potential communities to partner with to update their water infrastructure, it is important to identify the location of the nearest superfund site.

Figure 3: Puerto Rico Superfund Sites Locations



2.5.2 Microbial Pathogen Contamination

Even water considered to be "untouched" by humans is still subject to contamination from animals. In SAVerS systems, water is often exposed to fecal contamination from animals throughout the watershed and through improperly maintained storage tanks. This situation emphasizes the importance of providing treatment even if the source water is considered to not be impacted by human activity. Furthermore, upstream communities discharge their wastewater into rivers and streams, which flows downhill away from the community producing the waste and becomes part of the downstream community's drinking water source. This is a phenomenon replicated all across the world, and PR is no exception. Only 20% of the world's wastewater is treated, leaving 80% as a consistent pollutant of our freshwater ecosystems (UN Water, 2017). Only 60% of PR's wastewater is managed by PRASA (AAFAF, 2023), and it is difficult to find recent accurate data on how the remaining 40% is managed and how well the PRASA 60% is managed. Over 50% of PR residents have septic systems (Norat-Ramirez, 2018). "There are some 562,000 septic tanks across Puerto Rico, disposing of about 170 million gallons of wastewater daily, versus the 230 million gallons a day flowing into [PRASA's] sanitary sewer system. Most septic tanks were constructed under unregulated conditions, with little knowledge and crude technology, and placed in inadequate areas. Once they start malfunctioning, it is very difficult to make repairs" (Norat-Ramirez, 2018). This situation highlights once again the high probability of drinking water sources containing fecal contamination and the importance of adequate treatment. According to a 2023 press release, PRASA has plans to launch 17 new wastewater projects totaling $534 million (EPA Press, 2023).

2.5.3 Water Perception & Awareness

PRASA vs non-PRASA Perceptions

A hurdle in some rural communities in Puerto Rico is the misconception that source water with "good" visual quality is inherently safe and clean (based on conversations with water professionals in PR). Although there is turbidity at times, clear water is often the norm, misleading people to perceive their water as safe or "untouched". In reality, clear water can still harbor numerous pathogenic protozoa, bacteria and viruses.

A study of four rural PR CWSs revealed that older community members had few memories of any major health issues such as diarrhea or parasitic infections during their childhood (Opitz-Stapleton, 2008). Yet, these observations contrast with studies from their childhood years, which reported widespread (69%) schistosomiasis infections in children in low-income rural communities (all of which these communities would have been at the time) (Pimentel et al, 1961, Opitz-Stapleton, 2008). Two prevailing themes emerged from this study. First, most community members believed their waters to be pristine, especially when compared to PRASA, even if they had heard about contamination in other non-PRASA communities. There is an impression that PRASA water is of lesser quality because it is stored in large reservoirs which people believe to be a breeding ground for bacteria due to stagnant water and high pollution loads, while their water comes from an “untouched” natural source in the mountains (Opitz-Stapleton, 2008). While there are arguments to be made about the quality of PRASA water and the necessary improvements there, it does not negate the need for treatment of non-PRASA waters. This report primarily focuses on improved treatment of non-PRASA waters due to the limited focus they receive from the government. Secondly, community members observed that no one was dying from drinking the water and did not attribute any illnesses to the water, therefore concluding the water must be safe (Opitz-Stapleton, 2008). Nevertheless, there was copper and lead contamination present in one of the community’s source water and *E. coli* in another (Opitz-Stapleton, 2008).

During a brief visit to Puerto Rico, I personally experienced the perception that city water (PRASA) is less safe than inland rural water (often non-PRASA, but not always). In a coffee shop in San Juan, I asked four young adults if they drink the water from the tap. They all said no, but mentioned when they go home (which I clarified was in the more rural areas) they are more comfortable drinking the tap water there. This preference could be due to a belief that the more remote the area, the safer the water, distrust in the government, or turbid water sometimes coming out of the tap in PRASA served areas. PRASA source waters are often at a lower elevation and thus are likely to have more turbidity than most non-PRASA source waters. Perceptions are truly community independent as many non-PRASA communities believe their water is not completely safe. These communities actively sought out alternative water sources, such as bottled water, private wells, or friends with PRASA water (Jain, 2014).

A study involving 602 adults across 15 non-PRASA and 15 adjacent PRASA communities found that self-reported gastrointestinal illnesses were not statistically higher in non-PRASA communities (37%

of adults) compared to PRASA communities (43% of adults) (Arce-Nazario, 2018). This does not diminish the importance of installing water treatment facilities in non-PRASA communities given 37% of adults still reported gastrointestinal illness (Arce-Nazario, 2018). These high numbers highlight the need for water treatment systems for PRASA and non-PRASA that are designed for the context rather than conventional treatment plants that have frequent failures and are too "low tech" to be able to adequately treat the source waters. These numbers also reinforce the difference between the support U.S. territories receive versus the states in the mainland U.S. According to the Center for Disease Control (CDC), 2.7 million Americans get sick from waterborne illness every year or less than 1% of the population (CDC, 2023). This number is likely lower than the real number, and yet is still substantially less than the water disease burden small rural communities in PR experience.

Treatment Perceptions

The most common treatment method in SAVerS systems is simple chlorination (Robinson 2015) and although chlorine can kill up to 99% of all bacteria and viruses, it *does not* kill all protozoa (ex: *Cryptosporidium*) which has been found in SAVerS source water in PR (Robinson, 2015). Additionally, chlorine in high turbidity or high organic matter raw water can produce disinfection byproducts, which include toxic and carcinogenic chemicals. Often consumers are unaware of these chemical and microbiological risks and many communities do not think their water is contaminated or believe that the diarrheal diseases in their communities are caused by unclean water (Appendix A: CU SAVerS, 2023). Turbidity is commonly positively correlated with Dissolved Organic Matter (DOM) and DOM produces disinfection byproducts that can cause an increase in chlorine demand. This process means that the chlorine dose is generally not sufficient to provide any significant disinfection when the turbidity is high, and given that pathogens are particles, it is also likely that the pathogen concentration increases as turbidity increases.

Based on conversations with one of the Cornell AguaClara Program's partners, the Center of Environmental Education and Conservation (CECIA) at the InterAmerican University of Puerto Rico

(IAUPR) in San Germán, many communities believe chlorination is enough treatment emphasizing the importance of community education and engagement. Treatment processes like coagulation, sedimentation and filtration are incredibly beneficial and can remove protozoa like *Cryptosporidium*.

Changing Perceptions

After CECIA's educational interventions in a few small communities in PR, the rate of diarrhea decreased significantly (Hunter et al., 2010). CECIA's work helps to prove how educational interventions are a crucial part in decreasing disease and empowering communities to want to build and maintain their own water systems.

Educational Interventions are essential for helping SAVerS to accurately understand their water quality and the cause of sickness in their communities. A crucial component of the success of well-maintained CWSs is for the community to believe it is necessary for their health. For a community to desire a system, most of its members must understand their water quality and the need for improvement for them to want to invest time, money, and energy into operating a CWS. However, once a community is at the point of wanting to improve their CWS or build a new one, workforce training is still key.

Care should be taken when sharing information with people currently operating a CWS that the water still has contamination because there is often a sense of pride in the water system and substantial effort has already been invested in trying to provide clean water to their community. Types of educational interventions that have proved successful in PR and workforce training are described further in sections 4.3.2. and 5.4.

3. Resilient Systems Technology (AguaClara)

3.1 AguaClara Background

The AguaClara program was founded by Dr. Monroe Weber-Shirk in 2005 at Cornell University as a student-based research program to address the drinking water technology gap for small cities and towns. Twelve years later, AguaClara Reach (ACR) was established as a nonprofit organization. Over the past 18 years, the AguaClara program (led by ACR since 2017) has designed 24 plants that deliver safe, reliable “water on tap” to ~ 100,000 people (ACR Project Sites, 2023). All 24 WTPs are still operating well. There are 21 plants in Honduras, 3 in Nicaragua, and a few smaller systems in India. Locations and information about each plant can be found on ACR’s website.

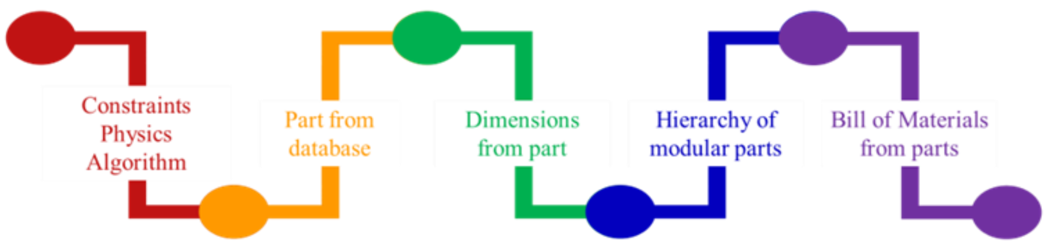
The ACR plants are designed to run on gravity to avoid reliance on grid electricity. Students from project teams at Cornell University (CU), Ohio State University (OSU), and New Jersey Institute of Technology (NJIT) continue to work on projects to improve the treatment efficacy. ACR is looking to expand into PR and has recently applied for a National Science Foundation (NSF) Convergence Accelerator Grant underneath the “Equitable Water Solutions” Track with CU’s CEE, SU EFC’s CSCS, and IAUPR’s CECIA. The partners in this grant application are discussed further in Section 4.3. Whether this grant is successful or not, the Cornell AguaClara Program and ACR will use the partnerships and connections created prior to the grant and through the application process to further work in PR.

In ACR, teams involved in innovation and implementation are purposefully kept separate from the funding source to enable community members, plant operators, implementing engineers, researchers, and inventors to be allies in searching for the best solutions (Appendix A: CU SAVerS, 2023). ACR believes this strategy is a key factor in its success. Community members feel more comfortable giving honest feedback to personnel who are not responsible for securing funding for the community’s system improvements. ACR develops high quality designs (Section 4.2) and acts as the intermediary between finance institutions and Implementation Partners (IPs). A high caliber and reliable IP is crucial for the long term operation and maintenance of a treatment plant. IPs can be construction firms, government water ministries, NGOs/non-profits. More information about standards for IPs and potential IPs in PR is discussed in Section 5.2

3.2 Description of AguaClara Plant Design & AIDE

A more detailed description of how the typical ACR plant is designed and operated can be found on ACR's website and even further detailed design information is free and available through ACR's "Physics of Water Treatment Design" online textbook (ACR, 2023). One element of ACR that sets them apart is their AguaClara Infrastructure Design Engine (AIDE) for drinking water treatment systems. AIDE provides open-source designs for flow rates between 3 and 80 L/s (~1,000-50,000 people) and "continues to improve with advances in understanding of the physics of water treatment and with evolution in manufacturing techniques" (ACR AIDE, 2023; Appendix A: CU SAVerS, 2023). Users can input parameters such as desired flow rate and AIDE will create detailed 3D Onshape® models of drinking WTPs for communities with populations between 1,000 and 50,000, complete with a detailed CAD design and bill of materials. The constraints are integrated into the AIDE unbroken design algorithm to generate the documentation needed for fabrication of the WTP parts which helps to expedite piloting and scaleup (ACR AIDE, 2023; Appendix A: CU SAVerS, 2023). Figure 4 below shows the unbroken design algorithm AIDE follows.

Figure 4: Unbroken Design Algorithm (pioneered by ACR using the Onshape® platform that enables rapid prototyping of designs over a wide range of flow rates and given different constraints)



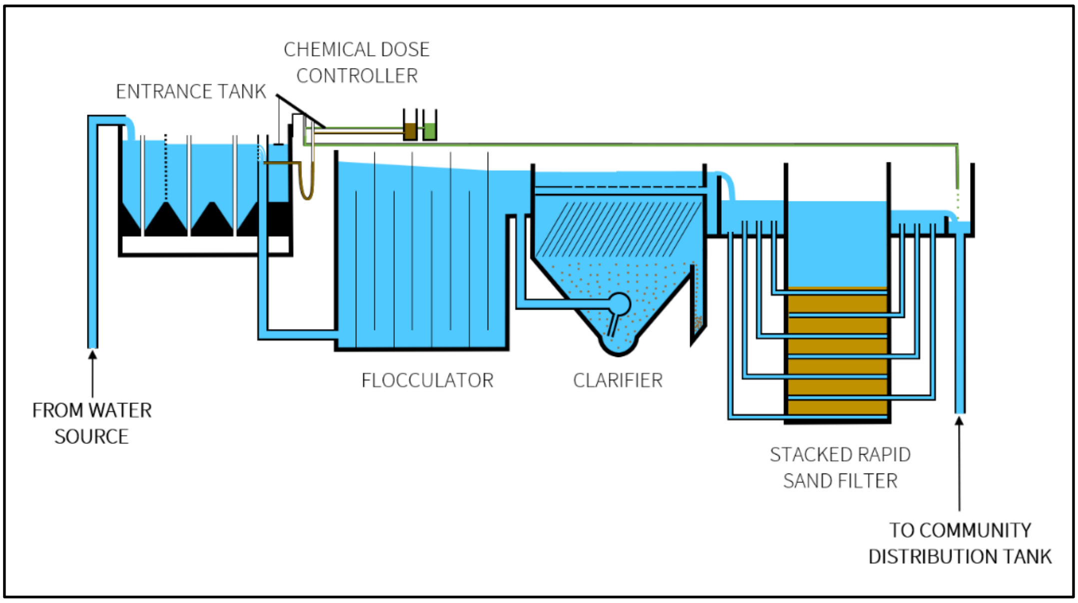
Guiding constraints are listed below.

- Tap water fit for human consumption
- Low cost of capital
- Low O&M costs
- Reparability by operators
- No proprietary parts/patents
- Easy to operate and monitor
- Designed for operator comfort
- Few moving components
- No need for electrical power.

AIDE is an immense benefit to communities because it substantially reduces the time required for communities to know what they need to purchase and decreases the amount of necessary expensive engineering design. Architectural, structural, and site-specific design are still necessary, but it provides a mechanism for feedback to efficiently be incorporated into future designs.

A small, generalized design summary is provided below for ease of reference. The design is like that of a standard WTP, but components that normally require electricity, do not. For example, a standard WTP would use a sensor to measure an influent flow rate which would send a signal to a small pump to dose coagulant, where the ACR Chemical Dose Controller uses a linear flow orifice meter, a float, a lever and linear resistance dosing tubes to dose coagulant and chlorine. Additionally, a conventional mechanized WTP uses powered "mixers" for flocculation, but the ACR plant uses a series of baffles to not only avoid using power but to minimize moving parts. Figure 5 below is from ACR's website along with the list below describing each component.

Figure 5: AguaClara Plant Treatment Process Schematic



- **Entrance Tank:** Tank that removes trash and grit and then measures the flow through the water treatment plant with a linear flow orifice meter.

- **Chemical Dose Controller:** Semi-automated, flow-pacing chemical feed system for coagulant and chlorine.
- **Flocculator:** High-rate and high-efficiency baffle flocculator with a 10-minute residence time, high-uniformity velocity gradient, and no moving parts.
- **Clarifier:** Unit process that contains the floc filter and plate settlers. The floc filter has a 10-minute residence time and provides enhanced particle removal, improved flow distribution to the plate settlers, and removes sludge from the clarifier with no moving parts. The plate settlers have a 15-minute residence time and are fabricated from generic polycarbonate sheets and are located above the floc filter in the clarifier.
- **Stacked Rapid Sand Filter:** High-rate filter that has a residence time of less than one minute. It is six times more compact than conventional rapid sand filters, does not use any large valves, and is self-cleaning without requiring any pumps.

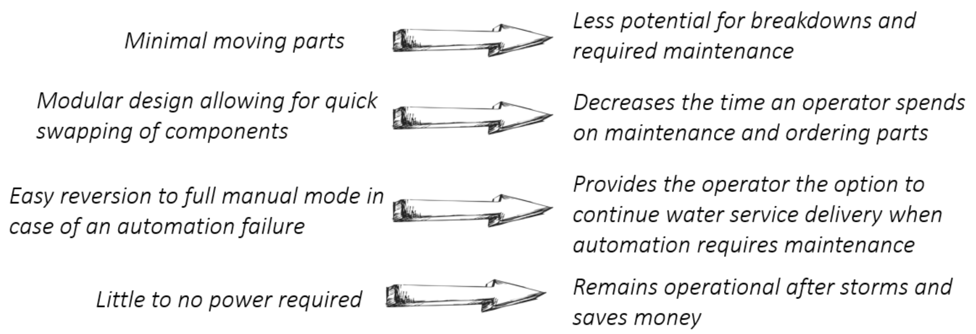
3.3 Alignment of AguaClara Design with Puerto Rico Needs

AguaClara's design aligns well with the needs of numerous small community run systems, including non-PRASA communities in PR. As mentioned before, after natural disasters in PR, it takes up to six months in some areas for electricity to be restored (Keenum et al, 2021). Puerto Ricans already experience frequent power outages caused by the weak electrical grid, and having a plant that requires little to no electricity is incredibly valuable (Bonillo, 2020). The Central American ACR plants range in size from 1 L/s to 120 L/s, using the design criteria of about 3mL/s per person. Central American communities larger than about 1,000 people are able to support a full-time water operator. Water infrastructure for very small communities (<1,000 people) must be able to operate without requiring a full-time operator as most communities of this size do not have the funds to pay a full-time employee. These numbers are anecdotal and should be expected to vary slightly based on location. Current ACR WTPs can treat water for communities with populations down to approximately 1,000 persons. Therefore, engineering students working with AguaClara at CU, OSU, and NJIT are working on the ACR plant design to enable it to better serve communities with less than 1,000 people while adhering to SWDA regulations and to require less time from an operator.

To gain EPA approval, ACR needs to show their technology can meet SDWA regulations. The current ACR plant design implemented in Central America met Honduras's turbidity standard of 5.0 Nephelometric Turbidity Units (NTU), however the SDWA requires more than an order of magnitude greater particle removal of 0.3 NTU (EPA, 2001, Potable Water and Sanitation Sector Framework Law, 2003). Engineering students are working to obtain greater particle removal with ACR technology. One of these projects is being conducted with the Cornell-AguaClara Program and is described in Section 4.2. The Cornell-AguaClara Program is overseen by Dr. Ruth Richardson, professor of Civil and Environmental Engineering at Cornell University.

Plants for SAVerS need to be able to dose coagulant and chlorine without an operator present. ACR is in the process of creating a semi-automated dosing algorithm using a sensor that only requires the bare minimum amount of inputs to be able to vary chemical doses for treatment (Du et al 2019), and this is already being tested at pilot scale. The sensor will require power, but a very minimal amount, and should not noticeably increase the cost of operation. Figure 6 below provides a summary of the main ways to simplify the design and how it helps the operator and community.

Figure 6: Benefits of Simplified Design



ACR's treatment system and many small treatment systems struggle to address industrial chemical contamination. Given the presence of over 200 hazardous waste sites in PR (Lin, 2020), it is important for the implementation teams' source water assessments during the exploratory phase to test for these types of contaminants to prevent the use of an unsuitable water source. The hazardous waste sites are primarily concentrated near the coast, and most of the non-PRASA systems are located in the inland mountainous areas. In cases where a water source, whether groundwater or surface water, is unavailable due to heavy chemical or metal contamination, the community needs to collaborate with the DOH and the EPA to pursue environmental remediation.

4. Cornell & AguaClara Research in Puerto Rico

In development work, it is common for researchers and students to engage with local communities over time, take advantage of hospitality, and often provide little to any improvements in SAVerS drinking water quality and access. The AguaClara approach is to not work directly with communities, but instead to work with a well-respected local partner organization as an equal, respected partner.

The goal of the following section is to inform future research students about the previous and ongoing small scale water systems research project that Cornell and AguaClara have been conducting focused on Puerto Rico. This recent focus on PR mostly began in 2019. The below sub-sections start with earliest work to the most recent. This information is meant to prevent redundancies and to assist students in creating more thoughtful project designs by building on existing work. As it is not feasible to list all the on-the-ground initiatives and organizations besides Cornell and AguaClara working to improve SAVerS in PR, it is very important for students looking to start a project to conduct their own research on existing programs to prevent overlap or to potentially create more meaningful partnerships. Additionally, there is a wealth of technical engineering design research that has been conducted by ACR students not specifically related to PR but related to optimizing small-scale water treatment for vulnerable communities.

4.1 The Engaged Cornell Grant: Sustainable Water Treatment Technology for Puerto Rico Communities

The first research project initiative was to bring a smaller version of the currently implemented ACR plants to an unattended community in Puerto Rico. Dr. Richardson and Cornell students made a connection with Dr. Graciela Ramirez-Toro at IAUPR and traveled to PR during April of 2022 to learn about existing small water systems and assess potential locations for an implementation. Through this project, Dr. Richardson along with the students made many of the connections that enabled the ongoing work today. The project team visited four communities suggested by Dr. Ramirez-Toro: Caguas (near San Juan), Yabucoa, Maricao, and San German. From these visits, they determined the next logical step would be to further collaborate with Dr. Ramirez-Toro to set up a pilot plant in San German at IAUPR while continuing to explore "EPA and DOH regulations for bringing new drinking water technology to Puerto Rico as well as funding streams to pay for them" (Wang & Sundaravadhanam, 2022). One regulation identified was turbidity which the subsequent project related to PR has focused on and is described in Section 4.2. Additionally, identifying funding streams and installing a pilot plant is a substantial component of the NSF Convergence Accelerator Grant ACR recently applied for and is described in Section 4.3.

The second initiative was to create a mapping application for water quality monitoring. This was done in conjunction with Surfrider's Blue Water Task Force. Google forms were created so that surface water quality monitors could use their mobile phones to scan a QR code and upload information about the water system. This information would automatically populate a spreadsheet, be sorted, and displayed in "Geo-Sheets". The display has potential to be very helpful to see surface water quality across PR, however the project is in its very beginning stages. To truly create a robust map with a lot of data, a partnership with the EPA Region II would be necessary to input water test results data.

4.2 NSF Partnerships for Innovation - Technology Transfer (NSF-PFI-TT): Bringing Open-Source Innovation and Resilient Hydraulic Designs to Municipal Drinking Water Treatment Infrastructure

Co-Principal Investigators, Dr. Ruth Richardson and Dr. Monroe Weber-Shirk, were focused on smart automation for this grant because non-powered automation can be vital in water treatment technologies in a tight labor market where operators are scarce. The research team designed and implemented automated control of an AguaClara pilot plant within CU's WTP on campus to develop and investigate physics-based algorithms for coagulant dosing. The work will be published; demonstrating the ability of very small-scale systems (serving less than 1,000 people) to treat source water to EPA's turbidity standards of 0.3 NTUs (EPA, 2001; Appendix A: CU SAVerS, 2023). Collaborations from this work are partially responsible for Cornell's ability to take lead on applying for the NSF Convergence Accelerator Grant.

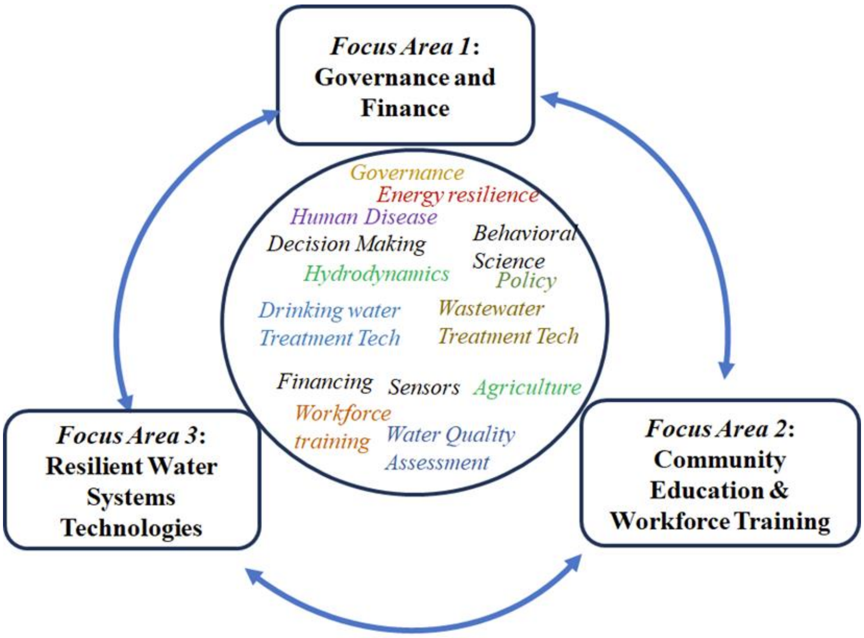
Additionally, a Cornell graduate student has traveled to PR to work with IAUPR students to conduct sanitary surveys for local water systems to assess how well they meet U.S. federal regulations for water. The aim of this project is to gain a better understanding of PR's source water quality and to quantify the amount of pathogenic viruses and fecal indicator viruses in raw water samples sourced from small water systems around PR. Sanitary surveys are being performed on cisterns and surface water sources in various locations. This data will be compared with levels of other pathogens such as *Salmonella*, *Cryptosporidium*, and *Giardia* in the same water samples. Their goal is to assess the extent of viral removal from source water to tap water within the existing rural, small-scale drinking water systems. This work will help identify where there are gaps in the current systems, determine if a small pilot plant with ACR technology can bridge those gaps, and ideally lead to the construction of technologically sound small-scale community drinking water treatment systems.

4.3 NSF Convergence Accelerator Grant: Water for Small And Very Small Systems (WaterSAVerS), A Convergence Framework for Equitable Water Systems Deployment

The work I did throughout 2022, including attending the CECIA-IAUPR Biennial Symposium on Potable Water Issues in San Juan, PR in February 2023 strengthened my understanding of the issues facing SAVerS in PR and my ability to assist in structuring the NSF Convergence Accelerator grant proposal. Even if we are unsuccessful in obtaining funding through this NSF funding stream, the principles of how to approach implementation of water systems and serve SAVerS in the long-term remain true and will assist in any future work regardless of the funding source.

Three Focus Areas (FAs) were identified as the main hurdles SAVerS face when building and maintaining a small drinking water system; Governance and Finance, Community Education and Workforce Training, and Resilient Water Systems Technology. These FAs align with general global development accepted issues. Figure 7 below shows the FAs in the outer ring, with all the required disciplinary knowledge that must be converged to enact real change in the inner ring. *Sections 4.3.1 – 4.3.4 summarize from the grant proposal what needs to be done within each focus area to develop a cross focus area framework for rapid deployment of SAVerS water systems.* The engagement, research, critical thinking, and design detailed below shows what must be considered when taking a holistic approach to improving a community's relationship to their water, especially on an island that has long seen underinvestment and been overlooked by the U.S. federal government.

Figure 7: Focus Areas for Proper Implementation of Small Pilot Plant with AguaClara Tech in PR



4.3.1 Governance & Finance

The lead on this portion of the grant is Syracuse University's Environmental Finance Center: Center for Sustainable Community Solutions (CSCS). CSCS "enhances the administrative and financial capacities of state and local government officials, nonprofit organizations, and private sectors to make change toward improved environmental infrastructure and quality of life (SU EFC, 2023)."

CWSs are less likely to access public funding and financing (Hansen and Hammer, 2022). In rural remote regions, not all water board members have computers and training on how to find funding sources and submit an application (CSCS, 2019). As a compounding factor, funding information from the U.S. government is often in English and many Puerto Ricans do not speak English. This is a task CSCS can assist communities with and is often the most vital part of helping a community build their own infrastructure. Organizations often do a poor job of ensuring marginalized communities are made aware of funding sources for infrastructure improvements, therefore hindering communities' ability to provide adequate and safe water services.

“In many cases, volunteers from the community directly manage water resources, operate small systems, or perform managerial or administrative functions.”

Traditional water funding sources used for building new or maintaining water infrastructure include:

- Public grants and loans
- Public programs that fund water infrastructure or State Revolving Loan Funds (usually funneled through the CWA and SDWA)
- Community Block Development Grants
- Water rates, taxes, and fees paid by residents or customers using the water service
- Various sources from the U.S. Department of Agriculture
- Bipartisan Infrastructure Law (BIL) (CSCS has a commitment to increasing access to BIL funds as a regional Environmental Finance Center)

To improve financing for SAVerS, CSCS plans to gather community and local expert perspectives and expand the research team to include water coalitions, industry groups, or practitioner networks that can offer direct insight on the existing organizational pathways and interventions commonly used to pursue funding and finance opportunities for SAVerS.

Since PR is the case study location for this grant, “CSCS will prioritize practitioner experts, such as the independent PR water systems operators group, OSAN [Non-PRASA Aqueduct Systems Organization], with lived experience or strong backgrounds in fields of environmental justice, environmental racism, and participatory action research” (Appendix A: CU SAVerS, 2023). This work will enable CSCS to identify the optimal most reliable funding streams for SAVerS in PR and develop policy recommendations for improving funding sources and access.

4.3.2 Community Education and Workforce Training

CECIA has worked with small potable water systems in Puerto Rico since 1993 and has conducted several studies about the best community education and training practices for SAVerS systems. This work has decreased diarrheal rates in a few communities and has provided successful training where community members have gone on to obtain their operator license (Hunter et al., 2010). CECIA plans to build on this work as part of the NSF Convergence Accelerator Grant.

CECIA also plans to interview administrators and operators of SAVerS systems to gather information about the needs that each community has. They will use this opportunity to update demographic information and structural information about the systems to investigate how these communities changed after a series of natural disasters that occurred in PR since 2017, which includes strong hurricanes, earthquakes and the COVID19 Pandemic. During their visits, they will provide educational and informational material about water quality and the health risk associated with improper system management. CECIA's educational interventions will include holding a workshop where at least one representative from each of the non-PRASA SAVerS systems on the island is invited, and participants will have the opportunity to listen to invited speakers and do hands-on activities designed so allow them to show their individual and collective needs, while demonstrating the importance of water quality.

Additionally, CECIA plans to visit regulatory agencies like the DOH and EPA to gather more robust information about the regulatory issues of these systems. After this work, they hope to update their previous educational strategy and offer courses to interested participants in water quality, monitoring, health risks, system management, and technology for resilient systems capable of going back to operations soon after intense weather events and natural disasters.

Lastly, the importance of biological and chemical water quality testing and its affordability and accessibility for SAVerS systems is often overlooked. CECIA has already developed and delivered training materials for onsite low-cost fecal indicator bacteria testing and has performed certified pathogen testing for a wide range of protozoal, bacterial, and viral pathogens and harmful algal blooms. The team will summarize up-to-date knowledge of rapid onsite or regional testing methods for biological and chemical water quality monitoring, focusing on *low-cost*, *on-site*, and *easy-to-use* tests. Additionally, they will also summarize state-of-the-art in rapid, affordable eDNA based quantification methods for viral, bacterial and protozoal pathogens as well as Antibiotic Resistance Genes (ARGs).

4.3.3. Resilient Water Systems Technology

Although a plethora of engineered solutions are available for water and wastewater systems, few of them are designed specifically to meet the needs of SAVerS. The grant application detailed the previously explained AguaClara design and design engine (AIDE), how it was unique, and if awarded the grant how design research would continue into cost effective "fit for purpose" sensing and integrated water and wastewater management.

4.3.4 Deliverables

The team (CU, SU-CSCS, IAUPR CECIA, ACR, and partners) broke down the work into clear deliverables which will come together to create a **Cross-Focus Area Framework for Rapid Deployment of SAVerS Water Systems**. The team believes a comprehensive detailed framework for CWSs between 100 to 1,000 and 1,000 to 10,000 people does not exist, and this tool can be used for many SAVerS in developing regions (not just Puerto Rico), especially those more affected by natural disasters and climate change. The initiatives and deliverables described above and detailed in Appendix A - Section E are a good example of high-quality development practice that is needed to ensure the longevity of a CWS.

5. Implementation of a Small-Scale Water System in Puerto Rico Utilizing AguaClara Technology

There is no guarantee that there will be funding to fully develop the Cross-Focus Area Framework. Regardless, by utilizing best practices and leaning on the partners who helped to develop what needs to be done for a holistic framework, ACR and the Cornell AguaClara Program hope to move forward with implementation. The below sections detail how this could be accomplished using ACRs proven implementation strategy with quality implementation partners and the in-depth knowledge CECIA and CSCS have of the water systems on the island.

5.1 Governance & Compliance

Where ACR operates, it is important for the country and local governments to support community-run water systems because all ACR plants are managed by the community. In some areas, governments only support government or private company control of water sources and systems. Puerto Rico is supportive of CWSs as long as they meet the U.S. SDWA regulations.

Ensuring compliance with the U.S. SDWA can be challenging for SAVerS. Adhering to the comprehensive sampling schedule and relying on volunteers and limited funds can set communities up for failure, because each contaminant comes with specific testing intervals and detailed sampling procedures. The fact that not all samples can be processed at the same labs and cost more money than customer tariffs can support adds additional complexity. Due to these complexities, numerous non-PRASA communities opt out of conducting the necessary sampling and do not send test results to the EPA and DOH.

Table 2 below outlines the sampling that a CWS must conduct and submit to maintain compliance with the SDWA. The table does not capture all of the details such as variations in intervals based on contaminant levels and does not summarize initial testing requirements for new systems. Instead, it provides an overview of the sheer amount of sampling SAVerS need to manage and the amount of work that is often requested of volunteer operators and community water boards. More detailed information and quick reference guides about each rule can be found on the EPA website (EPA Office of Water, 2015).

Table 2: Water System Compliance Monitoring Summary

Drinking Water Rule	Summary of Sampling Requirements
Arsenic Rule	GW systems every 3 years SW systems annually
Groundwater System Monitoring Rule	Requires daily sampling for E.coli, enterococci, and coliphage
Interim Enhanced Surface Water Treatment Rule	Requires daily turbidity monitoring
Long Term 1 Enhanced Surface Water Treatment Rule Long Term 2 Enhanced Surface Water Treatment Rule	Can require sampling for *Cryptosporidium* every two weeks. Requires additional monitoring requirements based on the type of treatment system
Lead and Copper Rule	Requires sampling every 6 months for lead and copper (unless CWS qualifies for reduced sampling)
Comprehensive Disinfectants and Disinfection Byproducts Rule (Stage 1 & 2)	Requires quarterly and annual monitoring depending on system size and source water type for trihalomethanes and haloacetic acids
Total Coliform Rule	Requires up to 10 samples per month for a system of 10,000 people for E. coli and total coliforms
Radionuclides Rule	Most often requires sampling for various radionuclides every 3 to 9 years based on contaminant levels
Additional Requirements	
Consumer Confidence Report Rule	Requires all CWSs to prepare and distribute a brief annual water quality report summarizing information regarding source water, detected contaminants, compliance, and educational information
Filter Backwash Recycling Rule	Requires systems that recycle water to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state
Small Systems Record Keeping Rules	Details for how many years the community must hold on to sampling test results.

When capacity building within a community interested in managing their own CWS and building a treatment plant with ACR technology, substantial effort needs to be invested into working alongside community volunteers to simplify the sampling requirements, make the materials available in Spanish, and connect them to the appropriate labs. Cornell AguaClara Program and ACR volunteers can partner with CECIA to accomplish these tasks and utilize CECIA's existing training materials for many of these tests and can assist in the development of remaining ones.

Before any treatment system is built, the technology must be approved by the EPA for effectiveness, ensuring that the plant design can successfully treat typical PR source water to meet the EPA's final plant effluent standards.

5.2 Implementation Partners

To move forward, ACR must find an implementation partner (IP). These partners can be construction firms, government water ministries, NGOs, or non-profits. An IP for ACR must have the following capabilities alongside a quality reputation in the water sector.

- Community education and engagement
- Design and build
- Commitment to the water sector in that region (10 year minimum)

In Central America, Agua Para El Pueblo (APP) has been the IP for all 24 of ACR's plants. APP offers a whole suite of services. They assist in community education and engagement, operator training, design and build, fabrication, and ongoing maintenance. Based on conversations with Dr. Graciela Ramirez-Toro, director of CECIA at IAUPR, and Dr. Melitza Medina, CECIA associate researcher, PR does not currently have an equivalent to APP. One option to overcome this is to use several groups working together to provide the same services as APP. Below is a summary of how this could work.

- **Community Education & Engagement & Operator Training:** CECIA has extensive experience in community engagement, education, and operator training. Additionally, if more support is needed CSCS can offer support if funding is available.
- **Design:** ACR's AIDE substantially reduces the amount of time for design, and ACR volunteers and staff could take on more of the detailed design than usual given the smaller plant size.
- **Fabrication**: APP could fabricate the plastic internal components in Tegucigalpa, Honduras and ship them to PR. If APP is unable to fabricate the hydraulic components, Cornell AguaClara Program and ACR volunteers will need to find a company in PR or in the mainland U.S. to manufacture them and ship them to PR.
- **Construction:** Although ACR has not done it this way previously, a standard construction firm could be hired for the building of the actual plant if funding is available. There is potential for APP to provide onsite supervision if they can obtain the proper visas. If they are unable to, members from one of the potential partnership organizations in Table 3 below, such as OSAN, could provide on-site supervision or an ACR volunteer or staff member.
- **Maintenance:** Several non-PRASA communities successfully complete their own maintenance. When a system is too complex, a breakdown is often when a system falls into disrepair. This risk can be mitigated by proper operator training, succession planning, and minimizing the number of parts that are prone to failure. Another risk is when an operator is fully trained and receives their certification. The operator is now eligible for higher paying jobs with larger systems and could leave the community for a different opportunity. With a small ACR plant in PR, a community member may be able to operate the system with only a few hours every other day, enabling that community member to maintain their other work.

Additionally, the AguaClara Cornell program has already begun developing partnerships with organizations working to assist SAVerS in PR and have experience in small-scale water treatment.

These partners are summarized in Table 3 and these relationships can be grown to further assist in the implementation process.

Table 3: Small-Scale Water System Partnerships for AguaClara Implementation in Puerto Rico as of October 2023

Organization	Knowledge Area(s)
Center for Environmental Education, Conservation and Research (CECIA) Inter American University of Puerto Rico (IAUPR) *Academia* (Contact: Melitza Crespo-Medina; Graciela Ramirez-Toro)	Applied and environmental microbiology; water quality (microbial and physicochemical) monitoring; human health impacts; water and sanitation interventions; environmental education; small community education
Syracuse University Center for Sustainable Community Solutions (CSCS) / Environmental Finance Center (EFC) *Academia* (Contact: Melissa Young; Tess Clark; Kaira Fuentes)	Community and environmental planning; infrastructure finance, qualitative and community-based research methods, rapid needs assessment, civil and environmental engineering, asset management, climate adaptation and island resilience
University of Puerto Rico at Mayaguez (UPRM) *Academia* (Contact: Chris Papadapoulos)	Engineering, sensing, and emerging contaminants
Non-PRASA Aqueduct Systems Organization (OSAN) *Non-profit* (Contact: Miriam Matos)	Small and very small scale and resilient water systems, water system operators, **local community water perspective**
Cornell Center for Public Administration (CPA) *Academia* (Contact: John Foote)	Sustainable Infrastructure administration
NY and PR Water Resources Institutes (WRI) *Government* (Contact: Brian Rahm)	Integrated water system perspective (including small scale systems)

Syracuse University: College of Engineering and Computer Science *Academia* (Contact: Elizabeth Carter)	Remote sensing, computational hydrology
Rural Community Assistance Partnership Solutions (RCAPS) *Industry*	Rural housing and infrastructure planning, funding, and capacity building
United States Environmental Protection Agency Region II (USEPA) *Government*	Water system compliance, needs assessment, non-PRASA system inventory development
United States Environmental Protection Agency (USEPA) - Small Drinking Water Research Group *Government*	Small scale water system technologies, knowledge of EPA funding structures
Cornell Civil and Environmental Engineering *Academia*	Water and wastewater treatment and nutrient recovery

5.3 Implementation Locations

The ACR plant is designed to run on gravity, and only needs approximately 1.5 meters of elevation drop throughout the plant to operate. Although there is not a special requirement for how water is delivered to the entrance tank of the plant, ACR prefers surface water sources to avoid pumping. Using a groundwater source means reliance on pumps and even if they are solar powered, they have many more moving parts and susceptible to breakdowns, increased maintenance, and higher costs. For these reasons, a handful of the 189 non-PRASA systems using groundwater may be interested in switching to surface water if an appropriate surface water source is identified. For areas where a gravity system is not an option, work must be done to optimize the required pumping. There are 99 communal non-PRASA systems using surface or spring water. These are listed below in Table 4. The first eight listings, highlighted in a darker gray, are communities with populations over 1,000. Exploring these communities would be an excellent initial step in narrowing down potential implementation locations since ACR's designs are currently better suited for communities over 1,000. However, as research continues to optimize ACR's plant serving less than 1,000 and to decrease the amount of necessary operator intervention, the feasibility of implementing with the other community sizes increases. Additionally, mapping the locations listed below and determining if any are close enough together and if the topography is suitable could open the possibility of building a larger system serving multiple, closely situated, very small communities.

Table 4: Non-PRASA Surface & Spring Water Community Run Water Systems

SYSTEM NAME	TOWN	REGION	POPULATION
ACUED. COM. BO. QUEBRADILLAS	BARRANQUITAS	EAST	1,751
ACUED. BO. GUAYABOTA	YABUCOA	EAST	1,608
COM. RANCHO GRANDE	NAGUABO	EAST	1,555
ZAMAS	JAYUYA	NORTH	1,400
ANON CARMELITA	PONCE	SOUTH	1,200
COPAR	COROZAL	NORTH	1,120
PERICHE	SAN GERMÁN	WEST	1,100
COREA METRALLA	PEÑUELAS	SOUTH	1,000
BO. QUEBRADA ARRIBA	PATILLAS	SOUTH	840
ASOCIACION ACUEDUCTO MULAS JAGUAL, INC	PATILLAS	SOUTH	652
ACUEDUCTO COMUNAL SAN JOSE	PEÑUELAS	SOUTH	600
LIJAS	LAS PIEDRAS	EAST	596
ACUED. COMUNAL COMUNIDAD CAÑABON ABAJO	BARRANQUITAS	EAST	563
BAYAMONCITO	AGUAS BUENAS	EAST	536
BO. REAL	PATILLAS	SOUTH	522
COM. CACAO - LA SAPIA	OROCOVIS	SOUTH	510
COMUNIDAD SANTA BARBARA	JAYUYA	NORTH	500
VACAS II	VILLALBA	SOUTH	500
VACAS III	VILLALBA	SOUTH	500
SANTA ROSA	JAYUYA	NORTH	460
ACUEDUCTO COMUNAL ELADIO ANDREU INC.	COROZAL	NORTH	450
CIUDAD EDUCATIVA DR. ROQUE	YABUCOA	EAST	440
SANTA BARBARA II	JAYUYA	NORTH	424
GUARAGUAO	YAUCO	SOUTH	420
ACUED. RURAL PEDRO CALIXTO	CAGUAS	EAST	402

DAMIAN ABAJO	OROCOVIS	SOUTH	400
EL MALTILLO	PEÑUELAS	SOUTH	400
ACUED. LOMAS DEL VIENTO - MAIZALES	NAGUABO	EAST	400
ACUED. RURAL SECT. EL VEINTE	YABUCOA	EAST	387
PORTILLO - MIRAMAR	JUANA DÍAZ	SOUTH	383
HACIENDA RULLAN	UTUADO	NORTH	340
VISTA ALEGRE	VILLALBA	SOUTH	340
ALTURAS DE COLLORES	JAYUYA	NORTH	320
CORPORACION PRO SALUD Y MEJORA	PEÑUELAS	SOUTH	320
APEADERO	PATILLAS	SOUTH	320
ACUEDUCTO COMUNIDAD BO. RUBIAS	YAUCO	SOUTH	312
VILLA BLANCA	VILLALBA	SOUTH	306
VEGUITA	UTUADO	NORTH	300
ACUEDUCTO LA ESTANCIA, INC.	UTUADO	NORTH	300
GUARAGUAO	JUANA DÍAZ	SOUTH	300
SERVICIO DE AGUA	PONCE	SOUTH	300
SISTEMA DE AGUA ROOSVELT ROAD	CEIBA	EAST	300
ALTURAS PIZA	JAYUYA	NORTH	280
SALTOS CAGUANA	UTUADO	NORTH	280
LOS BARROS	GUAYAMA	SOUTH	275
SIERRITA	VILLALBA	SOUTH	268
BARCELONA	RÍO GRANDE	EAST	260
COMUNIDAD CHORRERAS	UTUADO	NORTH	240
LA CASCADA MILAGROSA	UTUADO	NORTH	240
FINCA CARBONELL	UTUADO	NORTH	240
QUEBRADA HONDA	GUAYANILLA	SOUTH	240
PANDURA	PEÑUELAS	SOUTH	240
ACUEDUCTO COMUNAL SECTOR SANTA PASCUAS INC.	PONCE	SOUTH	240
MACANEA / ESPINO	SAN LORENZO	EAST	224
COM. RIO PIEDRAS	SAN GERMÁN	WEST	220
ASOCIACION ACUEDUCTO REVENTON	ADJUNTAS	SOUTH	212
VECINOS COMUNIDAD LUIS LEBRON	CAYEY	EAST	193
QUEBRADA ARENAS	MAUNABO	SOUTH	180
LA CUESTA	COAMO	SOUTH	172
ACUED. DE LA COM. EL DUQUE	NAGUABO	EAST	172
CUBUY-MARINES	CANÓVANAS	METRO	150
EL TESORO	PONCE	SOUTH	135
VEGUITAS GRIPIÑAS	JAYUYA	NORTH	130

PELCHAS	GUAYANILLA	SOUTH	120
LAS MESAS	PONCE	SOUTH	120
SISTEMA DE AGUA CACAO	YAUCO	SOUTH	120
VILLODAS	MAUNABO	SOUTH	120
ACUED. COMUNIDAD 18	SAN LORENZO	EAST	120
LA PRIETA CENTRO	COMERÍO	EAST	116
ACUED. CANABON SECT. EL PARQUE	BARRANQUITAS	EAST	113
LA JULITA	VILLALBA	SOUTH	108
LOS BARROS MARIN	PATILLAS	SOUTH	108
COMUNIDAD JUAN DIEGO	FAJARDO	EAST	103
ACUED. COMUNAL QUEBRADA FRIA	UTUADO	NORTH	100
SECTOR LAGUNA	LAS MARÍAS	WEST	100
COMUNIDAD EL FRIO	OROCOVIS	SOUTH	100
SISTEMA DE AGUA MATUYAS BAJO	MAUNABO	SOUTH	88
FINCA LOS GARCIA	CANÓVANAS	METRO	84
LOS VAZQUEZ	GURABO	EAST	80
ACUEDUCTO LA MONTANA INC.	YAUCO	SOUTH	75
ACUEDUCTO RURAL SAN JOSE (SPRINGWATER)	NARANJITO	NORTH	70
SIST. RURAL GRAULAO	UTUADO	NORTH	64
ACUED. LA GRAMA	UTUADO	NORTH	60
COMUNIDAD MENDEZ	SAN GERMÁN	WEST	60
TALANTE	MAUNABO	SOUTH	60
ACUED. DELGADO Y OTROS	CAGUAS	EAST	60
COMITE RESIDENTES SEC. BELLEZA	PEÑUELAS	SOUTH	58
CERROTE	YAUCO	SOUTH	58
VIVI ABAJO	UTUADO	NORTH	57
PALOMAS II	COMERÍO	EAST	47
LA CARMELITA	PONCE	SOUTH	38
ACEITUNA II	VILLALBA	SOUTH	37
ACEITUNA III	VILLALBA	SOUTH	36
SISTEMA CRUZ LEON	MAUNABO	SOUTH	30
HACIENDA PLANELL (SPRINGWATER)	LARES	NORTH	25
PLT. MUNICIPAL CAROLINA	CAROLINA	METRO	25
ACUED. COM. EDEM	SAN LORENZO	EAST	25
JEA QUALITY	COROZAL	NORTH	25
FINCA WILLIAM LUGO (SPRINGWATER)	UTUADO	NORTH	19

** Data was provided through personal communication with Cristina Moldonado at the EPA Region II office.*

The team at CECIA will be key when selecting a community to work with for implementing an ACR plant, because they have worked with and visited numerous non-PRASA communities over the past 30 years. Additionally, the EPA team completing the non-PRASA inventory study at EPA Region II will also be a quality resource for the AguaClara Cornell Program and ACR volunteers and staff to learn of more interested communities. Factors for narrowing down locations are listed below.

- There is a surface water source where existing treatment is insufficient
- The water source does not have heavy industrial chemical contamination
- There is an interested community willing to operate a new or upgraded CWS with ACR technology (See section 6.4)
- That same community does not want to be connected to PRASA

Beyond initial data gathering (Table 4), this project did not focus on assessing specific locations. Creating a short list of potential implementation locations is identified as the most logical next step in Section 6. IAUPR in San German, PR was highlighted by CECIA as a possible location for a very small demonstration ACR plant to enable community leaders to come and see how the plant operates.

5.4 Community Fit & Education

A WTP that meets the requirements of the surface water treatment rule will have more treatment steps than a simple chlorination system and therefore require more operation and maintenance from the community. Consequently, a crucial component to the success of CWSs using a more complex plant is community engagement. For the implementation to be a success, the community must want a new or upgraded water system.

Dr. Weber-Shirk and the ACR team found it was easier to aid Honduran communities because they recognized the need for treatment based on their very turbid and brown source water. Many operators and members of water boards within a CWS volunteer their time without any financial compensation, which underscores the need for people to believe a new or improved system is necessary. In Honduras, people believed diseases in their communities (e.g., diarrhea) were caused by unclean water, and were therefore willing to put effort into building, funding, and operating an AguaClara WTP. As discussed previously, since the source water in PR is often clear, this presents a challenge as some believe clear water means pure water.

One educational approach previously used by CECIA involved home visits where they would provide families with petri dishes containing fecal bacteria growth medium and fill them with their home tap water. CECIA then asked the family to monitor the samples and report back in a few days any signs of bacterial presence. Naturally, many of the petri dishes grew bacteria. This method was a non-confrontational way of showing individuals their water quality without explicitly advocating their need for enhanced water treatment (personal communication with Dr. Graciela Ramirez-Toro).

Another inexpensive and impactful educational method used by the Peace Corps involves a practical demonstration. Educators take four clear plastic water bottles, fill one with clean water, one with water and salt, one with water and sugar, and one with water and cinnamon or another visible spice. Participants are invited to choose which bottle they would prefer to drink from and take a sip. Follow-up questions posed to the participants include "Which water bottles look clean? Is a clean looking one always actually pure? How does this translate to our lives?" The objective of this activity is to prompt individuals to reflect on their own household water quality. The conversation then naturally transitions into discussing various contaminants such as germs, fecal particles, amoebas, worms, and other illness-causing substances that may exist in water that appears deceptively clean (Peace corps, 2023).

In PR, various organizations are already actively engaged in educating the local population about healthy water and sanitation practices. For instance, Project HOPE initiated a WASH program in the aftermath of Hurricane Maria. The program involves traveling to hard-to-reach areas and teaching residents about clean water and sanitation practices. It may be beneficial to explore collaboration with Project HOPE and similar groups operating in PR. Sharing information between the ACR implementation team and these organizations will help catalog areas they have visited and worked with to prevent overlap and gain knowledge about the water situation in that area.

If and when ACR extends into PR, they will collaborate with CSCS and CECIA to build upon existing educational and awareness programs. After these interventions, an assessment will be used to determine the level of community interest and capability in adopting an ACR plant. The assessment will determine whether there is a water treatment operator available or if there are community members willing to enroll in operator training and be certified. If the community is not interested after various educational interventions, ACR will redirect its focus to a different community.

Workforce training is vital for the community to operate a WTP after it is built even if the operation is quite straightforward. Training must include how to follow the complex sampling procedures and reporting requirements. ACR and its implementation partner will provide training in the specifics of operating an ACR plant and the required SDWA sampling. CECIA has experience in administering operator training and could potentially fill this need if multiple IPs are required. Previously, CECIA met with CWSs' management committees, operators, administrators, and volunteers. Through these meetings, interested members enrolled in CECIA's professional certification program for operators and administrators of small potable water systems. The program offered courses for system operators and administrators that provided a basic understanding of the physics, chemistry and engineering principles behind the safe operation and maintenance of a potable water system (Hunter et al., 2010).

5.5 Funding

There are several options for obtaining funding to pay for a project like the construction of an ACR plant in a non-PRASA community. However, the process for identifying these options and navigating the application process can be challenging, especially for small rural communities without access to computers and reliable internet. One barrier to SAVerS' ability to apply on their own is that most of the information is in English, and many Puerto Ricans living in the more rural regions of PR only have a basic understanding of English. Unfortunately, the challenge of ensuring all the information is available in Spanish is primarily a U.S. federal government policy issue. To overcome this hurdle, volunteers can use web translation services if necessary, but ideally work with partners to translate the most important information.

Much of the below information was gleaned from meetings and conversations with SU CSCS staff who have worked for several years with SAVerS in PR to obtain funding for upgraded water systems. The water operator and community water board must be included in the application process for funding to encourage ownership of their water system and to equip them to pursue funding for future projects and maintenance. It is important for the Cornell AguaClara Program and ACR staff assisting with implementation to ensure the community knows who to reach out to and partner with when applying for future grants after the implementation of an ACR plant.

In the workshop held by CSCS in February 2019, non-PRASA water operators indicated that their preferred kind of assistance for learning about water systems and financing is in-person one-on-one assistance and personalized training (CSCS, 2019). CSCS and CECIA (with support from the Cornell AguaClara Program and ACR) as part of the NSF Convergence Accelerator grant will be able to provide this preferred type of assistance. In the absence of the grant, under the current U.S. presidential administration, many EFCs have funding for employees to provide technical assistance to SAVerS pursuing grants (SU EFC, 2023). In the absence of the grant or available funding, it may be the Cornell AguaClara Program and ACR staff driving the grant and funding application process with support from CSCS. CSCS partners with OSAN, Rural Community Assistance Partnership Solutions (RCAPs), and EPA Region II when pursuing funding.

The following list details various funding streams and provides information when considering each option. For non-PRASA systems, CSCS usually starts with local funding through the PR government or municipalities. Federal funding for non-PRASA systems is seen as the last option because of the complexity involved in applying for these grants and the amount of reporting required while using the funds and systems must be registered as a 501(c)(3) nonprofit.

- PR Local Government Funds
  - Preferred by non-PRASA and is often the first stop for PR SAVerS water systems
  - Easier applications than U.S. federal funds, information is often provided in Spanish, and there are fewer reporting requirements
- US Department of Agriculture (USDA) Grants: Predevelopment Fund (USDA, 2023)
  - Grants are available to help low-income communities who are pursuing rural development water or waste disposal projects
  - Rural areas and towns with populations of 10,000 or less are eligible (i.e. SAVerS)
  - Most state and local governments, nonprofit organizations, and federally recognized tribes can apply
  - One of the top options for non-PRASA infrastructure projects for CSCS
- State Revolving Funds (PR DOH, 1999)
  - Often used for major infrastructure upgrades and improvements
  - Not as applicable for non-PRASA systems as they have a very detailed application process. Non-PRASA systems can qualify for these, however they have to prove they have the technical, managerial, and financial capacity to administer these grants, which can be a barrier
  - Although not public, several non-PRASA CWSs can qualify as well as some non-public transient systems and private systems. However, communities and organizations need to apply to receive the right designation, which can be complicated.
  - Often more successful if applied for by the PR municipality on behalf of the non-PRASA CWS

- Community Block Development Grants
    - Can be used to upgrade or develop public infrastructure
    - In 2020, $8.3 billion was allocated to PR for CBDG Mitigation. These funds are for "high-impact activities that mitigate disaster risks and reduce future losses." Water infrastructure that can be resilient in times of natural disaster can qualify for this funding (PR CDBG, 2023).
- Bipartisan Infrastructure Law (BIL)
    - These federal funds are still quite hard to access. Although CSCS has a commitment to increasing access to BIL funds as an EPA-EFC, the center is currently not pursuing this funding for non-PRASA CWSs because of the difficult application process and the amount of reporting required by the community.
- Water rates, taxes, and fees paid by residents or customers using the water service
    - Water tariffs are usually not enough to cover a new WTP or significant upgrades. Instances where water rate collections are usually used are when a grant does not give an amount but rather a percentage of the total project cost (i.e. 75%), and the community can cover the rest (25%).
    - It is important to note that it may not be worthwhile for the community to contribute the remaining 25% if they have not had an opportunity to visit an AguaClara treatment plant and talk with community leaders in an AguaClara treatment plant community. However, if the funds available cover 100% of the cost, they may be more open to installing a system without first-hand knowledge of how that system will perform. Even when applying for funds that cover 100% of the cost, the CWS administrators must be part of the application process so they feel a sense of ownership of the system.

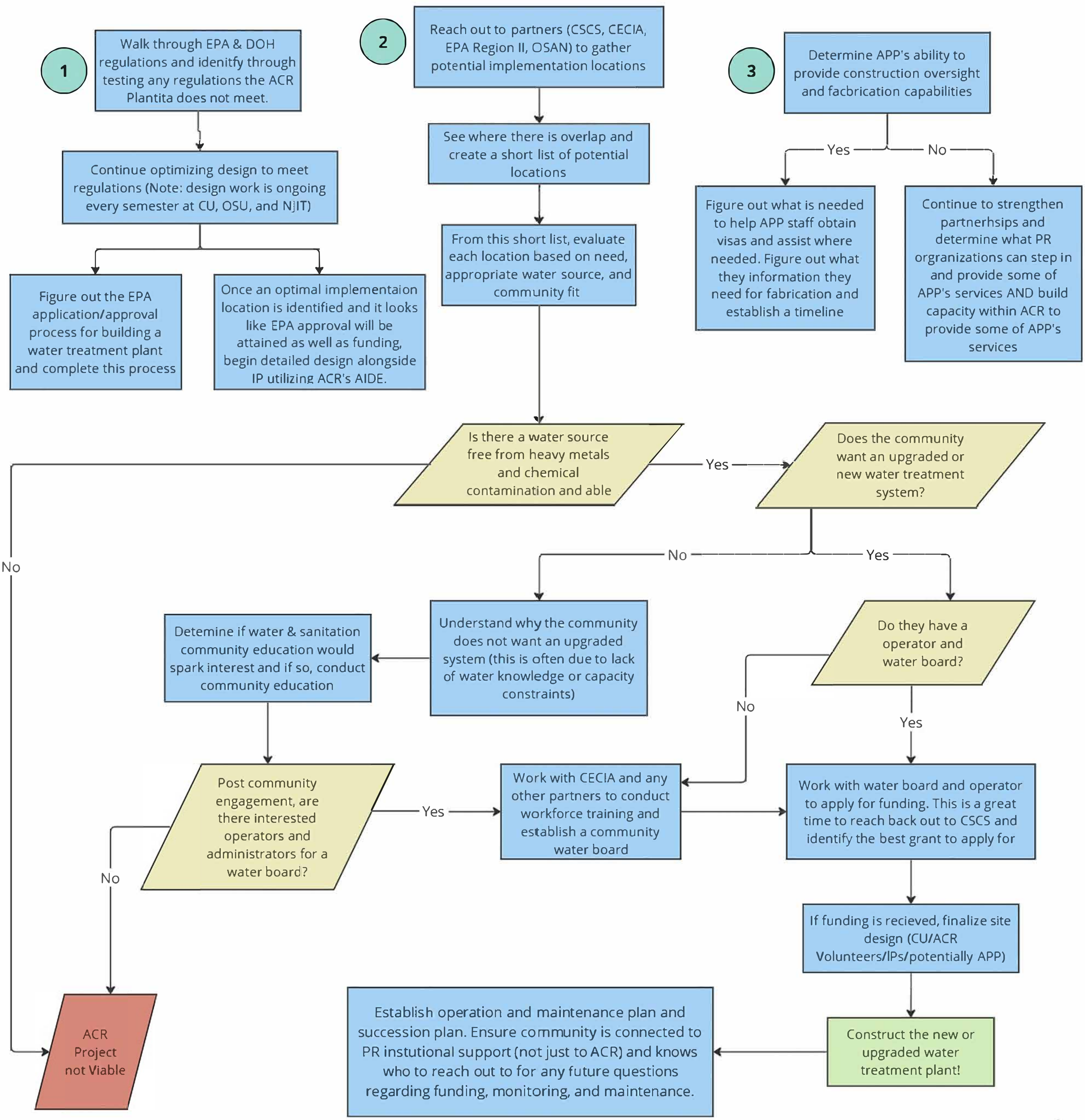
Lastly, loans are often not helpful in development work, especially for water. It is very difficult for communities to charge enough money from their small community to pay back the loans, pay for sampling and testing, perhaps pay an operator, and pay for maintenance on the system. Loans often cause communities to take on debt they will never be able to repay, where grants enable communities to upgrade or launch their CWS from a more secure financial position.

6. Next Steps

Pursuing a location, assessing APPs capacity, and optimizing design are all steps that can happen simultaneously. Figure 8 is a generalized project map showing potential next steps for implementing an ACR plant in a non-PRASA community. The steps shown are for those who want to assist ACR in implementing resilient water treatment technology in Puerto Rico.

Figure 8: Potential Next Steps for ACR Water Treatment Technology Implementation for non-PRASA/SAVerS in PR

Potential Next Steps for ACR Water Treatment Technology Implementation for non-PRASA/SAVerS in Puerto Rico



It is my hope that the above information and project diagram will enhance the understanding of Puerto Rico's water landscape and how to aid non-PRASA SAVerS in improving their water systems without compromising their autonomy. It aims to demonstrate good development practice and how to holistically implement a quality water treatment system by addressing the educational, technical, and funding needs of SAVerS.

A crucial step identified in Figure 8 is to establish a succession plan and an operation and maintenance (O&M) plan. Many development projects make little effort to ensure how a community elects or finds a new water operator or water board members if the current operator or board members leave their positions. It is imperative that the community water board has institutional support. The previously mentioned, OSAN and RCAPS, are two nonprofits who assist small communities across Puerto Rico that the communities could be connected to throughout the implementation process to provide institutional support. Ideally this support would come from the DOH, but some communities may prefer a NGO or nonprofit that can work as a liaison between the water board and the below project partners to provide technical assistance.

- Manufacturers for when they need a replacement part
- Engineers/Designers for when a potential improvement is identified
- The organization that helped build the treatment plant for future construction or expansion
- The organizations that helped secure funding for future grant applications
- The organizations that trained water board members on how to operate the plant and conduct all required sampling for when there is a transition between personnel or questions
- Labs for sending the samples for analyses consistent with EPA and DOH compliance

Organizations who assisted in the implementation of the WTP must schedule regular check-ins in the years following the plant's initial launch and establish internal succession plans (i.e. who checks in if the original employee on the project moves to a different company). This internal due diligence ensures continuous support and guarantees effective monitoring of operations. This flow of communication and support is vital for the long-term sustainability of the project.

7. Conclusion

Empowering U.S. Territories to thrive as prosperous and vibrant regions is an essential undertaking, especially in light of the historical mistreatment and disinvestment they have endured. These territories are not just land to be owned for resource extraction, but rather are integral components of the United States, and deserve equitable treatment and freedom from debt. Helping communities rebound and mitigate the repercussions of detrimental practices that impact their lands and waters embodies a transformative and restorative effort vital for genuine justice. My hope is that others share this conviction and dedicate themselves to this work.

Finally, concentrating on the frequently neglected SAVerS is a strategic avenue to foster equitable development across the entire island. Access to clean water or “safe water on tap” is often the first step out of poverty. Clean water means less sickness, fewer missed days of school and work, better education and jobs, better opportunities, and a higher quality of life.

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Appendix A: National Science Foundation Grant Application

- Cornell University: Department of Civil and Environmental Engineering
- InterAmerican University of Puerto Rico: Center for Environmental Education, Conservation and Research
- Syracuse University: Environmental Finance Center - Center for Sustainable Community Solutions
- AguaClara Reach

NSF Convergence Accelerator Track K: Water for Small And Very Small Systems (WaterSAVerS) - A Convergence Framework for Expediting Equitable Water Systems Deployment

A. Objectives and Significance of the Proposed Activity

Safe water is not equitably distributed. Small, disadvantaged communities especially in disaster prone regions lag behind other community types in achieving water security. Our project focuses on Small and Very Small communities (SAVerS) as they are often: excluded from sampling programs for emerging pathogens and other contaminants, overlooked by non-governmental organizations (NGOs) and governmental bodies, located in remote and/or disaster prone regions that require heightened resilience due to the escalating impact of climate change, lack capacity to apply for available capital funding streams, and lack funding to support a full time operator for water treatment facilities. There is substantial funding through the Bipartisan Infrastructure Law (BIL) for water infrastructure projects and they represent opportunities to implement holistic systems that consider wastewater management as well.

The United States (US) Safe Drinking Water Act (SDWA) categorizes small public water systems (PWSs) as those serving less than 10,000 customers. They are further divided into those serving 3,301 to 10,000 persons, serving 501-3,300 persons, and those serving 500 persons or less. SAVerS potable water supply systems around the world typically serve remote, underserved populations, which are most at risk from waterborne illness due infrastructure that wasn't designed to reliably deliver safe water given the constraints of limited capacity to operate and maintain their systems (US EPA 2006; Hunter et al. 2010; Crespo-Medina et al., 2020). These systems are usually excluded from comprehensive sampling campaigns to evaluate the prevalence and occurrence of pathogens, toxic chemicals, and emerging contaminants, due to the perception that they represent a smaller risk because they serve a lesser population at any given time (Crespo-Medina et al., 2020). However, SAVerS represent a large number of systems around the world. In the US and its associated territories, it is estimated that there are over 148,000 SAVerS water systems, serving approximately 39 million consumers (Hunter et al., 2010); this number includes publicly owned and community systems.

Despite the substantial improvement to water and sanitation access for vulnerable populations over the past several decades, many of the 148,000 SAVerS continue to struggle to build and maintain resilient and effective water and wastewater systems. NGOs tend to focus on household level treatment and water systems for communities with populations less than 1,000 persons. Central governments tend to focus on large scale treatment plants for cities where the centralized systems using conventional technologies are sufficiently reliable. This dynamic causes SAVerS to be caught in the middle between household level water treatment/processing and large city systems (e.g. >10000 persons). Our team will focus on this often-overlooked middle range (1,000-10,000 persons) as well as very small systems (<1,000 persons). Figure 1 below shows the crucial niche in which our team will be operating.

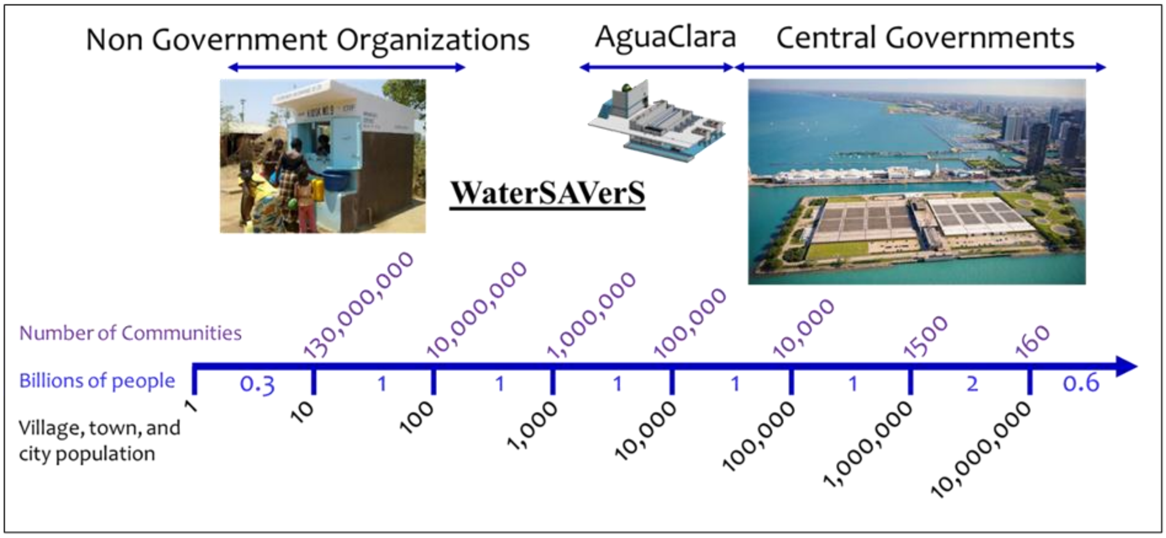

Figure 1: Ranges of community size and approximate number of communities and number of individuals served. WaterSAVerS will focus on a framework for safe water systems in overlooked and underserved communities. AguaClara has advanced the frontier of sustainable water treatment plants for communities as small as 1000 people. WaterSAVerS will push that frontier further by another factor of 10.

Poor water sanitation and hygiene access is exacerbated for small and rural communities prone to natural disasters which face climate uncertainties including changes in storm frequencies and precipitation patterns. Within the US, tropical territories like PR and the US Virgin Islands (VI) are prone to hurricanes and floods and have an ongoing need to increase their resilience during and after these events. Power outages after hurricanes can last for weeks and thus the ability to operate off-grid is imperative for water supply systems. The increased frequency of high intensity rainfall means that water supply systems must be designed to handle high turbidity events.

Federal funding for water infrastructure has dramatically expanded since the Bipartisan Infrastructure Law was passed in 2021, but these increases in federal funding will not fully cover the needed investment. The funding gap will likely persist unless we improve local capacities, system efficiencies, leverage private capital, and introduce system-wide policy changes that address systemic inequities in our funding programs (ASCE, 2021). Access to funding and financing is a persistent barrier for SAVerS. Federal funding programs disproportionately fail to reach small and nonwhite communities. Small or "non-PRASA" (Puerto Rico Aqueduct and Sewer Authority) systems in PR struggle to meet eligibility requirements for federal loans in part due to the complexity of financing eligibility, regulations, and paperwork. In some circumstances—particularly in terms of disaster response and recovery— federal programs can exacerbate economic disparities (Howell, 2018). A majority of water infrastructure funds are also distributed as loans, not grants, through state-administered revolving fund programs, which advantage larger communities with the capacity to leverage or take on debt. Innovative technologies, funding and financing streams are needed to address water inequities.

The barriers to equitable and resilient safe water in SAVerS are technological, socio-economical, geo-political, cultural, and educational. An interdisciplinary approach is required to create a long lasting impact. Our team will converge experts in sustainable water systems engineering and governance, water treatment designs (drinking water and wastewater), water quality monitoring, capacity building, and implementation and monitoring of community-supported water systems interventions. The team represents academics, nonprofits, and government-associated agencies. Figure 2 shows the variables that will vary among the focus communities.

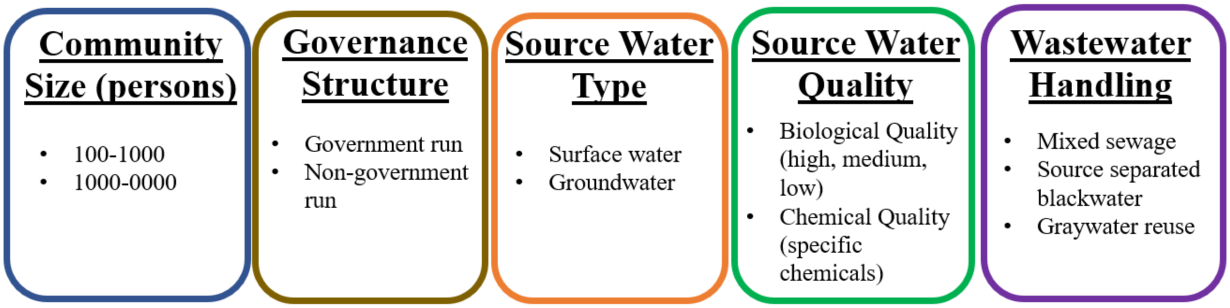

Figure 2: SAVerS-relevant variables to consider in our framework

Key constraints for SAVerS include lack of funding for both capital and operating costs or knowledge of potential funding sources, lack of knowledge and awareness of the impacts of low water quality and quantity on human and ecosystem health, lack of high performing technologies that are easy to maintain, undependable electrical grids, and limited supply chains. Our team will use an Exploration, Constraint Identification, Innovation, Demand Creation, Decision Making and Implementation approach (www.sswm.info) to establish a practical framework that facilitates advances in technology, funding, community education, capacity building, and the implementation of "fit-for-purpose" technology. This framework aims to explore the current needs and constraints of SAVerS in order to develop resilient and comprehensive water infrastructure.

Our framework will converge disciplinary knowledge and local community leaders to:

- Address lack of funding through mapping funding sources and structures and creating a network between communities to share knowledge
- Provide opportunities for capacity development of managers and operators about the production of safe drinking water by improving operation and management and system performance
- Create an educational strategy tailored to the common and actual needs of these communities while raising awareness about the poor water quality within the community
- Identify the deficiencies of available technologies for resilient SAVerS systems
- Use the community requirements for success to develop the design constraints for community friendly infrastructure

The impact of our proposed project extends beyond its focus on island communities in Puerto Rico, by applying more broadly to other communities facing issues developing holistic water systems within the United States and beyond.

B. Convergence Research

Our team's activities and network building will revolve around three Focus Areas (FAs) of convergence (Figure 3): FA1. Governance and Financing; FA2. Community Education and Workforce Training; and FA3. Resilient Water System Technologies. Each FA is discussed below.

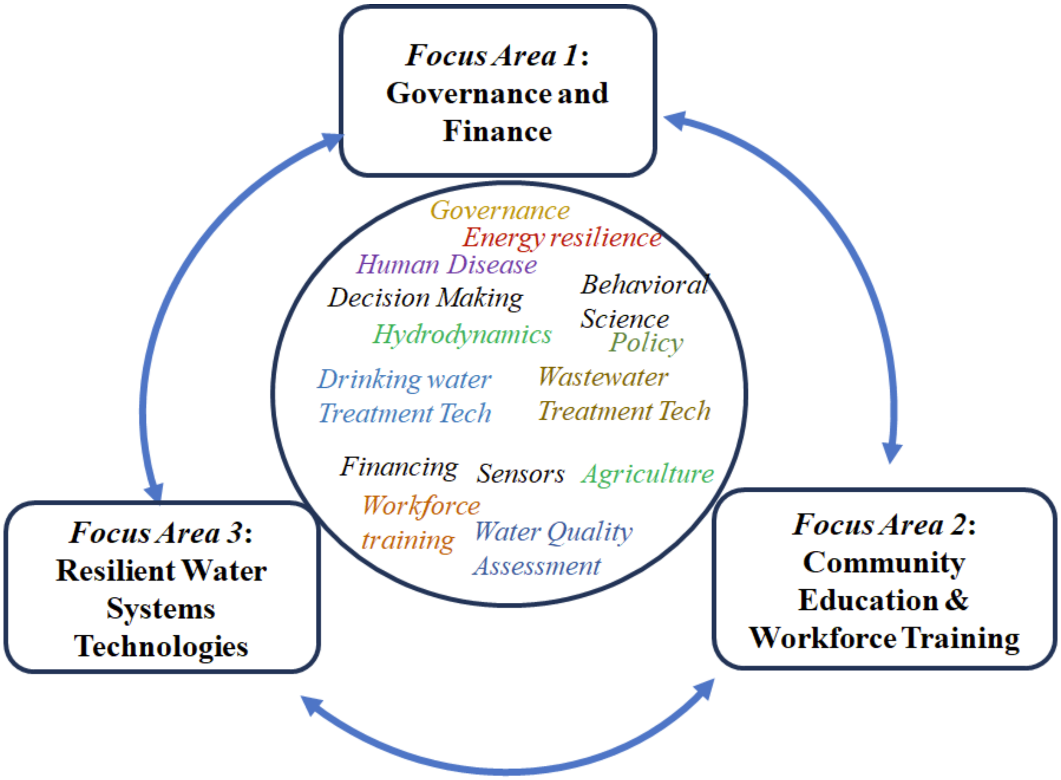

Figure 3: Overview of the three convergence Focus Areas (outer ring) and the disciplinary knowledge areas to be converged (inner circle).

B.1 Focus Area 1: Governance and Financing (Lead: SU-CSCS)

There is considerable diversity in the governance arrangements and structures for SAVerS. SAVers play a vital role in providing access to clean water and are often organized by community groups operating under democratic principles. Like community-based organizations (CBOs), SAVerS may be formal or informal, performing various functions related to water resources management (Bennett & Satterfield, 2018). In many cases, volunteers from the community directly manage water resources, operate small systems, or perform managerial or administrative functions. Traditional water funding and finance mechanisms include public grants and loans, often used for major infrastructure upgrades and improvements as well as water rates, taxes, and fees paid by residents or customers for the purpose of maintaining and providing water service. Public programs that fund water infrastructure originate from the Clean Water and Safe Drinking Water Acts, including state administered revolving loan funds, Community Block Development Grants (which can be used to upgrade or develop public infrastructure) and various sources from the U.S. Department of Agriculture. Systems administered by community members are less likely to access public funding and financing (Hansen and Hammer, 2022). These systems often need help to secure resources for infrastructure improvements, which can hinder their ability to provide adequate and safe water services to their communities.

Under FA1, led by the Syracuse University Environmental Finance Center CSCS, team members will draw upon disciplinary knowledge including but not limited to 1) funding and finance expertise; 2) applied technical assistance experience and 3) application of community-of-practice and collaborative governance principles to inform the convergence of equitable water solutions that fully addresses the financial and administrative capacities of SAVerS water systems. By exploring how SAVerS engage or take part in communities of practice, our research can better recognize and respond to a full range of social, political, technological and institutional barriers that persist in small communities and describe how these barriers scale to larger social and economic systems. A community of practice (CoP) is an organized group of people with a common interest or shared problem, engaging in a shared learning environment where they advance best practices and create new knowledge (Graven, 1998). CoPs provide a conceptual starting point for understanding how small communities, particularly those with volunteer-led water systems, are organized to overcome or circumvent barriers, how they make decisions, and how they access financial and technical resources. Furthermore, CoP frameworks also help to situate the position of the project team and how it will interact with, support, and engage with stakeholders and practitioners in the water sector.

In Phase 1, CSCS will engage collaborative governance and community of practice concepts to identify community perspectives and local experts that may inform the convergence research approach. In doing so, CSCS will leverage hands-on technical assistance experiences supporting PR water systems, drawing upon the Center's 5-year commitment to increasing access to BIL funds as a regional Environmental Finance Center. Team members for CSCS bring applied research and social science expertise to the convergence accelerator as well as highly specialized subject matter expertise in water infrastructure finance. CSCS will broaden the convergence research team by seeking out and engaging with stakeholder groups, including water coalitions, industry groups, or practitioner networks that can offer direct insight on the existing organizational pathways and interventions commonly used to pursue funding and finance opportunities. CSCS will prioritize practitioner experts, such as the independent PR water systems operators group, OSAN (see table C.2), with lived experience or strong backgrounds in fields of environmental justice, environmental racism, and participatory action research. CSCS will identify and invite prospective team members to join through a snowball approach, whereby the project team starts consultations with an initial list of stakeholders and, through those stakeholders, seeks out introductions to other potential members. CSCS will identify and implement community engagement events, in collaboration with other tracks and project team members. Community and stakeholder engagement opportunities, especially in the context of exploratory, convergence focused research not only support efforts to build a broad and diverse team but also will allow CSCS to better identify best practices, governance models, and finance approaches that circumvent historical barriers, including barriers linked to inequitable policies. These events may include listening sessions, workshops, or sessions at existing Caribbean forums. In Phase 2, CSCS will shift to synthesizing results and developing policy recommendations. As insights, prototypes, and system design strategies begin to emerge across focus areas, CSCS will integrate promising water system technologies, management procedures, and decision-making processes into its long-standing technical assistance services to communities, offering a direct way to move research into practice.

B.2 Focus Area 2: Community Education and Workforce Training (Lead: CECIA)

The Center for Environmental Education, Conservation and Research (CECIA) based at Inter American University of Puerto Rico, has worked with small potable water systems in Puerto Rico for years and has documented water and sanitation problems in these systems, which has been suggested to be a major driver for diarrheal diseases among consumers (Hunter et al., 2010). CECIA has demonstrated the presence of *Cryptosporidium* in small water supplies in Puerto Rico (Robinson et al., 2015) and has detected Shiga Toxin encoding genes in the same water systems (Crespo-Medina et al., 2020). The most common treatment method in these systems is simple chlorination which has limited effect on *Cryptosporidium* and in high turbidity raw water can produce disinfection byproducts. Together, these findings demonstrate that consumers from these systems are exposed to unnecessary risks, often without realizing it.

Educational interventions are valuable tools that provide community members with the knowledge needed to maintain and manage their own community water systems, taking informed decisions, while understanding the risks of not correctly managing their water supply. In an educational intervention, delivered by CECIA to community volunteers from small potable water systems throughout PR (Hunter et al., 2010) it was demonstrated that, after the intervention, the rate of diarrhea decreased significantly. The intervention consisted of meetings with the system management committee, operators, and administrators.

Volunteer trainees enrolled in CECIA's professional certification program designed to provide education and training to persons who were or wanted to be responsible as operators or administrators of small potable water systems. The courses were divided between operators and administrators and gave them a basic understanding of the physics, chemistry, and engineering behind the maintenance and safe operation of potable water systems (Hunter et al., 2010). This program helped trainees relate the recently acquired knowledge to the practicalities of systems they operate or administer.

As part of Phase 1 of this project, we will visit different small and very small potable water systems, in different regions of PR. We will interview administrators and operators of the systems to gather information about the needs that each community has. We will use this opportunity to update demographic information and structural information about the systems to investigate how these communities changed after a series of natural disasters that had occurred in PR since 2017, which includes strong hurricanes, earthquakes and the COVID19 Pandemic. During our visits, we will provide educational/informational material that addresses the issue of water quality and the health risk associated with improper system's management.

We propose to organize a workshop, where we invite at least one representative of each of the small and very small non-PRASA SAVerS systems on the Island. During this workshop, participants will have the opportunity to listen to invited speakers and do hands-on activities designed so they can express their individual and collective needs, while demonstrating to them the importance of water quality.

We propose visiting regulatory agencies, such as the Department of Health and the regional offices of the Environmental Protection Agency, to gather more robust and general information on the regulatory issues of these systems.

At the end of Phase 1 we will have designed an educational strategy, based on the experience developed and piloted by CECIA (Hunter et al., 2010), but tailored to the common and actual needs of SAVerS while integrating the findings of the other FAs of this project (FA1&FA3). We will end up with updated demographic and structural information on the systems and we will have a list of possible participants interested in taking the classes designed as part of the educational strategy.

During Phase 2 we will implement the educational strategy offering courses designed during Phase 1, to the participants that demonstrated interest during Phase 1. Ultimately, we will have transferred knowledge to community members about water quality, monitoring, health risks, system management and about specific technology that we propose to apply, and about how to make a resilient system capable of going back to operations soon after a meteorological/natural phenomenon.

With respect to water safety, biological and chemical water quality testing also needs to be more affordable and accessible to SAVerS systems. Though rapid sensors are difficult for biological entities, tools are available for onsite low-cost fecal indicator bacteria testing (e.g. the Compartment Bag Tests (CBTs) which the team has already developed and delivered training materials to citizens of Maricao, PR and Kenya (Collins 2017)). Additionally, CECIA coPI Crespo-Medina performs certified pathogen testing for a wide range of protozoal, bacterial, and viral pathogens and harmful algal blooms. The team will summarize up-to-date knowledge of rapid onsite or regional testing methods for biological and chemical water quality monitoring - focusing on low-cost, on-site, easy-to-use tests like CBTs or dipstick style tests similar to Covid antigen tests. We will also summarize state-of-the art in rapid, affordable eDNA based quantification methods for viral, bacterial and protozoal pathogens as well as antibiotic resistance genes (ARGs). PI Richardson has expertise in eDNA tools applied to surface and ground water quality testing (Brooks 2018, Brooks 2020; Fernandez-Baca 2021).

B.3 Focus Area 3: Resilient Water Systems Technology (Lead: ACR)

Although a plethora of engineered solutions are available for water and wastewater systems, few of them are designed specifically to meet the needs of SAVerS. The AguaClara program was founded in 2005 to address the drinking water technology gap for small cities and towns. Over the past 18 years the

AguaClara program (now led by AguaClara Reach with student project teams at multiple US universities) used the convergence strategy to invent a suite of new technologies that enable small cities and towns in Central America to reliably deliver safe water on tap. Their success with 24 out of 24 AguaClara plants in Central America and India - which continue to deliver safe water in an environment where no other technologies were successful - provides a starting point for our proposed work to further invent and adapt technologies to enable scaling to even smaller communities.

The AguaClara convergence strategy began with the observation that none of the existing approaches for providing safe water on tap for small cities and towns were sustainable. The core convergence concepts are:

- The innovation process begins with a deep understanding of both the community and physics constraints.
- The technologies must meet more rigorous standards to be successful in a much more challenging environment.
- The innovation ecosystem includes academic researchers, students, a non profit engineering organization with extensive community experience, plant operators, and key community members.
- Potential power differentials are intentionally minimized by keeping the funding source separate from the teams involved in innovation and implementation. This enables community members, plant operators, implementing engineers, researchers, and inventors to be allies in searching for the best solutions. This is likely the single most important factor in the success of the AguaClara convergence approach.
- Decisions and design choices are made with a goal of creating win/win/win scenarios so that all stakeholders benefit.

The AguaClara program developed the open source AguaClara Infrastructure Design Engine (AIDE) for drinking water treatment systems. Their open-source designs are available for flow rates between 3 and 80 L/s(~1000-50000 people) and continue to improve with advances in understanding of the physics of water treatment and with evolution in manufacturing techniques. Guiding constraints are tap water that is fit for human consumption, low cost of capital, low O&M costs, reparability by operators, no proprietary parts/patents, easy to operate and monitor, designed for operator comfort, few moving components and no need for electrical power. The constraints will be integrated into the AIDE unbroken design algorithm to generate the documentation needed for fabrication of the water treatment facilities to expedite piloting and scaleup.

AIDE creates detailed 3D Onshape models of drinking water treatment plants for communities with populations between 1000 and 50,000. This parametric design approach will be used to create a proof of concept design for SAVerS. The design approach creates an unbroken algorithm from constraints to a detailed CAD design and bill of materials (Fig. 4). AIDE revolutionizes the design process and addresses the core challenge of creating designs for a wide range of community sizes. The AIDE system has the design flow rate as an input parameter and the entire design is automatically recreated as the flow or other input parameters are varied.

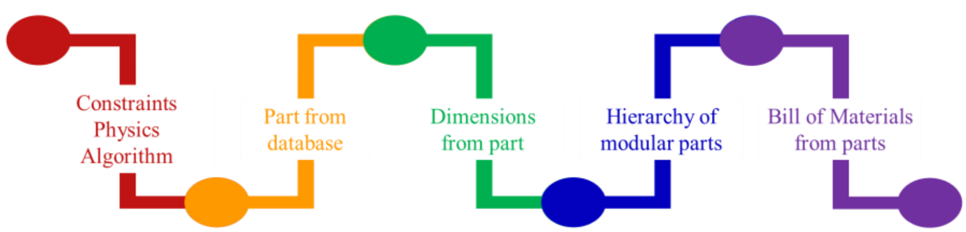

Figure 4: Unbroken algorithm pioneered by AguaClara Reach using the Onshape platform that enables rapid prototyping of designs over a wide range of flow rates and given different constraints.

The convergence strategy used by AguaClara will be extended to SAVerS. One key constraint that has already been identified is that water infrastructure for SAVerS must operate without requiring a full-time operator. Technologies and systems of systems that utilize sensors for basic operations and simple actuators for control are desirable. Conventional automation approaches fail rapidly when applied to SAVerS due to their large number of moving parts and switches. A new approach to automation that extends the design criteria developed by AguaClara will be developed in Phase 1. The design criteria include minimizing the number of moving parts, modular design to allow quick swapping of components, and an easy reversion to full manual mode in case of an automation failure.

Fit for Purpose Sensors. Cost effective "fit for purpose" sensing, control algorithms, and actuators will eliminate the need for a full time operator. High priority automated operation includes dosing of treatment chemicals and emergency plant shut off. An adaptive coagulant dosing algorithm based on the AguaClara hydraulic flocculation model (Du et al. 2019) and using a bare minimum of sensor inputs is already being tested at pilot scale. Repairability, readily available modular components, and minimal data requirements are critical requirements to ensure system resilience for SAVerS.

Integrated Water/Wastewater management. Designing water systems for "end of use" resource recovering is also critical. Motivating wastewater treatment has been challenging as poorly treated wastewater contamination usually flows downhill away from the community producing the waste. The high contamination levels were highlighted in our teams' recent studies of post-Maria PR waters (Warren et. al., 2023). Systems and attitudes that separate out blackwater (toilet water) from other greywater in the home allows not only smaller systems to focus intensive wastewater treatment on the fraction of household water that is used for toilet flushing, it also allows beneficial direct reuse of greywater for lower purposes (ie. uses not requiring drinking level water quality).

C. Partnerships including a Roles and Responsibilities Table

The overall goal of this project is to increase equitable access to safe water in small and very small scale water systems, with case studies focused on PR, a large tropical island and a US Commonwealth with extreme climate risk to water security as well as basic blackouts/brownouts of the regular electrical system power grid.

Our project builds on the growing collaboration among US mainland and PR institutions around resilient water infrastructure capacity building and water quality monitoring and recent federally funded projects dedicated to water system equity. Table C.1 presents the roles and responsibilities of senior personnel and Table C.2 presents the broader participation network we will develop during Phase 1. The senior research team brings diverse expertise in the water sector including innovation, engineering, treatment processes, water quality monitoring, and finance and governance of small scale water systems-of-systems. Cornell will lead the project overall and provide expertise in wastewater treatment designs. Through work with the AguaClara Cornell student project team (40-60 students per semester across 12+ sub- teams) PI Richardson will continue to work on challenges for resilient small scale safe water systems. AguaClara Reach (ACR) will bring expertise in innovation, design, and implementation of water treatment infrastructure that is specifically designed to produce high quality drinking water for small cities and towns. Weber-Shirk and PI Richardson are former NSF-PFI -TT grant recipients and received NSF-iCORPs training. The AguaClara innovation approach is based on identifying the constraints that govern the design space. Previous NSF and EPA sponsored research focused on defining the constraints provided by the physics of the water treatment processes. Many of the key constraints adopted by the AguaClara program went beyond physics and were based on the goal of being suitable for communities. These two broad types of constraints, physics and community, combined to form a set of guiding principles that has proven to be far more resilient than we could have anticipated.

It can take years to develop relationships with communities. Given the short timeline of this project (3 years) it is critical to have senior personnel with strong existing rapport and experience in the target communities. Another important role for the organizations connecting with communities in the early stage is to assess what the community constraints are for the infrastructure. This will help guide the evolution of infrastructure design. CECIA-IAUPR has extensive experience (over 20 years of experience) working with small water supply systems in rural communities in Puerto Rico. CECIA will participate in the community engagement and in the establishment of water interventions, and will be responsible for water quality monitoring, and human health outcomes.

SU-CSCS brings over 12 years experience collaborating with community leaders from non-PRASA communities to enhance their adaptive capacities and governance practices, aiming for a sustainable integration into long-term water resiliency strategies and adaptation planning. CSCS will lead efforts to investigate governance and finance innovations that transform clean and safe water access. This will be achieved through an interdisciplinary and participatory approach that focuses on identifying and addressing institutional, financial, and capacity-related barriers, particularly with respect to accessing historic investments from the Bi-Partisan Infrastructure Law. By the end of phase 2, CSCS will provide regionally relevant and responsive recommendations for policy makers, technical assistance providers or practitioners, and local water resource managers, ensuring scalability and replicability across Puerto Rico and the Caribbean.

Table C.1: "WaterSAVerS" Roles & Responsibilities/Program Partnerships Overview

Organization	Lead and other senior personne	Expertise	Roles
Cornell University *Academia*	Ruth Richardson	Biological water quality monitoring; water and wastewater treatment; eDNA; anaerobic blackwater treatment; bioenergy; resource recovery;chemical analyses;	Overall Project Lead: Responsible for hiring and supervising projec manager. FA 2 and 3: Contributor
Syracuse University Center for Sustainable Community Solutions (CSCS) / Environmental Finance Center (ESF) Academia	Melissa Young; Tess Clark; Kaira Fuentes	Community and environmental planning; infrastructure finance, qualitative and community-based research methods, rapid needs assessment, civil and environmental engineering, asset management, climate adaptation and island resilience	FA 1 Lead FA 3 Key Contributor
Center for Environmental Education, Conservation and Research (CECIA) Inter American University of Puerto Rico (IAUPR) *Academia*	Melitza Crespo-Medina; Graciela Ramirez-Toro	Applied and environmental microbiology; water quality (microbial and physicochemical) monitoring; human health impacts; water and sanitation interventions; environmental education; small community education, support SAVerS connections	FA 2 Lead FA 1 Key Contributor

AguaClara Reach (ACR) *Non-profit*	Monroe Weber-Shirk	Designing community scale drinking water treatment plants based on community and physics constraints and continuous feedback	FA 3 Lead FA 1 and 2 Contributor

Table C.2: "WaterSAVerS" Broader Partners/Collaborators to be developed during Phase 1

Organization	Disciplinary or Specialty Knowledge Area(s) or Resources Contributed	Focus Areas
Received letters of collaboration		
University of Puerto Rico at Mayaguez (UPRM) *Academia* (Contact: Chris Papadapoulos)	Engineering, sensing, and emerging contaminants	FA2 FA3
Cornell Center for Public Administration (CPA) *Academia* (Contact: John Foote)	Sustainable Infrastructure administration	FA1 FA3
Non-PRASA Aqueduct Systems Organization (OSAN) *Non-profit* (Contact: Miriam Matos)	Small and very small scale and resilient water systems, water system operators, local community water perspective	FA1 FA2
NY and PR Water Resources Institutes (USGS) *Government* (Contact: Brian Rahm)	Integrated water system perspective (including small scale systems)	FA1 FA2
Syracuse University: College of Engineering and Computer Science *Academia* (Contact: Elizabeth Carter)	Remote sensing, computational hydrology	FA3
Ongoing dialogue with plans to grow relationship throughout Phase 1 (no official current commitment)		
Rural Community Assistance Partnership Solutions (RCAP) *Industry*	Rural housing and infrastructure planning, funding, and capacity building	FA 1 FA 2
United States Environmental Protection Agency (USEPA) *Government*	Water system compliance, needs assessment, non-PRASA system inventory development	FA1 FA2
United States Environmental Protection Agency (USEPA) - Small Drinking Water Research Group *Government*	Small scale water system technologies, knowledge of EPA funding structures	FA1 FA3

Plenitud PR *Non-profit*	Permaculture, source separated wastewater treatment, small agriculture systems	FA1 FA2 FA3
Cornell Civil and Environmental Engineering *Academia*	Wastewater treatment and nutrient recovery	FA3
TBD	Disciplinary experts in agriculture, sensors, groundwater, climate impacts	FA1 FA2 FA3

D. Coordination Plan

- Culture: The project team places a strong emphasis on fostering an inclusive and caring partnership towards a common goal. The work environment will value diverse viewpoints and backgrounds as we believe this approach will maximize our impact and outcomes.
- Information Hub: Our team will decide collectively which platforms to use (e.g. Microsoft Teams, GoogleDrive, Dropbox) to best serve the team's needs and capacities.
- Team Rhythm: The team will follow a schedule that aligns with the team's needs, including regular meetings, active participation in the Convergence Accelerator Curriculum. The rhythm will ensure timely effort to reach benchmarks and deliverables deadlines. Weekly zoom meetings will enable debriefing and strategizing after curriculum events.
- Project Manager: The project manager (Cornell) will coordinate the team including scheduling, planning meetings with stakeholders, soliciting input and feedback from team members, communications organization, establishing timelines for deliverables, and at times contributing to applicable focus areas.
- Team Retreat: One "kickoff" team retreat will be held for senior personnel.
- Mid-year Convergence Summit: A mid-year meeting will bring the project team, potential collaborators, as well as community leaders together to explore strategic project development for Phase 2. The meeting, or "convergence summit" will be organized by SU CSCS. CSCS will work with project leadership to incorporate participatory elements and directly reach out to and invite small water system stakeholders who can take part in the co-creation of Phase 2 projects.
- Decision Making: The team will use consensus based decision making and focus on creating win/win/win opportunities.

E. Deliverables

The deliverables (Table E.1) are built on the proven community engagement approaches used by CSCS and CECIA and by the AguaClara innovation ecosystem.

Table E.1: WaterSAVerS Deliverables

Focus Area	Deliverables
Combined Focus Area Deliverables	● ***Phase 1***: FA 0.1: Straw-man cross-Focus Area framework for rapid deployment of SAVerS water systems ● ***Phase 2***: FA 0.2: Refined cross-Focus Area framework for rapid deployment of SAVerS water system
Focus Area 1: Governance and Financing	***Phase 1*** ● FA1.1: Enhanced understanding of financial, managerial, and technical barriers, and how they are mediated by inequities, constraining small-scale implementation of new treatment technologies ● FA 1.2: Strategic engagement of small water system stakeholders, especially in Puerto Rico, to support the development of the team and shape project goals and direction ● FA 1.3: Development of a finance matrix describing key constraints and examples ***Phase 2*** ● FA 1.4: Synthesis of water system governance models and collaborative strategies in community water management ● FA 1.5: Re-tooled finance and governance best practices for practitioners and water system audiences ● FA 1.6: Policy recommendations to support community-driven water infrastructure improvements, ensuring equitable access to clean water for all community members
Focus Area 2: Community Education and Workforce Training	***Phase 1*** ● FA 2.1: An educational strategy based on the experience developed and piloted by CECIA (Hunter et al., 2010), but tailored to the common and actual needs of the communities while integrating the findings of the different focus areas (FA1 & FA3) ● FA 2.2: Updated demographics and structural information of the impacted systems and a list of possible participants, interested in taking the classes designed as part of the educational strategy ● FA 2.3: Selection and demonstration of onsite fecal contamination testing (CBTs and dipstick tests) and community ***Phase 2*** ● FA 2.4: Training materials for biological and chemical contamination testing in English and Spanish for SAVerS communities ● FA 2.5: Implementation of the educational strategy, offering courses designed during Phase 1, to the participants that demonstrated interest during Phase 1. At the end, transfer knowledge to community members about water quality, monitoring, health risks, system management and about specific technology that we propose to apply, and about how to make a resilient system capable of rapid recovery after a disaster

	● FA 2.6: Establish network and tour of successful WaterSAVerS systems (peer training and demonstration network)
Focus Area 3: Resilient Water System Technologies	***Phase 1*** ● FA3.1 Fact sheet on smart automation for water quality monitoring and control of pilot drinking water treatment plant ● FA3.2 Fact sheet on wastewater treatment technologies appropriate for SAVerS (greywater and blackwater) ● FA3.3 Key constraints for sustainable drinking water supply systems for communities smaller than 1000 people (ACR) ● FA3.4 Key requirements for wastewater treatment systems for communities smaller than 1000 people ● FA3.5 Technological gaps that are preventing suitable solutions for communities smaller than 1000 people ● FA3.6 Solution paths and prioritize innovations that are within reach in 1-2 years ● FA3.7 Design for drinking water and a proof-of-concept design for wastewater using the AIDE ***Phase 2*** ● FA 3.8: Fully deployable system of sensors and actuator for auto dosing of coagulant to meet EPA turbidity standards ● FA 3.9: Detailed designs using AIDE and the Onshape platform ● FA 3.10: Ranked list of select demonstration site(s) in Puerto Rico for appropriate very small scale water technology (200 persons) ● FA 3.11: List of vendors who can prefabricate the systems and/or construction firms to build the systems ● FA 3.12: Pilot scale demonstration of wastewater and drinking water infrastructure in Puerto Rico

Table E.2 Project Timeline

	Phase 1 - 2024												Phase 2 - 2025				Phase 2 - 2026			
Milestone	*Kickoff*					*Summary Progress Report Mid-year Convergence Summit*				*Phase 2 Pitch*		*SAVerS Framework FA0.1*								*Refined SAVerS Framework FA0.2*
Tasks	*Planning*	*FA1.1*											*FA1.4*							
		FA1.2												*FA1.5*						
							FA1.3											*FA1.6*		
		FA2.1											*FA2.4*							
					FA2.2									*FA2.5*						
								FA2.3										*FA2.6*		
		FA3.1-3.5											*FA3.8*							
					FA3.6								*FA3.9*							
						FA3.7								*FA3.10*						
														FA3.11			*FA3.12*			
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4

**Note: All tasks will continue throughout the full year from when they are iniated. The shaded color simply notes when the most time will be allocated towards those tasks/deliverables*

F. Track Alignment

This work aligns with Track K: Equitable Water Solutions. We align with major themes of Community-driven Solutions, Environmental Justice, and System-of-Systems Approaches. Our project resonates with multiple of the Track suggestions of two key NSF-sponsored reports that informed the current RFP. From Managing Water for a Changing Planet (Award ID: 2231723) we align well with 1.) Cooperative Communities as a Catalyst for Change; Relevance; 2.) Building a Community of Learners; and 3.)Ensuring Water Supply for the Future. From Climate Resilience and Water Resources (Award ID: 2231916) we align well with: 1.) Nimble, scale-aware governance; 2.) Identify opportunities for fit-for-use water; 3.) System-of-systems approaches; and 4.) Reducing pollution sources. Given our focus on SAVerS it is likely that we complement other applications to Track K - especially those filling known gaps in our disciplinary knowledge base (sensors; groundwater recharge; agricultural/industrial reuse of recovered water and nutrients).

G. Broader Impacts

Coinciding with this proposed project, our team will be leading a five-year project as an EPA supported Environmental Finance Center (EFC) to distribute federal infrastructure and other funds to resilient rebuilding and infrastructure projects that are related to water equity. Some key stipulations for the federal funding are >49% of funds going to small communities and >25% going to disadvantaged communities. This project includes an in-depth CSCS project with Puerto Rican community water systems. Exploitative practices and policies as well as PR's territorial status have contributed to deforestation, overfishing, pollution, reclamation of land, solid waste mishandling, destruction of coastal ecosystems, input-intensive export-oriented agriculture, and mass tourism in PR as well as other islands in the Caribbean (Braveboy-Wagner, 2008; Lewis, 2013; Baver & Lynch, 2006). Co-occurring high poverty rates, inequitable access to energy and water resources, exposure to industrial pollutants, superfund sites, and a history of disinvestment across the water, solid waste, and power infrastructure sectors place many PR communities at increased risk. Disproportionalities such as these are widely understood to increase exposure to climate hazards, reinforcing the fact that adverse and severe impacts of climate change are likely to be felt by the most vulnerable groups (EPA, 2021). These challenges render PR an ideal candidate for a project focus and implementation location for WaterSAVerS. The success of the proposed framework in PR would serve as a compelling indicator of its efficacy in diverse contexts. Beyond the specific focus on PR SAVerS our framework for resilient provision of safe water on tap will be replicable elsewhere in the US, its territories, and globally.

Training is a key aspect of the framework we will be developing. We will develop educational materials and strategies for underserved American communities to finance, deploy, and manage their water infrastructure. In addition to direct benefit to disadvantaged communities and equitable water security, our project also will provide educational opportunities for diverse learners. These include practitioners and students from multiple stakeholders. AguaClara Cornell (the founding AguaClara chapter) will work with UPR Mayaguez engineers to establish a chapter dedicated to piloting SAVerS appropriate technologies and training STEM students. This will broaden participation using the AguaClara project team model developed at Cornell University. Ongoing university research across multiple AguaClara chapters will be integrated into the technology exploration phases as well as into the effort to bridge the identified technological gaps. AguaClara has developed novel dosing systems for water treatment chemicals and treatment processes as well as a ground-breaking design approach that addresses multiple obstacles that were preventing small cities and towns from accessing reliable high quality drinking water. This grant will extend these innovations to SAVerS within the United States and its territories.

Broadening Participation Plan: We will actively engage diverse stakeholders ranging from graduate and undergraduate students in engineering, environmental science, governance and international development from multiple universities to community members to partner organization types (NGO, academia, government, and industry). Partners outlined in Table C.2 will be contacted and invited to contribute insights and perspectives on the project through a combination of in-person and online meetings, as well as site visits. Training plant operators will represent a broader community of learners. We will use the seed network laid out within this proposal in a “snowball” approach to find other stakeholders with diverse perspectives. With respect to student recruitment and training, IAUPR, UPRM are both minority serving institutions in PR. Additionally, at both Cornell (including AguaClara Cornell) and Syracuse (CSCS) the team has a strong track record of recruiting, training, and mentoring diverse student researchers.

H. Results from prior NSF support

Richardson, Weber-Shirk were coPIs on an NSF-PFI-TT project entitled “PFI-TT: Bringing Open Source Innovation and Resilient Hydraulic Designs to Municipal Drinking Water Treatment Infrastructure” (Award 1919084). Discovered through extensive interviews that smart automation is essential for water treatment technologies in the United States due to the tight labor market. The research team designed and implemented automated control of an AguaClara pilot plant to enable ongoing investigation of physics-based algorithms for coagulant dosing. The work will be published demonstrating the ability of very small scale systems to meet EPA turbidity and E coli standards. Collaborations among the coPIs from PR were made possible in part by this project.

Weber-Shirk was PI on an NSF-CBET project entitled “WRF: Experimental Observation And Modeling Of Coagulant Mediated Contaminant Removal: Flocculation, Floc Blankets, and Sedimentation” (Award 1704472) Investigated the fundamental mechanisms of particle removal in floc filters (also known as sludge blankets). The research team developed a new model detailing how floc filters form and what controls their ability to capture the primary particles that didn’t form flocs in the flocculator. These insights are being incorporated into the automated coagulant dosing model.

Crespo-Medina and Ramírez Toro were coPIs in an NSF RAPID project entitled “Collaborative Research: RAPID: Assessment of Water Quality in PR after Hurricane María” (Award # 1812620). The original project goal was to characterize the chemical and biological quality of the water that was being consumed/utilized in response to the emergency. Water samples were from different sources, such as PRASA, Non-PRASA and side of the road springs. The research resulted in the following publication: Warren et. al., 2023, ACS EST Water. 3 (2) 354-365 https://doi.org/10.1021/acsestwater.2c0042

The other team coPIs have no current or recent NSF awards within the specified timeframe.

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