AguaClara Reach

The AguaClara Drinking Water Treatment Program Delivered in the Republic of Honduras

Working Draft

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Executive Summary

The Honduran AguaClara Program has been developing *next generation* drinking water treatment technologies to deliver safe water and meet the essential need of individuals and families in towns and cities since 2005. Over a period of 14 years, through implementation of a process of innovation, Cornell University has continually improved both its treatment processes and project management methodologies to support acceleration of the program and potential scale-up of activities across other areas of the world. Through public involvement, the program today ensures safe water, appropriate pricing for low-income residents, and the management of water supply and demand on a sustainable basis in support of the good health and productivity of the community.

AguaClara is proven drinking water treatment technology that is cost effective and suitable for use in any village, town or small city. After successfully demonstrating the ability to transfer this technology to Honduras through a 2005 pilot demonstration project, the AguaClara Program in Honduras is today being delivered as a national initiative on a community-demand basis. This overview of the Honduran AguaClara Program presents background information on the importance of water for life, introduces the program and technologies in use, and discusses the benefits and costs to be realized through the provision of adequate water infrastructure and services to promote human health and productivity growth.

The Honduran AguaClara Program is a partnership between Cornell University AguaClara Innovation Laboratory and the National Water and Sewerage Utility (SANAA), Honduran civil society, and select international development partners. Eighteen water treatment facilities that do not require electricity and have minimal maintenance requirements have been successfully installed to date. These facilities continue to provide safe, clean drinking water to low-income communities ranging in size from 170 to 12,000 persons. A new facility designed to serve 40,000 people will be commissioned in June 2019.

The sustainability of the AguaClara Program is evident. Members of each beneficiary community continue to operate, maintain and manage the simple-to-operate treatment facilities, built completely of locally-sourced materials. Each month, each household in these low-income communities demonstrates both a willingness to pay and the ability to afford the low cost of water tariffs.

Today, the AguaClara Program may be the best-kept secret of the water and economic development practitioner communities. This Case Study for potential client and partner organizations highlights the performance of three drinking water treatment facilities. These each required the Honduran AguaClara Program to tackle different technical challenges and propose effective solutions for delivering real results in closing the water security gap in the Republic of Honduras.

The AguaClara Program is now being implemented in other countries through partnerships formed by AguaClara Reach, a non-profit organization established to facilitate universal access to safe water on tap.

Table of Contents

1. Introduction

The provision of adequate water and sanitation in poor and low-income communities in developing countries is a key strategic global development challenge of the 21st Century (Tipping, 2006). Access to safe water and sanitation infrastructure and services played a pivotal role in the transformation of living standards in today's advanced economies, through its positive impact on human health and productivity. Yet, despite access to water being a key development goal of the international community for over 30 years, the challenges of sustainable water management continue to increase. The great driving forces of globalization, urbanization and environmental change translate differently in locally-specific ways. Proven solutions that are suitable for the range of countries and a diversity of political-economic contexts are needed.

The United Nations *2030 Agenda*, in particular Sustainable Development Goal 6 (SDG 6), now calls for wider scope and massive scale-up of action on water and sanitation systems. Forward-looking investment is needed in all areas, ranging from hardware for information collection and assessment, to software for institutional strengthening and good governance (Tipping, 2006). The social, economic and environmental returns on investments in drinking water treatment at the local level are substantial and even more significant at the global level.

There is increasing global recognition that access to sufficient quantities of good quality drinking water and adequate sanitation, also known as water security, is a human right. The human right to water and sanitation entitles everyone to "sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use" (UN, 2003). Lack of access, also known as water insecurity, leads to avoidable health outcomes such as illness from water contamination, sanitation and hygiene-related illness, dehydration, emotional distress (fear, worry, anger, bother) and mental health issues (depression and anxiety). Reduced water availability can also contribute to vector- and food-borne diseases and threaten food production, thereby contributing to food insecurity and malnutrition, especially for low income populations.

However, in many low-income and emerging economy country contexts this public good (water security) cannot be provided for a variety of reasons. A public good was defined in 2008 as "a good or service that is deemed to be essential for the basic existence needs of individuals and societies, and access to which therefore demands public involvement in ensuring high quality standards, quality and reliability of service, appropriate pricing and the management of supply and demand on a sustainable basis" (Tipping, 2008).

To respond to this strategic development challenge in the Republic of Honduras, in 2005 Cornell University established a partnership with the National Water and Sewerage Utility (SANAA). The basic development challenge of access to adequate water and sanitation is well recognized by the context of Honduras. The objective was to develop and trial next-generation drinking water treatment technology that would be fit for purpose, delivering safe water to meet the essential needs of individuals and families across towns and small cities.

The Honduran AguaClara Program is a multi-stakeholder partnership between SANAA, Honduran civil society, the Cornell University AguaClara Innovation Laboratory, and select international development partners. As a joint initiative, it began when Agua Para el Pueblo (APP), a Honduran not-for-profit organization, made a request for Cornell University help to develop water treatment technologies that could meet the service gap in a diverse array of local communities. This aim was to promote good public health and position the country for sustainable socio-economic development.

This Case Study is for water professionals and economic development practitioners seeking *next generation* solutions for achieving SDG 6 through provision of the public good of adequate water and sanitation infrastructure and services. It first provides summary information on the AguaClara Program for Drinking Water Treatment in the Republic of Honduras. The following sections present more detailed information, including:

- Information on the AguaClara organizations AguaClara Reach and the Cornell University AguaClara Innovation Laboratory
- technical information on *next generation* drinking water treatment technologies developed for use in Honduras,
- general characteristics of successful AguaClara drinking water treatment facilities and their operational performance,
- discussion of the performance of three recently commissioned Honduran facilities, and,
- key project statistics related to design, capital and operating costs, local tariffs and revenue.

The conclusion provides a broad overview of the Honduran AguaClara Program along with discussion of the benefits and costs to be realized through a drinking water treatment initiative that will promote human health and productivity, in accordance with international goals and targets.

2. AguaClara Reach and Cornell University

This section presents information about AguaClara Reach and its Science, Technology and Innovation partner, the Cornell University AguaClara Innovation Laboratory.

2.1 AguaClara Reach

AguaClara Reach (ACR) was established as a non-profit organization in 2017, after operating as a social enterprise since 2013. Its mission is to facilitate universal access to safe water on tap. ACR provides a range of capacity building and technology transfer services internationally, including planning, programming, training, and technical and design support to Technology Implementation Partners who adopt AguaClara technologies for providing drinking water treatment.

The initial success of the Cornell University AguaClara Innovation Laboratory in introducing drinking water treatment in communities across Honduras, led several staff and students in the Cornell University AguaClara Innovation Laboratory to find a way to replicate the program in other countries. Several alumni of the program established AguaClara LLC, a Certified B Corp, in 2013. The social enterprise set the objective of transferring technologies from the Cornell AguaClara Innovation Laboratory to Technology Implementation Partners. During this period, programs were commenced in India. However, it was determined that AguaClara LLC was not a suitable vehicle to contribute to UN Sustainable Development Goal 6 (SDG6), as environmental markets in many developing economies and economies in transition do not exist or are not sufficiently developed and cannot be relied on to provide drinking water treatment infrastructure and services. Adequate funding did not appear, because water is more of a public good than an economic good. At this time the leaders of the organization began planning to transition from a social enterprise to a non-profit organization, culminating with the establishment of the AguaClara Reach, Inc. in 2017, a registered US non-profit 501(c) 3.

2.2 Cornell University AguaClara Innovation Laboratory

The School of Civil and Environmental Engineering at Cornell University established the AguaClara Innovation Laboratory in 2005. The aim of the academic research program is to give Cornell students an advanced understanding of water challenges facing the world and an opportunity to develop new technologies to meet those challenges. Dr. Monroe Weber-Shirk has led the program since its inception.

Known as The Lab, it provides scope for fellows, researchers and students to research, develop and test new methods of drinking water treatment. The program targets resilient, gravity-powered drinking water and wastewater treatment technologies. Cornell students (from undergraduate to doctoral levels) lead the research and development process, fostering the collaborative environment required for creativity and innovation.

During each academic semester, approximately 80 Cornell University students work in teams to create new treatment technologies and improve existing technologies. They conduct research, build prototype treatment equipment, and test these new technologies under laboratory conditions. This allows the Technology Implementation Partners to utilize proven technologies in new drinking water treatment facility designs that are to be managed by beneficiary communities.

The AguaClara Innovation Laboratory at Cornell University is the Science Technology and Innovation Partner of AguaClara Reach. The Lab conducts deep research on the fundamental mechanisms of contaminant removal and treatability issues and invents new technologies to both improve contaminant removal and to reduce capital and operating costs. The AguaClara technologies owe their origins to the less-mechanized hydraulic water treatment plants that were invented in Peru starting in the 1960s.

The Cornell University AguaClara Innovation Laboratory has expanded the knowledge base for high-rate water treatment processes and created parametric designs for new drinking water treatment systems. Staff and students have developed a series of innovations in drinking water treatment that have succeeded in eliminating moving parts, substantially reducing capital construction and operation and maintenance costs for drinking water treatment. These innovations are built on fundamental research into the underlying physics of the water-particle-reactor interactions. The program has published key findings on gravity-powered chemical dosing (Swetland *et al*, 2013), a predictive flocculation model (Pennock *et al*, 2018), floc blanket performance (Garland *et al*, 2016), plate settler failure modes (Adelman, Hurst *et al*, 2013), and stacked rapid sand filtration (Adelman *et al*, 2012; Adelman, Weber-Shirk *et al*, 2013).

3. The Honduran AguaClara Program

The Cornell University AguaClara Innovation Laboratory and Agua Para el Pueblo (APP)--a local Technology Implementation Partner--established the Honduran AguaClara Program in 2005 in cooperation with SANAA. The purpose of the partnership program was to design and build drinking water treatment facilities in Honduran communities that could overcome the problems of conventional drinking water treatment, including built-in-situ and package plants. At the time, conventional drinking water technologies in Honduras were associated with high capital and operation and maintenance costs. The high tariffs required to achieve full cost recovery were unaffordable for low-income communities, while cheaper technology options were not capable of treating raw water to meet Honduran drinking water standards on a sustained basis. A new technology solution was required. The first Honduran AguaClara Program drinking water treatment facility was commissioned in 2007.

APP is a Honduran not-for-profit organization with a mission to help communities and families obtain safe, clean drinking water. By 2005, this organization had around 20 years of experience in the construction of water supply distribution systems, though no experience with drinking water treatment systems. APP requested Cornell University help to design and build drinking water treatment facilities specifically for low-income communities and the range of raw water quality conditions found across the country. Cornell AguaClara Innovation Laboratory staff and students have supported and enabled APP to introduce and use *next generation* technologies in new drinking water treatment facilities.

Today, APP continues to design, coordinate and supervise the community-led construction of AguaClara drinking water treatment facilities across Honduras. These facilities are suitable for use in both rural and regional towns and small cities. Since 2005, the Honduran AguaClara Program has commissioned eighteen drinking water treatment facilities and associated infrastructure across Honduras. Upon request of local communities in neighboring Nicaragua, an additional two facilities were commissioned in that country in 2017.

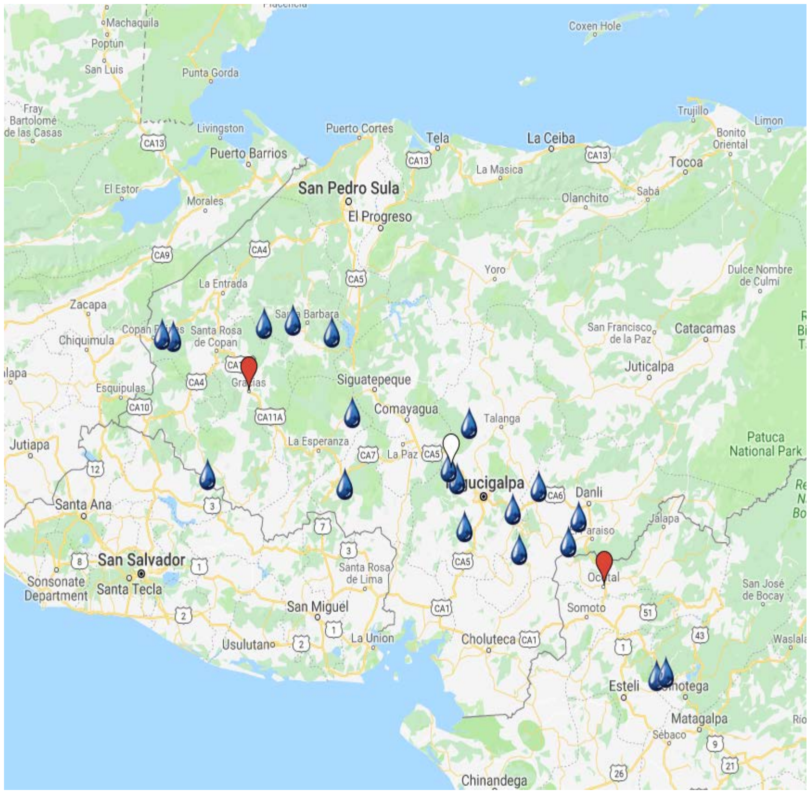

Figure 1. Distribution of AguaClara drinking water treatment facilities in Honduras and Nicaragua. Operational facilities and those currently being constructed are represented by blue and red raindrops, respectively.

The eighteen Honduran facilities were built in sequence with progressively improved versions of drinking water treatment technologies. The technologies that were incorporated into the original designs evolved rapidly, especially during the first decade of the AguaClara Honduras program. Commencing in 2012, stable floc blankets and stacked rapid sand filters were fully integrated into each new treatment process design.

The regional focus of the international development partners who funded the development and delivery of projects largely influenced the selection of Honduran AguaClara Program beneficiary towns and small cities. The range of Project Funding Partners who provided capital for projects includes: the Swiss Agency for Development and Cooperation, the Spanish Agency for International Development Cooperation, the Italian Agency for Development Cooperation, and Rotary International. In one case, a Honduran municipality of 12,000 people directly financed a Honduran AguaClara Program facility using their own resources.

This Case Study presents three facilities that were commissioned in Honduras after 2012. The improved technologies were incorporated in the design management process, then implemented during construction. To facilitate greater understanding of the AguaClara drinking water treatment facility Life Cycle, the Case Study discusses the operational performance of each project and identifies key project statistics related to design, capital and operating costs, local tariffs and revenue.

4. Strategic and Operational Considerations

Drawing on the lessons learned implementing the Honduran AguaClara Program over 14 years, this section describes strategic and operational considerations that needed to be documented and understood to establish a successful program for development and delivery of drinking water treatment infrastructure and services:

- Socio-Economic Context
- Raw Water Quality and Treatability Issues
- Treatment Technologies for use in Honduras
- General Characteristics of AguaClara drinking water treatment facilities
- Design Configuration, Capital, and Operation and Maintenance Costs
- Technical Data Collection
- Select Honduran AguaClara Program Treatment Facilities
- Key Statistics and Cost Data

4.1 Socio-Economic Context

To develop a national AguaClara Program, infrastructure planners and designers of drinking water treatment facilities need to understand the socio-economic status and the development challenges of a country.

The Republic of Honduras is a democratic constitutional republic. The head of state and chief executive is the President. The population is 9.42 million. The country has a young demographic profile with around 50% of Hondurans under the age of 23. Approximately 57% of the population live in urban areas. The capital city Tegucigalpa has experienced rapid urbanization.

Honduras is one of the least developed countries in Central America. Its key exports are coffee, bananas, shellfish, meat, timber, coal, gold and other minerals. The 2017 Gross Domestic Product was US$22.98 million. This is approximately US$5,600 on a per capita basis. The Gross National Income per capita is around US$1,870.

Many households in Honduras are classified as poor or low-income. Approximately 29% of the population live below the poverty line. Malnutrition, poor housing and unsafe water are widespread.

The large majority of communities in rural and remote towns and small cities (with population size less than 10,000 persons) do not have access to adequate water. The water they do consume is susceptible to contamination and pollution. It is often not improved nor treated to high drinking water quality standards.

In response to public health issues such as water-related diseases that were undermining livability and quality of life on the one hand, and productivity and economic growth on the other, APP approached Cornell University in 2005 with a request for help to develop improved drinking water treatment technologies for the range of Honduran contexts. SANAA was very supportive of the idea of developing the Honduran AguaClara Program as a partnership with APP and Cornell University. The organization had extensive experience with multiple stage filtration plants, highly mechanized package plants, and a variety of conventional mechanized and hydraulic water treatment plants. While having only limited access to resources, SANAA also had experience in facilitating local government projects. Based on this experience, the organization provided guidance to the Honduran AguaClara Program.

4.2 Raw Water Quality and Treatability Issues

To develop a successful AguaClara Program, infrastructure planners and designers of drinking water treatment plants need to understand the rainfall, geography, surface and groundwater sources, and other environmental and local community factors and constraints for siting a drinking water treatment facility, including: water laws, current water governance arrangements, land property rights, community willingness and ability to pay for safe water, population growth and more.

In Honduras, surface water quality has been highly degraded by deforestation, land degradation, mining, and agriculture practices used on steeply sloping lands. Over time, raw water quality has become increasingly poor. This has undermined the integrity and safety of traditional water systems used by local communities.

The key contaminant in water across Honduran communities is turbidity. Turbidity in raw water is caused by the presence of suspended particles in water. These particles scatter and reflect rays of light directed at the water, making it look cloudy. Particles that cause turbidity in natural waters can be inorganic or organic, which includes microorganisms.

Turbidity is strongly correlated with increased health risk due to pathogenic organisms. There are a range of pathogenic organisms potentially found in water, including bacteria, viruses, protozoa and helminths that can infect humans and cause a range of fatal diseases.

Natural organic matter in water is associated with turbidity. It can protect pathogens from chlorine or other disinfectants that need to be added during drinking water treatment processes (Lechevallier *et al*, 1981). Organic matter can also interfere with the water disinfection process by creating a higher chlorine demand for drinking water treatment and making it more difficult to maintain proper chlorine residual in a water distribution system (Lechevallier *et al*, 1981). Water with a turbidity greater than 5 NTU (nephelometric unit measure of turbidity) is visibly cloudy and may also be unacceptable to consumers (Lechevallier *et al*, 1981).

5. AguaClara Treatment Technologies Used in Honduras

The Honduras AguaClara Program uses flocculation, floc blanket, plate settlers, stacked rapid sand filtration and disinfection technologies to treat contaminated and polluted surface water and produce high quality drinking water. The Cornell University AguaClara Innovation Laboratory has conducted extensive research on ultra-low energy and high-rate water treatment processes. Staff and students have invented process designs that increase reliability by eliminating moving parts and reduce operating costs. The result has been the development of a compact drinking water treatment facility that does not require an external power source. Figures 2 and 3 present the general arrangement and unit processes of a typical AguaClara plant in Honduras.

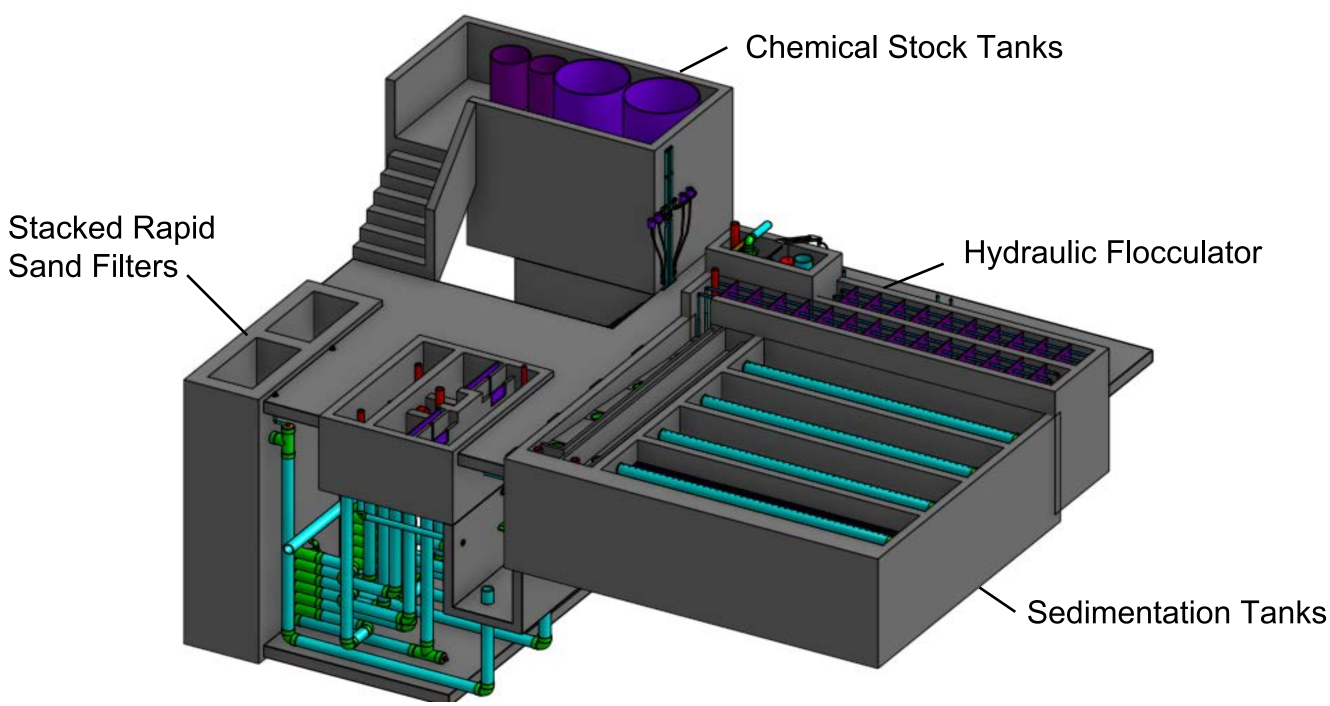

Figure 2. Isometric drawing of a 20 L/s AguaClara plant (1.8 MLD) showing the compact layout and the chemical stock tanks, vertical flow hydraulic flocculator, sedimentation tanks, and stacked rapid sand filters.

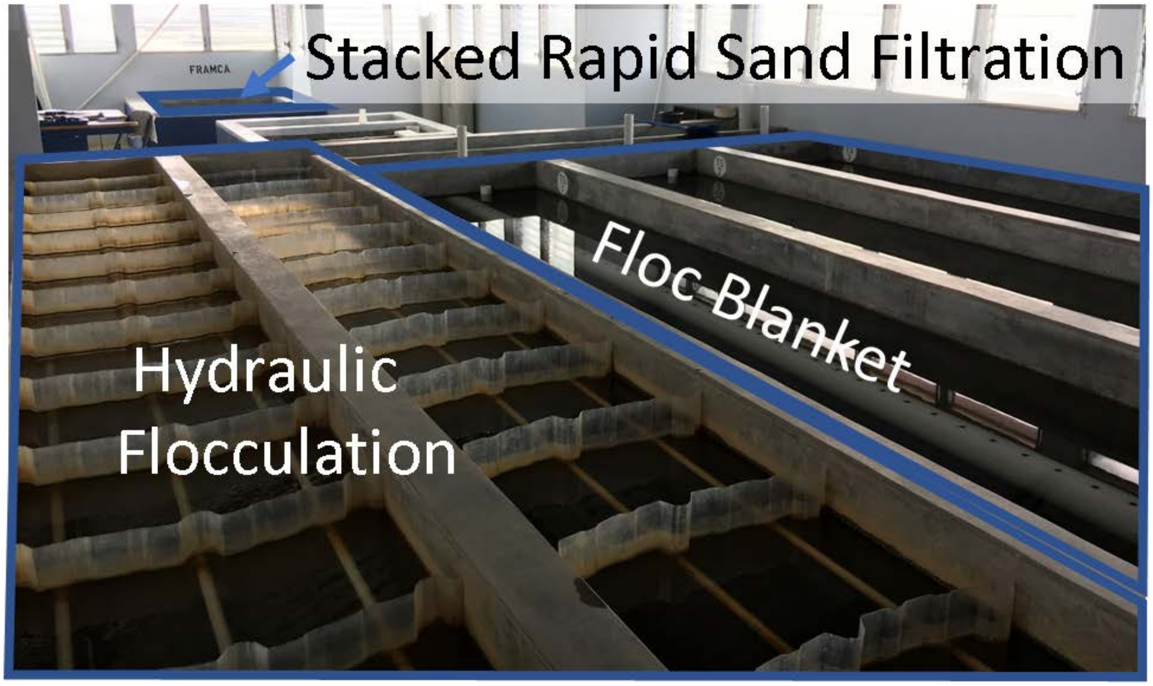

Figure 3. Photo of the Moroceli Drinking Water Treatment Facility (1.4 MLD), Honduras showing the hydraulic flocculator, sedimentation tanks, and stacked rapid sand filter.

Each AguaClara drinking water treatment facility is designed with a key focus on ease of operation and maintenance. The facilities are designed with elevated walkways that are optimized to allow plant operators to easily observe the performance of unit processes. A chemical control system is also installed, allowing plant operators to manually set the coagulant dose based on fluctuating requirements. This device is located just steps away from the location where the plant operator observes the flocculated water.

The AguaClara facilities are designed to be built using generic, locally-available materials, including bricks, sand and cement, and PVC pipe. This allows the use of construction methods adapted to local conditions. More importantly, without any need of imported or proprietary parts and componentry, this also allows routine and ad hoc maintenance to occur in a scheduled or more-timely manner.

Additionally, all of the AguaClara treatment processes--from chemical addition to filter backwashing--are accomplished without the need of any electrical power supply. While several facilities in Honduras continue to operate off-the-grid, an electricity connection to facilities is encouraged. This is to provide adequate lighting and enhance facility safety overall.

The AguaClara drinking water treatment facilities are gravity powered. They use approximately two meters of elevation drop between the height of the water inlet to a plant and the water outlet (exit point). The facilities are also designed to be integrated into any water supply distribution system that requires removal of particles and pathogens. Whereas the local geography allows Honduran water treatment and distribution systems to be completely gravity powered--from the water source to the consumer's tap--these designs are also optimal for incorporation into system designs that are reliant on pumping, for elevation of raw water from a river to a treatment plant, or from a treatment plant to a water distribution system.

5.1 Flocculation

AguaClara flocculators are designed to create uniform velocity gradients to enhance flocculation efficiency and to minimize or eliminate floc breakup. Figure 4 presents a vertical flocculator that is used to minimize the space and footprint required for the unit process. Vertical flocculators have been found to have fewer problems with premature sedimentation in the flocculator channels—as compared to horizontal flocculators--due to the enhanced scour achieved by changes in direction of water flow at the bottom of the tank. The internal baffles are assembled from polycarbonate sheets and PVC pipe. These can easily be removed for maintenance purposes.

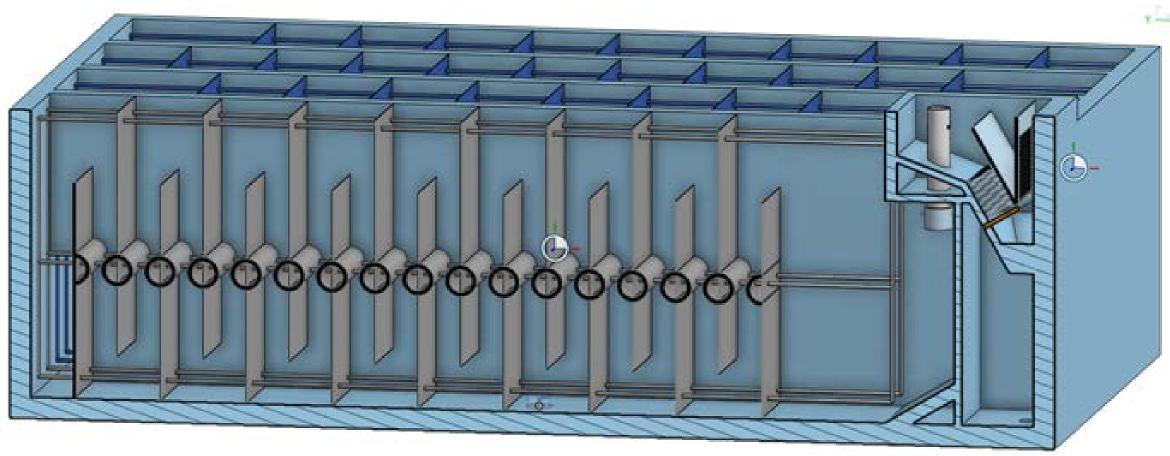

Figure 4. Side section of the AguaClara vertical flow flocculator showing the addition of obstacles (pipe sections) used in low-flow plants to obtain more-uniform velocity gradients and more-efficient flocculation performance.

Hydraulic flocculators use far less energy than mechanical flocculation methods. The AguaClara design uses 40 cm of potential energy for the overall flocculation process. Built-in-situ, the AguaClara plants have a flocculator residence time requirement of around 10 minutes. As the flocculator has no moving parts, plant operators are able to observe the entire flocculation process and verify that a coagulant dose is correct.

5.2 Sedimentation

The AguaClara sedimentation tanks (Figure 5) are one of the highest rate clarification systems available for municipal water treatment. The hydraulic residence time of less than 30 minutes in a 2 m deep tank reduces construction costs by reducing plant footprint and by reducing the depth and hence hydrostatic forces on the tank walls. AguaClara sedimentation tanks in Honduras produce settled water that is less than 1 NTU about 75% of the time based on the case studies below. This high performance is due to three factors.

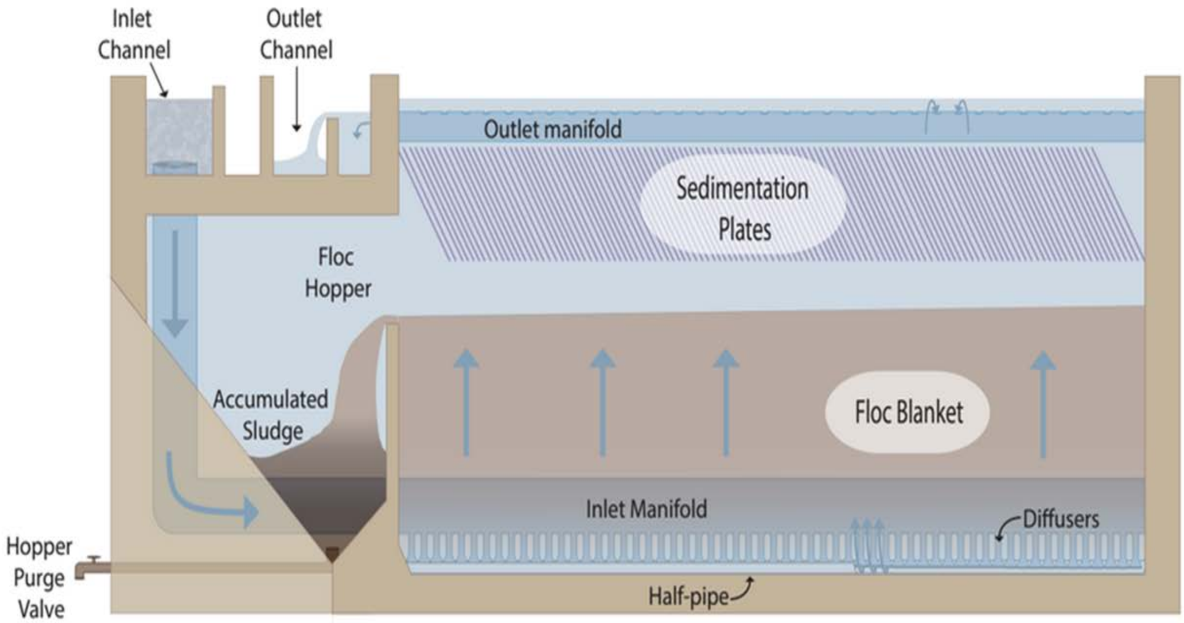

Figure 5. Side section of an AguaClara sedimentation tank showing the 4-channel hydraulic control system, the inlet manifold with diffusers, floc blanket with level controlled by a weir, floc hopper for consolidation of sludge, and plate settlers.

First, the inlet manifold (see Figures 5 and 6) has a diffuser system that straightens the fluid jets that are exiting the manifold so that they have no horizontal velocity component. This is critical because even a small horizontal velocity causes a large-scale circulation that would transport flocs directly to the top of the sedimentation tank. Inlet manifolds without flow straightening diffusers are commonly used in vertical flow sedimentation tanks including designs by leading competitors.

Second, the diffusers create a line jet that spans the entire length of the sedimentation tank (see Figure 6). The line jet enters a jet reverser and the vertical upward jet momentum is used to resuspend flocs that have settled to the bottom of the sedimentation tank. The resuspended flocs form a fluidized bed (floc blanket) with a suspended solids concentration of approximately 1 to 5 g/L. The high concentration of flocs in the floc blanket leads to an increase in collisions and particle aggregation. The floc blanket reduces settled water turbidity by a factor of 10 (Garland et al., 2017) and provides two additional benefits. The floc blanket creates a uniform vertical velocity of water entering the plate settlers and the floc blanket transports excess flocs to a floc hopper for final removal by opening a small drain valve.

Third, the bottom geometry is shaped so that all flocs that settle are transported to the jet reverser. Thus there is no accumulation of settled flocs in the main sedimentation basin. Sludge that accumulates in conventional sedimentation tanks in tropical and temperate climates decomposes anaerobically and generates methane. The methane forms gas bubbles that carry suspended solids to the top of the sedimentation tank and cause a reduction in particle removal efficiency. The AguaClara sedimentation tank bottom geometry prevents sludge accumulation. The hydraulic self-cleaning sedimentation tank with a stable floc blanket, zero sludge accumulation, and with no moving parts outperforms conventional sedimentation tanks on capital cost, performance, and maintenance costs. Mechanical sludge removal systems are well known to be costly to install and a challenge to maintain.

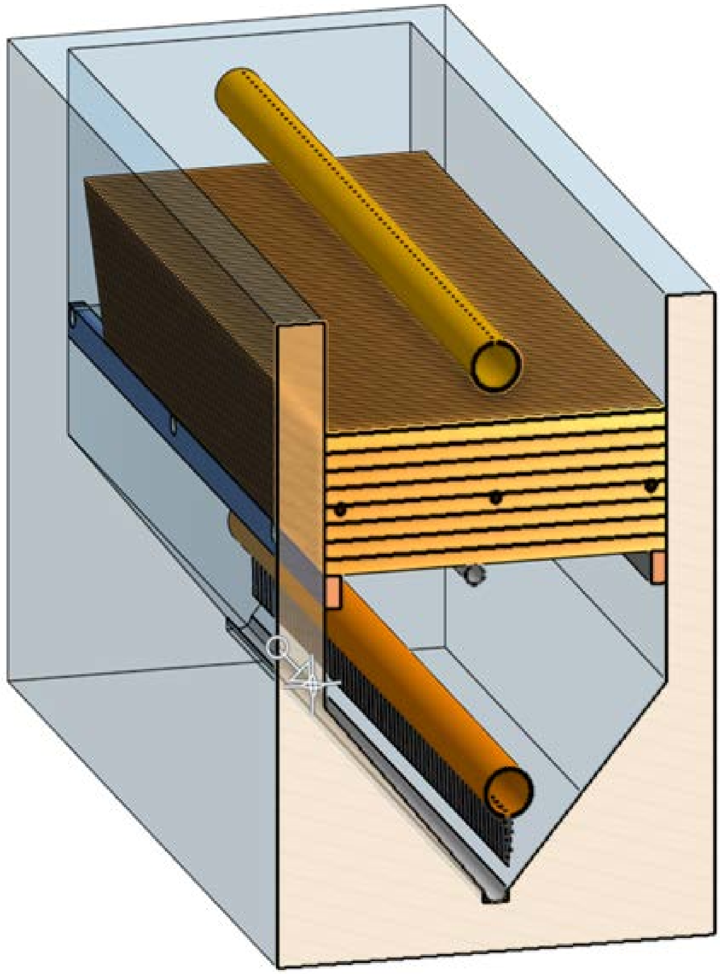

Figure 6. Isometric end view of a sedimentation tank showing the inlet and bottom geometry that were developed by AguaClara for stable floc blanket performance. The inlet manifold has diffusers that create a downward directed line jet that enters a jet reverser that is designed to resuspend all settled flocs and maintain a stable floc blanket.

5.3 Filtration

The Cornell University AguaClara Innovation Laboratory invented stacked rapid sand (StaRS) filters in 2010. This was in response to the need for a new technology that would both eliminate the need for backwash pumps and not require the construction of six filters for small towns. StaRS filters instead use six 20 cm deep layers of sand, stacked vertically and with no requirement for dual filter media. The six layers give a total sand depth of 1.2 m. The filters are able to operate with the same design flow rate for both backwash and filtration modes, using very clean settled water for backwash purposes. This eliminates a startup problem for a rapid sand filter that does not have any initial source of backwash water. The shallow filter layers take advantage of new insights into filtration mechanisms.

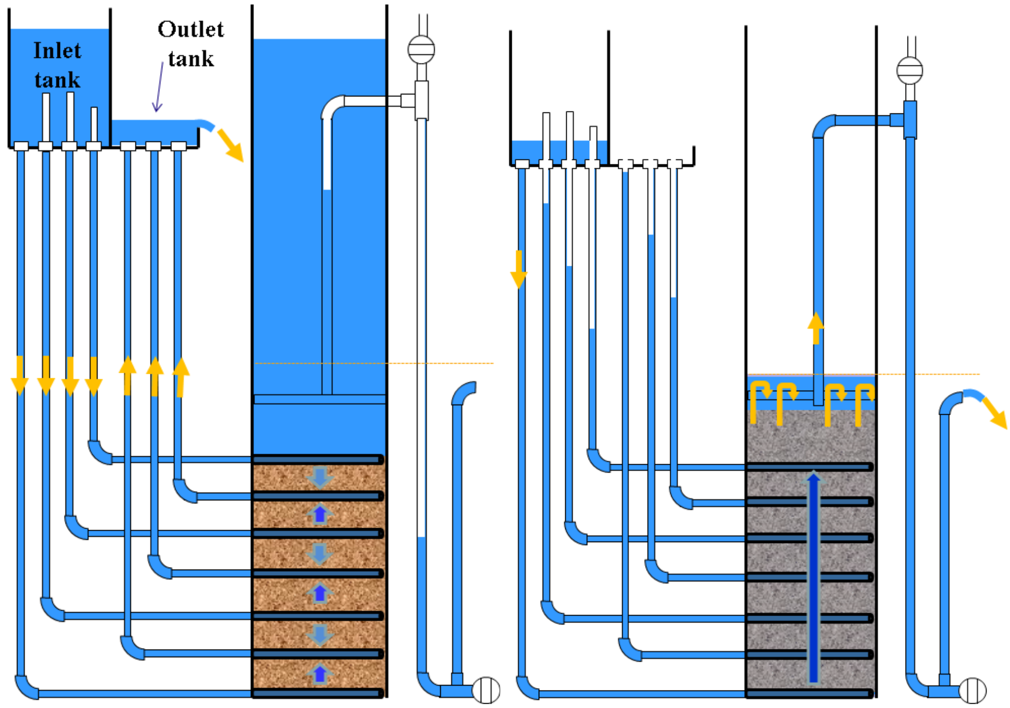

Figure 7. Side section of the AguaClara Stacked Rapid Sand (StaRS) Filter (left in filtration mode, right in backwash mode). A single StaRS filter has six rapid sand filters that operate in parallel during filtration and operate in series during backwash. This eliminates the need for backwash pumps.

5.4 Disinfection

The Cornell University AguaClara Innovation Laboratory invented the chemical dose controller that is for disinfection in the Honduran AguaClara plants. In this final treatment step, concentrated chlorine solution is added after sand filtration. The chemical dose controller is a unique, non-electric design. The chemical addition is made automatically in proportion to flow, allowing accurate chlorine dosing under changing flow conditions.

5.5 General Characteristics of Honduran AguaClara Facilities

The Honduran AguaClara Program experience is with local communities that already have piped water distributed to each household. As many communities in other countries and the diversity of political-economic contexts do not have treated drinking water distribution systems, AguaClara Reach has engaged experts with over 30 years of experience designing and building municipal water supply systems to advise clients on this aspect of water supply projects. The general characteristics of Honduran AguaClara drinking water treatment facilities are:

- Facilities are designed to remove particles, pathogens, and dissolved organic material from surface water sources.

- Facilities easily treat water that exceeds 500 NTU and there is some successful treatment data for turbidities as high as 1000 NTU. The majority of water produced meets the US EPA standard of 0.3 NTU. A pilot study is always recommended for ensuring a drinking water treatment facility will perform according to local community requirements. In all cases, raw water quality needs to be tested to ensure that the designed flocculation, floc blanket, sedimentation, filtration, and disinfection processes will produce good quality water. This includes having a sufficient chlorine residual to maintain the quality of water through the distribution system.

- Facilities are designed to be built-in-situ using generic construction materials that are available in a national market. There is no mechanical or electrical equipment that is required for plant operation. The AguaClara drinking water treatment facilities have few moving parts, which substantially reduces the number of proprietary parts and componentry that can fail or require replacement. The moving parts that may need to be replaced include standard PVC gate valves and ball valves for tank drains and miniature PVC float valves for chemical dosing. Additionally, turbidimeters need to be regularly calibrated to ensure water quality conforms to standards and to confirm facilities are operating optimally.

- The unit processes are gravity powered (potential energy) by less than two meters of elevation drop between the height of the water inlet to a plant and the water outlet (exit point). The elimination of an electrical power requirement for the process train also eliminates many of the failure modes that make a conventional mechanized plant difficult to maintain, particularly in a low-income community context.

- Facilities require around 6 square meters of space per L/s of drinking water treatment plant capacity. This factor varies slightly with smaller capacity plants. These facilities require additional land per L/s of capacity.

- Water storage tanks are required downstream of the treatment plant. Generally water storage tanks would provide storage of 8 to 12 hours of water. This requirement may need to be increased based on national regulations.

- AguaClara Reach provides technology transfer support and training in engineering design and construction, as well as for facility operations and maintenance. This support and training is scheduled during both the planning and delivery phases of a project.

- Facility operations are carefully designed to ensure they are easy for plant operators to learn. Plant Operators are only required to have minimum literacy levels, as full training is provided. Facility design processes have a core focus on simplicity and easy of functionality, which enables community members with a range of educational levels to staff and run them.

- AguaClara plants are designed and built within a secured building. Each building provides safety and security for both plant operators and the functioning processes. The building protects the process water from the environment, the plant operators from the elements, and further protects the piping and materials used in baffles and plate settlers.

6. Design Configuration, Capital, and Operation and Maintenance Costs

This section introduces three recently commissioned drinking water treatment facilities in Honduras, in the towns of Jesus de Otoro, Moroceli, and San Matias. These facilities are each using state-of-the-science technologies, as described in the previous sections. Each facility has a vertical flow hydraulic flocculator, self-cleaning sedimentation tanks with floc blankets, and stacked rapid sand filters.

At the onset of the program, the Cornell University AguaClara Innovation Laboratory forged a strong partnership relationship with SANAA and APP, the Technology Implementation Partner. Following the initial successes of the Honduran AguaClara Program, SANAA began to refer local communities in need of drinking water treatment to APP. APP worked with those communities to assess the technical and financial feasibility of initiating a Honduran AguaClara Program project. Other local organizations have also played a key role in engaging local communities and key stakeholders. The ability to secure funding for project development and capital to finance project delivery ultimately controls project commencement and completion timeframes.

The Honduras AguaClara Program establishes and builds capacity in local community water boards that become responsible for the entire water system, from regulation of the local water catchment area to operations and maintenance of the treatment plants and distribution systems. The Government of Honduras also provides a delegation of authority to each community water board, which gives them responsibility to set and collect household water tariffs, and to use annual revenues to ensure proper operation and maintenance of the water supply system from water source to the consumer's tap. Water boards are authorized to save funds for future major costs, such as maintenance and upgrades.

During the Life Cycle of each Honduran drinking water treatment facility, Cornell University AguaClara Innovation Lab staff and students have worked alongside the Technology Implementation Partner to conduct the planning, development, and delivery stages of projects. This included training the Technology Implementation Partner to fabricate and install the equipment needed for treatment processes, as well as training their staff and collaborating in the training of community members who become responsible for operating facilities.

Each of the three following sub-sections on the Jesus de Otoro, Moroceli, and San Matias facilities provides a short discussion of the operational performance of these commissioned drinking water treatment plants. These towns do not currently meter water usage. The local community water boards have instead chosen to base water tariffs on per household access to the water supply. While this does not limit the volume of water individual households can consume, at the present time this approach has not led to any water supply issues.

AguaClara Reach encourages the metering of water usage as best practice for water supply. This practice has not been widely adopted in Honduras. Water consumption in the Jesus de Otoro, Moroceli, and San Matias communities varies from 194 L/day/capita to 259 L/day/capita.

6.1 Technical Data Collection

Water quality and operational performance data is collected and reviewed as best practice for water supply. The approach ensures safe water is always supplied, and supports innovation and continuous improvement in service delivery.

Technical data is used to monitor water quality and track the operational performance metrics of all AguaClara drinking water treatment facilities. Drinking water treatment plant operators are required to monitor and record water quality and treatment plant performance data every hour. The Honduran Ministry of Health measures chlorine residual and coliform bacteria on an *adhoc* basis.

Following the commissioning of a facility, over a period of two months the Technology Implementation Partner will measure the concentration of the chlorine disinfection residual at the clearwell of the facility, the storage tank, and at the first and last house connections of the distribution system on a daily basis. Each facility is then provided with a chlorine measurement kit, which allows the local water board to take chlorine disinfection residual measurements in response to consumer requests. The local water boards also measure fecal coliform bacteria concentration at the entrance and exit of facilities. In some communities, on an *adhoc* basis, the local health center will take confirmatory coliform measurements.

In Honduras, the Cornell University AguaClara Innovation Laboratory has found there is rarely any need to customize the treatment train of the drinking water treatment facilities. The treatment processes are designed to handle a wide range of water quality, noting the variability of surface water quality at particular locations over the course of a year generally have far more variability than that between various water sources. Raw water turbidity measured during the wet season may typically range from 100 to 1000 NTU, whereas in the dry season it is much lower, often below 5 NTU. However, as surface water turbidity in Honduras almost always exceeds 5 NTU after rainfall events, a particular requirement is that each treatment train include flocculation, floc blanket, sedimentation, filtration and disinfection.

More specific data on the operational performance of the three commissioned facilities in the towns of Jesus de Otoro, Moroceli, and San Matias is presented in the following section.

7. Select Honduran AguaClara Program Treatment Facilities

Three treatment facilities commissioned since 2014 were selected for further discussion in this Case Study. These facilities were each designed and constructed with the most recent unit process designs and full AguaClara treatment trains. They have been operating for a sufficient duration to allow an evaluation of performance over more than one year.

7.1 Jesus de Otoro

The AguaClara plant in Jesus de Otoro, Honduras, was built during the period from May to November, 2014. Operation was turned over to the Jesus de Otoro Administrative Water Board in January of 2015. It was the tenth AguaClara plant in Honduras.

Figure 8 presents the interior view showing the four flocculator channels (foreground), three sedimentation tanks (background), and filter (left background). APP built the tanks in-situ using suspended concrete slabs, reinforced brick walls, polycarbonate baffles, and PVC pipes.

Figure 8. Interior view of the flocculator and sedimentation tanks at the Jesus de Otoro drinking water treatment facility.

Figure 9 presents data from a year of operation that is sorted to concisely present the plant performance. According to the manufacturer, the turbidity meters have a resolution of 0.02 NTU. Thus all turbidity measurements less than or equal to 0.02 NTU are shown on the graph as 0.02 NTU (rather than 0.00 NTU). The filtered water was less than or equal to 0.02 NTU approximately 47% of the time. The filtered water has always met the Honduran drinking water standard of 5 NTU at all times, as well as the USEPA standard of 0.3 NTU around 84% of the time.

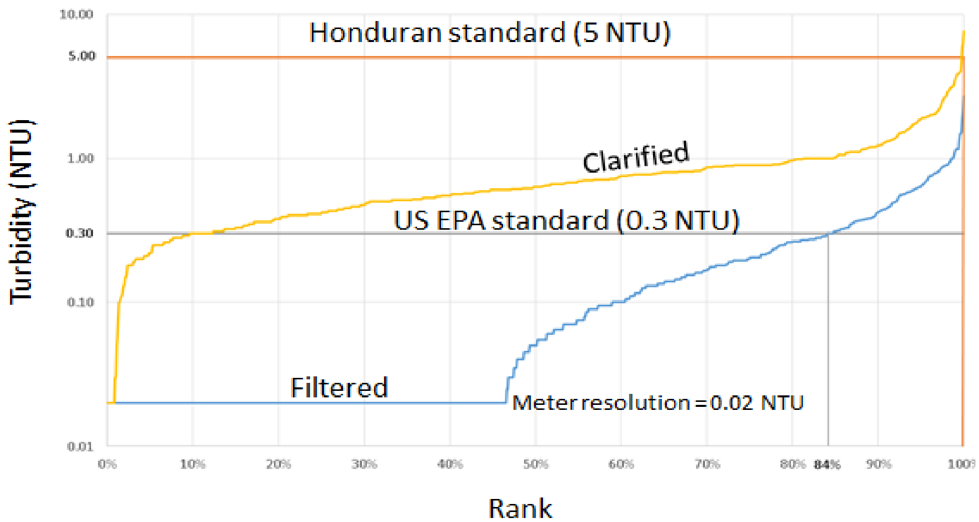

Figure 9. Cumulative distribution curves of settled and filtered water turbidity at the Jesus de Otoro drinking water treatment facility during one year of operation.

7.2 Moroceli

The AguaClara plant of the municipal seat of Morocelí was built during the period from April 2014 to January 2015 (Figure 10). Operation was turned over to the Moroceli Administrative Water Board in November of 2015.

Figure 10. Left photo: Moroceli's flocculator (left) and three sedimentation tanks (right) with filtration in the background. Right photo: the water source is a small river that is very turbid after run-off events.

The raw water turbidity ranged between 2 and 4 NTU during the dry season from November 20, 2015 to mid-May 2016. In the rainy season, May to November 2016, the turbidity level varied with rainfall events with peaks of up to 1000 NTU.

The flocculation sedimentation unit processes show a high removal efficiency with the settled water turbidity less than 1 NTU 40% of the time and less than 5 NTU 99.67% of the time. The StaRS filter produced water that was less that 0.3 NTU 75% of the time and produced water that was below the turbidity meter detection limit of 0.02 NTU 28% of the time. The filtered water has always met the Honduran standard of 5 NTU.

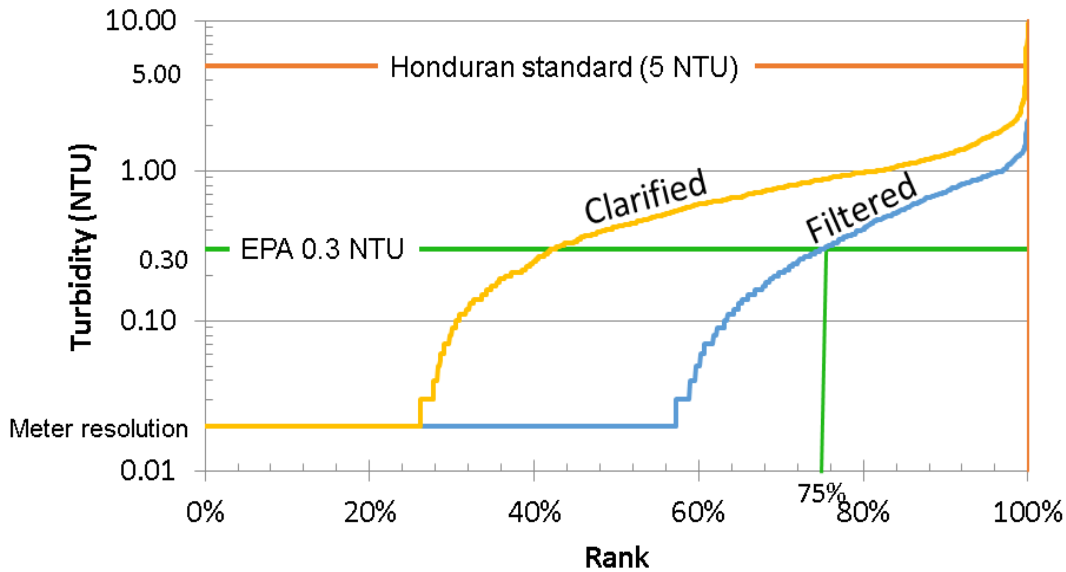

Figure 11. Cumulative distribution curves of settled and filtered water turbidity during one year of operation for the AguaClara plant at Moroceli

7.3 San Matías

The AguaClara plant of the municipal seat of San Matías was built during the period from March to September 2015 (Figure 12). Operation was turned over to the San Matias Administrative Water Board in November of 2015.

Figure 12. Exterior view of the AguaClara plant at San Matias. The compact layout of the water treatment plants makes it possible to enclose the entire facility inside a secure building.

The raw water turbidity ranged between 1.5 to 4 NTU during the dry season from January to mid-May 2016. In the rainy season, May to November 2016, the turbidity level varied with rainfall events with peaks of up to 595 NTU.

The flocculation sedimentation unit processes show a high removal efficiency with the settled water turbidity less than 1 NTU 80% of the time and less than 5 NTU 99% of the time. The StaRS filter produced water that was less than 0.3 NTU 66% of the time and produced water that was below the turbidity meter detection limit of 0.02 NTU 12% of the time. The filtered water has always met the Honduran standard of 5 NTU.

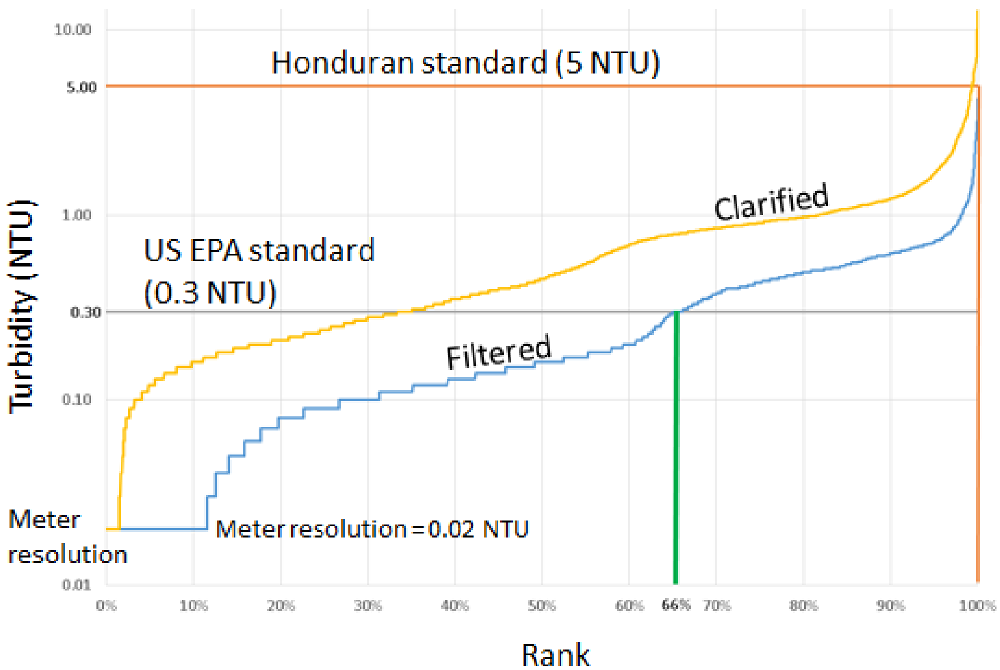

Figure 13. Cumulative distribution curves of settled and filtered water turbidity during one year of operation for the AguaClara plant at San Matias.

8. Key Statistics and Cost Data

Table 1 presents key project statistics related to design as well as capital and operating costs, local tariffs and revenues for the three selected facilities described in this Case Study. The table provides town population size, design and realized water flow rates, and financial information for each of facility.

Table 1. Summary Statistics for Select Honduran AguaClara Program Facilities

Town in Honduras	Jesus de Otoro	Moroceli	San Matias
Current population	4,675	5,775	3,850
Drinking Water Treatment Plant Commissioned	January 2015	January 2016	January 2016
Honduran Development Partner	Swiss Agency for Development and Cooperation		
Number of months for planning	Intermittent, typically 6 to 12 months		
Number of months for construction	8	6	6
Design flow (L/s)	20	16	14
Average flow (L/s)	14	13	9
Current per capita consumption (L/d)	259	194	202
Capital Cost in 2018 dollars (USD)*	$233,453	$200,883	$191,248
Annual Chemical Cost (USD)	$10,332	$6,814	$7,675
Chemical cost per million liters	$23	$17	$27
Annual Plant operator wages (USD)	$5,412	$27,245	$8,118
Annual tariff income (USD)	$30,529	$51,660	$34,440
2018 household water tariff (USD)	$35.92	$49.20	$49.20

** Reported capital costs include the value of community self-help inputs during the planning and construction of projects, as estimated using local labor rates. The capital cost excludes the acquisition of land and right of ways, as well as Cornell University AguaClara Innovation Lab inputs that were funded by the National Science Foundation, United States Environmental Protection Agency, Cornell University, and other donations to the Cornell Lab.*

The financial information is specific to these particular projects and is not directly applicable to the development and delivery of AguaClara projects in other locations and contexts. The development of these projects benefited from ten years of training and experience of Honduran AguaClara Program partners in one country and its diverse contexts. The planning phase for each project also includes public participation and stakeholder engagement activities, collaboration with government agencies and Project Funding Partners, technical evaluations, and civil and hydraulic design management. Whereas the full monetary value of each project is difficult to estimate, the total cost of developing and delivering these facilities is estimated to be less than $100 per capita.

Operation and maintenance costs are limited to operator wages, the coagulant (poly aluminum chloride is used in these plants), and the disinfectant (calcium hypochlorite). The operating costs of AguaClara drinking water treatment plants is strongly influenced by both the cost of chemical inputs ($17 - $27 per million liters in this study) and labor (an operator is required to be on duty whenever the plant is operating).

Operation and maintenance costs have been kept very low through elimination of the need for electricity and elimination of moving parts that are prone to failure in conventional drinking water treatment facilities. Chemical cost varies based on raw water characteristics, which determines the required coagulant dose for efficient treatment. Labor costs can vary considerably between local communities. In all cases, the water tariff is designed to provide sufficient revenue so the local water board can accumulate funds for unanticipated expenses and future capital expenditure.

9. Conclusion

To get to the heart of sustainable development, the Republic of Honduras has implemented the first AguaClara Drinking Water Treatment Program since 2005. Government and civil society recognize that good quality water for drinking, cooking and hygiene is essential at the local level to improve health and productivity. As many traditional sources of water supply had been impacted by globalization, urbanization and environmental change—in particular, the effects of rapid deforestation and new agricultural practices on steep slopes--it was realized that new drinking water treatment technologies were required. By entering into a partnership with Cornell University AguaClara Innovation Laboratory and local non-government organization APP, towns and small cities have been able to secure sustainable and affordable access to safe water supplies, shifting social progress and economic development onto a more sustainable trajectory.

The Honduran AguaClara Program has taken eighteen towns and small cities the last mile on SDG 6, improving both health and quality of life for individuals and families. By providing a treatment technology that can be constructed using locally sourced materials available in national supply chains, construction costs are kept low and communities can schedule and undertake all maintenance works required to keep the plant running at capacity. The partnership program has been implemented and evaluated over fourteen years to learn lessons and continually improve treatment technologies for Honduran contexts. The AguaClara drinking water treatment facilities are classed as sustainable. Honduran communities can develop proven solutions for their localities, fit-for-purpose drinking water treatment facilities from the onset, thus conserving scarce resources over the long run. As a result, the Honduran National Council for Drinking Water and Sanitation (CONASA) has designated AguaClara as the preferred drinking water treatment technology for the country. The Swiss Agency for Development and Cooperation also views AguaClara program as highly sustainable. Accordingly, through a South-South and Triangular Cooperation project established in 2017, the AguaClara drinking water technology was transferred to neighboring Nicaragua.

This Case Study on the Honduran AguaClara Program demonstrates that sustained high-quality water services can be provided at affordable costs through strategic planning, quality construction, and scheduled operation and maintenance activities. The information provided on the three commissioned facilities in the towns of Jesus de Otoro, Moroceli and San Matias brings to light key features that set AguaClara apart from conventional drinking water treatment facilities:

1. Structured engagement with government authorities and local communities in each phase of the program.
2. Training and expert planning and programming support for local Technology Implementation Partners to ensure proper transfer of the technology to new communities.
3. Lower cost construction, using community labor, equipment and locally-available materials.
4. Affordable operation and maintenance costs over the long term through use of community labor.
5. Demonstrated performance that consistently produces safe water under varying conditions, without any requirement for electrical power.
6. Satisfied communities willing to pay for delivery of a safe water service.

AguaClara Reach provides essential inputs in each phase of new program development, many of which were previously provided by the Cornell University AguaClara Innovation Laboratory during the development of the Honduran AguaClara Program. In the initial engagement and planning process, the organization is setup to collaboratively assess with potential Technology Implementation Partners the potential program scope and cost requirements, including the applicability of the AguaClara technology in various locations. AguaClara Reach then adds value through the detailed planning and development phases, providing hydraulic design support and training of Technical Implementation Partners. During the construction of an initial pilot demonstration facility, the organization facilitates training in AguaClara-specific construction methods and prepares Technology Implementation Partners for selection and training of a local community water board and operation and maintenance of the facility. AguaClara Reach can provide advanced technical support during ongoing operations and maintenance and is able to troubleshoot facility performance issues.

Adequate access to water and sanitation is a fundamental necessity of civilization. Nations can only advance socially and economically as livability and quality of life are progressed. This can be ensured through enhanced action at the local level for the common good.

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