THE PENNYSLVANIA STATE UNIVERSITY – CORVINUS UNIVERSITY

Water in Haiti:
The Nan Plim Facility

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Executive Summary

The Island of La Gonave is a developing region that suffers from poverty and water scarcity. Supplying potable water to communities across La Gonave Island is a challenging task. Organizations such as Roots of Development and the Peasant Association for the Development and Advancement (APDAG) of Grans Sous are working to assist communities on the island with this task. Roots of Development has sponsored this report, which addresses critical issues associated with the challenge of providing potable water. This report focuses on the water facility that is currently being constructed in the town of Nan Plim, which is representative of communities in La Gonave.

To address the needs outlined by Roots of Development, a comprehensive literature review that addresses water treatment methodologies and financing mechanisms for water facilities in rural Haiti has been performed. A quality assurance calendar, treatment methodology design, and financial plan have been developed based on appropriateness and effectiveness. While conducting these tasks, development ethics were considered.

The quality assurance calendar is a tool that serves to ensure that the water facility is properly maintained and operated by reminding the facility operator of tasks that need to be completed, such as inspecting the facility for cracks and leaks, refilling the tank, testing the water, and removing sedimentation from the tank. The calendar also allows for maintenance records to be documented. In the future, it is recommended that an educational system be developed to inform the community of safe water treatment and consumption practices.

As part of the treatment methodology design, a flow-dependent chlorination device has been designed and recommended for the facility of Nan Plim. Design calculations for this device have been provided. It is recommended that this device be tested, calibrated, and implemented. Also, commercial bleach should be used and a five month supply of bleach should be maintained at the facility. Future considerations should include an analysis to understand the point at which it would become beneficial to use a chlorine generation device.

A financial plan that incorporates initial funding costs has been developed, and it is recommended that Roots of Development use crowdfunding websites. Additionally, plans for generating the operation and maintenance costs were developed to enable sustainability and self-financing. It is recommended that the community grow mangoes and coffee to sell abroad, or sell jerry cans filled with water to local communities.

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1. Introduction

La Gonave; The Forgotten Island

La Gonave is a small (65km x 15km) island off the coast of Haiti, with a population of approximately 130,000 people. While Haiti is a country with a number of endemic problems, this region suffers from particularly difficult circumstances. This is largely a result of the central government's apparent disregard for the population; for example, the island's power lines were discontinued in 1987. Additionally, it has no major surfaced roads, sewage and latrines were never built, and water infrastructure is extremely scarce (La Gonave, The Forgotten Island, 2010). The situation in La Gonave is further complicated by the earthquake which struck Haiti in 2010. Approximately 40,000 people left the main island of Haiti and fled to La Gonave in search of shelter, food, and the hope to reunite with their families. This led to the small island's population increasing by more than 30% within two weeks, driving an already stressed community to the brink.

Figure 1.1: La Gonave Island off the coast of Haiti (Economy of Haiti)

Water Scarcity

Over the last two centuries, extreme deforestation has taken place on the island as residents have cut down trees to use as fuel. Combined with significant rainfall (800-1600 mm per year) and hilly terrain, serious erosion has taken place. With nothing to retain moisture, rainfall is lost directly to the sea through surface runoff on a regular basis, and access to fresh water has become a critical issue. Prior to 2009, La Gonave did not have any source of treated drinking water that conformed to the World Health Organization Guidelines. While there is a recently-built water facility in Gran Sous that addresses this issue, serving an estimated 6,000 users with 18,000 liters of capacity, many people must walk almost 15 km per day to collect water. In order to alleviate the strain on Gran Sous and provide a more local supply, another water facility has been proposed for the smaller community of Nan Plim; it is intended to serve about 2,000 people with a reservoir capacity of 20,000 liters (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011).

Figure 1.2: Haitian gathering stream water (Economy of Haiti)

PESTEL

PESTEL framework is a commonly used tool to describe and analyze the macro-environment; it stands for Political, Economic, Social, Technological, Environmental and Legal factors. All of these components, which are defined in Foundations of Economics (Gillespie, 2011), will be included in the following subsections.

Political

Due to recent Haitian history, significant political issues can be expected. The indicators of political risk and instability are high; since 1987 there have been 12 separate governments. Democracy is formally in use, even if there is no effective governmental structure (Poverty Reduction and Economic Management Unit, 1998).

Economic

Haiti is the most economically disadvantaged country in the Western Hemisphere. This is a result of recent natural disasters, like the earthquake that struck in 2010, combined with historical factors. Correspondingly, the government must rely on formal international financial support for fiscal sustainability (Economy of Haiti).

In addition to the previous issues, poverty, high inflation, and corruption handicap the economy and hamper new investments in the region. This is exacerbated by a lack of education, which is unattainable for much of the population. However, Haiti is a free economy and exhibits some favorable economic factors such as low labor costs and tariff-free access to the US market for numerous products, which promotes the volume of exported goods (CIA).

The economy of La Gonave is limited, as it relies on small farming enterprises which produce primarily coffee, cocoa and mango. These are sold either locally or at the capital Port-au-Prince, but once the ferry fee to the mainland has been paid farmers are typically left with next to nothing. Also, while there are industrial enterprises operating on the island, their performance is negatively impacted by the lack of electricity. (Orietta, 2010)

In Haiti the official currency is the Haitian Gourde (HTG). Nevertheless in many places the prices are not determined in HTG, but in “Haitian dollars” (HT). Due to the difference in currencies it is necessary to be aware of the average exchange rates: 5 HTG = 1 HT and 8 HT = 1 USD.

Social

Like La Gonave, a majority of Haitians depend on the agricultural sector, but since cultivable land is limited due to the number of mountains, these Haitians can be described as small-scale subsistence farmers. This defines the social fabric of the country, as other industries like mining, manufacturing, textiles, sugar refining, flour milling, cement, and light assembly have a low GDP contribution and limited importance. Other than farming, the only significant contributor is the service sector, which accounts for about 52% Haiti’s GDP but only 25% of overall employment. Research has shown that this sector is steady and initially expanded in the 1990’s (Economy of Haiti).

According to the CIA database, 80% of the population lives under the poverty line and 54% in abject poverty, which is one of the most significant problems in Haiti (CIA). There is no official information on unemployment, but it is estimated that more than two-thirds of the labor force do not have formal jobs and 50% of the population is unemployed. With regards to La Gonave, there are different income classes present on the island, but all of them are considered underprivileged. Most of the people have no formal jobs, but residents are willing to work and are actively looking for employment opportunities (Kenney, 2010).

Furthermore, in recent years over-fishing has resulted in a serious decline in the annual harvest which many residents rely upon. This, combined with the aforementioned factors, means employment opportunities are extremely limited and hunger is widespread. The increase in population has exacerbated the incidence of many diseases which are now prevalent on the island, but few people can afford medications and visits to the distant hospital. Last, but not least, transportation and means of communication are unavailable to most (Mitra).

Technological
Unfortunately, this factor is a difficult barrier for economic expansion. According to our client, Geoffrey Kurgan of the World Bank, infrastructure is in general disrepair or nonexistent. Roads are not paved, electricity is not common, and only rich families have access to a generator. Drinking water is not secured in this region, and is not provided at the municipal level. Additionally, telecommunications are extremely limited on La Gonave. Lastly, agricultural products are grown through outdated tools and methods; efficiency is limited.

Environmental
As mentioned, the island is largely deforested and suffers from soil erosion. This leads to low-quality crops and land loss, an unfortunate reality that has been problematic for decades. Also, recent natural disasters have not only disrupted the economy, but the local environment as well.

Legal
It is very difficult to collect information regarding this topic, so some assumptions with respect to regulations and legal terms in Haiti must be made. Namely, due to the low living standards and separation from the main island, governmental influence in La Gonave is minimal. Rather, local laws established in different communities are common.

1.1 Problem Statement

In order to address the needs outlined by Roots of Development, a comprehensive literature review must be performed that addresses water treatment methodologies and proven financing mechanisms for rural municipal water facilities. In particular, this will take into account the unique conditions present in developing countries. Additionally, a quality assurance calendar, treatment methodology design, and financial plan must be developed based on the best practices and knowledge gained in the literature review. When addressing these tasks, the overarching principles of development ethics will be taken into account and applied to proposed solutions. Therefore, the team performed a root cause analysis (Appendix C).

1.2 Project Definition

Value Proposition

The idea of this project is unique because it offers marginalized communities the opportunity to improve their lives in significant ways. The best financial and water treatment practices, combined with innovation and an awareness of development ethics, have real potential to change the current situation so that people are no longer afflicted by water-borne illnesses on a daily basis. With improved clean water access, health, economic and social improvements soon follow; children can attend school, fathers can work. This can be realized through the intersection of engineering knowledge from The Pennsylvania State University and business acumen from Corvinus University, which will produce a solution addressing the multitude of issues facing La Gonave.

Scope

Our proposed project consists of four distinct tasks, divided into two phases. The first phase, a literature review, encompasses equipment and techniques as well as funding sources. The former should be gathered from accredited organizations like the World Health Organization, National Ground Water Association, and Centers for Disease Control that have experience with conditions similar to those found in La Gonave. As for funding sources, they must be appropriately chosen and accessible to local residents or the sponsoring NGOs, APDAG, and Roots of Development.

The second phase, solution recommendations, consists of a quality assurance calendar, water treatment device, and financial management plan. The calendar must contain all testing, maintenance, and safety checks required by the facility managers in a manner that is appropriate for a largely illiterate audience. As for the treatment device, recommendations will be made and a suitable prototype constructed based on information gathered during the literature review. Specifically, this prototype will be accompanied by a list of all required materials and an operation guide. Lastly, the financial management plan will outline the facility's cost structure, including a means to mitigate the associated short and long term monetary demands. This requires exploring various foreign funding sources and their implementation, including the associated dependency imposed on the community.

Customers/Clients/Stakeholders

This section's aim is to provide information on the stakeholders of the project. These stakeholders include the La Gonave residents and the people who work on the project.

Stakeholders are entities within or outside an organization who are involved with the project. The three major categories include the sponsor of a project, those who have an interest in the successful completion of the project, and those entities that may have an influence in project completion (Project Stakeholder).

After thorough analysis, the following stakeholder groups were identified:

- La Gonave residents
    - Gran Sous residents
    - Nan Plim residents
    - Site manager
    - People living at the port of La Gonave
- People and organizations working on the project
    - Roots of Development, sponsor
    - APDAG
    - Yee Chen, on-site engineer working with local communities on the island of La Gonave
    - Geoffrey Kurgan, World Bank
    - Instructors and TAs at The Pennsylvania State University (PSU) and Corvinus University of Budapest (CUB)
    - Students of PSU and CUB.

Part I: Literature Review

2. Water Safety Practices

All major sources of water require a water safety plan (WSP) to ensure the safety and quality of the water provided. Traditionally, a WSP in an industrially developed region is established and controlled by a local governmental agency. However, due to the economic, social, and cultural differences between developed and rural areas, the specifications and requirements for a WSP must also be different. For the Nan Plim water facility, a WSP must only meet the basic health-based requirements. Maintenance and repair plans will be also limited due to resource availability (World Health Organization, 2011).

Steps to develop a WSP as suggested by the World Health Organization (WHO): (World Health Organization, 2011)

1. Describe and model the water system from source to consumer
2. Identify where and how hazards or contamination sources can affect the water
3. Assess the existing water system and its effectiveness to control hazards and contamination
4. Identify new or improved methods of controlling the risks and hazards
5. Define water quality standards
6. Establish a monitoring system to ensure the safety plan is effective
7. Develop supporting programs, like training, operating procedures, etc.
8. Prepare management procedures and incident correction methods
9. Document the procedure and suggest future improvements

For rural communities, the Centers for Disease Control and Prevention (CDC) encourages that a pilot program be conducted before a fully functional WSP is implemented. Pilot programs are used to, "Iron out logistics and understand community reaction and acceptance" (Lantagne & Gallo, 2008). The Gran Sous facility has served as a pilot program for the Nan Plim facility. However, the Nan Plim facility will not be the last water facility to be installed. Roots of Development, the Non-Governmental Organization (NGO) in charge of the project, will continue to improve water availability throughout Haiti. Each facility will improve upon the last, in a long-term effort to establish reliable water resources in rural communities throughout Haiti (Roots of Development).

For the Nan Plim facility, most of the WSP process has been completed by the NGO, the on-site engineer, and the Haiti 2011 project team. The most important step yet to be completed is the establishment of the monitoring system to ensure the safety plan is effective. However, this report will also include details for other critical aspects of the WSP, such as hazard identification and control, for the purpose of providing a thorough literature review for future water facilities in La Gonave.

2.1 Hazard Identification and Control

Hazards are defined as: physical, biological, chemical, or radiological agents that can cause harm to public health. A hazardous event is defined as: an event that introduces hazards to, or fails to remove them from, the water supply (World Health Organization, International Water Association, 2009). Based on this definition, all potential sources of contamination or threat to the water supply must be identified as hazards. These hazards occur at four general locations in the water system: catchment, distribution network, treatment, and consumer premises. Based on anticipated occurrence rate and level of severity, each hazard is assigned a risk rating. Hazards that occur more frequently and produce a greater threat to the quality or supply of the water receive higher risk ratings. Therefore, hazards with high risk ratings should receive the most attention when developing control and treatment methods (World Health Organization, International Water Association, 2009).

Control measures must be improved or implemented to address each hazard. Table 2.1 shows an example list of hazards, their risk rating, method of control, and risk rating after the control is implemented. For a more complete list of potential hazards and control measures, please refer to the WHO Water Safety Plan Manual (World Health Organization, International Water Association, 2009).

Table 2.1: List of potential hazards and respective control measures (World Health Organization, International Water Association, 2009)

Hazard	Hazardous event (source of hazard)	Likelihood	Severity	Score	Risk rating (see table 3.6)	Example control measure	Validation of control measure	Reassessment of risk post-control
Microbial	Low chlorine residual in distribution and reticulation systems	4	4	16	Very high	Set point designed to achieve established target chlorine residual to achieve microbial standards at consumer premises linked to alarms.	Alarms effective and demonstration of consistent removal of indicator organisms under range of operating conditions.	Low with appropriate operational monitoring.
Microbial	Power failure to disinfection plant	2	5	10	High	Dual power source.	Supplies confirmed to come from different generating sources. Automatic switching shown to be triggered under a range of operating conditions.	Low with appropriate operational monitoring.
Physical, chemical, microbial	Contamination of dosing chemicals or wrong chemical supplied and dosed	2	4	8	Medium	On-line monitoring controls. Laboratory analysis certificate from supplier.	Intensive audit of suppliers. Alarms triggered under a range of operating conditions.	Low with appropriate operational monitoring.
Chemical	Over or under dosing from fluoridation plants	3	3	9	Medium	Plants have alarms on high and low levels with dosing cut-offs on high levels.	Alarms triggered under a range of operating conditions.	Low with appropriate operational monitoring.
Chemical, physical	Over or under dosing of lime for pH correction	3	3	9	Medium	Plants have alarms on high and low pH with dosing cut-offs on high pH.	Alarms triggered under a range of operating conditions.	Low with appropriate operational monitoring.
Physical	Failure of pumps	4	3	12	High	Pressure measurement triggering back-up pumps. (Not in place.)	No controls in place.	High - priority for mitigation.
Chemical	Nitrate exceeds compliance standards	3	2	6	Medium	Blending with low-nitrate source from another water supply. (Alternative source itself has rising levels of nitrate and is subject to other demands.)	Unreliable long-term control.	Medium - keep trend under regular review and propose alternative mitigation scheme.

2.2 Water Quality Standards

Once control measures have been developed, water quality standards must be determined. These standards most often refer to bacterial, microbial, and chemical content within the water after it has been treated. For example, as indicated in the Haiti 2011 Final Report and WHO standards, treated water should have a Free Active Chlorine (FAC) concentration of no less than 0.2 ppm and no more than 1 ppm (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011). These concentration parameters are sometimes referred to as critical limits. Critical limits are determined by the tolerable effects of the hazard (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011). As such, developed countries are likely to hold a lower tolerance for disease caused by water-borne bacteria than a rural village.

2.3 Quality Assurance and Maintenance Plan

Every water safety plan must be financially sustainable, especially in undeveloped rural areas where resources are scarce. When developing control measures, the WSP team must consider what local resources are available, and if resources must be purchased, the water facility must generate an income in order to sustain such expenditures.

Long term care can be divided into two categories: water quality assurance and facility repair. Water quality assurance includes testing the water for harmful chemical or bacterial concentrations on a regular basis. This requires resources such as testing equipment and chemicals that the water facility must purchase. The facility repair includes regular maintenance work such as general cleaning of the facility, cleaning of the filters or sediment tank, and repairing any damaged equipment or structural components. The tools and equipment necessary to perform these tasks must also be available should they need to be replaced (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011).

These maintenance tasks hold great importance and must be carried out on a regular schedule. Failure to comply with a strict schedule can result in unsafe drinking water, the spread of water-borne illnesses, or costly damage to the water facility (World Health Organization, International Water Association, 2009). Therefore, a schedule must be developed that is easy to follow and understood by the locals in charge of the facility. In rural areas, the WHO suggests that the residents be educated on the importance of the WSP and the implications of contaminated water (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011).

3. Case Studies

The need for clean water is imperative, and the impact caused by its absence is felt throughout the world. Over 3.5 million people die each year due to water related causes, and an estimated 884 million people lack access to clean water (The Crisis). The issue has become so pressing the United Nations (UN) has declared it one of its prime Millennium Development Goals, as part of the objective to ensure environmental stability (Millennium Development Goals). The method by which communities approach this problem is unique, varying widely between countries and even local regions, as can be seen in the following representative examples.

3.1 PEACEwater

In Karongi, Rwanda there are several challenges that mirror those found in Gran Sous and Nan Plim, Haiti; namely, due to nonexistent infrastructure, these African communities make use of open springs that are consistently unsafe to drink due to bacterial contamination (McBride & McBride, 2010). This problem is exacerbated by an absence of sanitary education, leading to individuals lacking an understanding about contaminated water and health issues. In order to address these problems, the solution presented by PEACEwater (Clean Water Initiative) is twofold: implementation of McGuire purifiers invented by Water for the World (New Life International) in addition to Hach coliform bacteria test kits. PEACEwater as well as Water for the World are Christian outreach organizations providing clean water education and purification technology to the developing world, mainly based upon the aforementioned approach. The McGuire purifiers were selected for their ease of use, reliability, and applicability to community-level solutions where water is readily accessed but not clean. With regards to the Hach testing kits, they are used to serve a practical and educational purpose, checking the safety of pre- and post- treated water as well as providing visual proof of an otherwise invisible danger (Figure 3.1).

Figure 3.1: Hach testing kits (PEACEwater – 1)

Each solution is accompanied by a maintenance and operations guide which combines step by step images with translated instructions (PEACEwater - 1) (PEACEwater - 2). This documentation is integral to the deployment of the systems, carried out by volunteers who train local maintenance workers.

Figure 3.2: McGuire system in Haiti (Sawyer Products)

In addition to the McGuire systems, several other solutions have been implemented as well. Point of use Sawyer filters (Sawyer Products) have been successful on a smaller scale, again in locations with readily available but unsafe water. Furthermore, in regions with underground water supplies, wells were constructed to provide clean water without further purification. In this particular case there was an emphasis on health training as community members traditionally use dirty jerry cans to transport their water, which reintroduces pathogens.

3.2 Drinking Water in Kuna Yala: Field Notes from Panama

Kuna, off the northeastern coast of Panama, is an island facing many of the same issues as La Gonave (Halperin). As reported by a Peace Corps volunteer, the long standing and accepted filtration method was a sand tank (Figure 3.3), but design failures led to ineffectiveness and prevalence of water-borne diseases in the community.

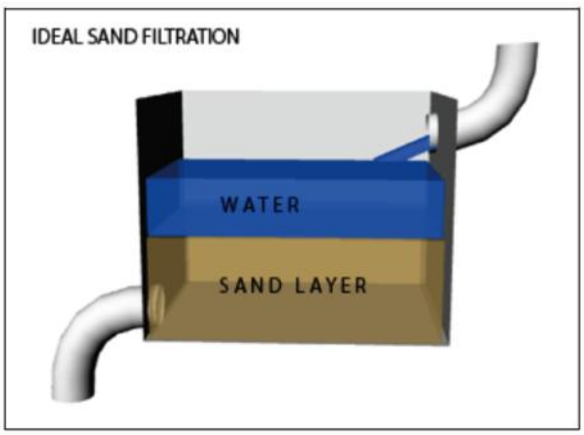


Figure 3.3: Sand filtration tank (Halperin)

Fixing the current system was financially impossible, so alternative solutions were pursued in a sequential manner. Among these solutions, the idea of solar purification was proposed, where a bottle was filled with water, sealed, and placed in the sun for six hours; this method was particularly ideal because plastic bottles were inexpensive and plentiful on the island. While this method didn't encounter cultural resistance, it lacked widespread interest because the community didn't have an understanding of the invisible dangers they faced. Eventually, they had to be presented with a microscope and visual proof of pathogens, which spurred the women to action and thereby resulted in consistent use by families across the community.

3.3 Community Water Solutions

In Northern Ghana, many women spend a significant portion of their day collecting water from open sources known as dugouts. As is the case with many unprotected springs, the water has a large amount of suspended particles and bacteria, primarily from animals using it as well. Therefore, Community Water Solutions (CWS) decided to intervene, introducing centralized water treatment in the form of small businesses (Community Water Solutions). Community members pay a nominal fee to collect their water, and then use it in their homes with safe storage containers designed, manufactured, and distributed by CWS; domestic recontamination is a major issue addressed by these specifically designed containers (Figure 3.4).

Figure 3.4: CWS distribution and Storage (CWS)

Women operating these centers are then able to take the profit and reinvest it in their families and village – there is one particular story about the operator of the Kasaligu facility sending her children to primary school, the first in her family to do so. Also, the operators are given financial training in money management, further enhancing the sustainability of these projects. Ultimately, this clean water solution is owned, run, funded, and maintained by the community in which it operates, as can be seen across thirty five locations and 20,000 users to date.

3.4 Safe Water for Families Project

The community of Jolivert is located in northern Haiti, and while it is on the mainland, it still suffers from a lack of clean water infrastructure (Safe Water for Families Project). In order to address this problem the Safe Water for Families Project utilizes the AquaChlor chlorine generator (Figure 3.5) (Equipment and Systems Engineering, Inc.).

Figure 3.5: AquaChlor chlorine generator (Equipment and Systems Engineering, Inc.)

The operators of the generator are local technicians who, in addition to production, conduct training, household visits, regular testing, and maintain records. The disinfectant is distributed to families in 250 ml reusable bottles that are available in the village (at $0.10 per bottle) or from a number of resellers in surrounding communities (at $0.16 per bottle). The profits from these sales allow the program to be sustainable, and all staff salaries are supported in this manner.

4. Chlorination Methods in Developing Countries

4.1 Manual Chlorination

In developing countries, chlorination is typically performed manually, either at a storage reservoir or at the point of use (Schuhmann & Karlheim, 2012). Point-of-use chlorination involves treating the water after it is gathered, but before it is used. The advantage of point-of-use treatment is that it can be implemented on any existing water system. Typically, chlorine is distributed to users, who are then responsible for treating their water. While point-of-use treatment is easily achievable, there are several disadvantages, including a likelihood of insufficient contact time between the water and disinfectant, over dosing, or under dosing, all of which can be dangerous (Chlorine Dispensers for Safe Water).

Many times, manual chlorination is performed on the water storage tank in a village. Treating the water at the reservoir is advantageous, yet the same concerns with point-of-use chlorination are present. The common practice involves dosing the reservoir daily, or each time the tank is filled. The dose is usually based on previous chlorine demand. In some situations, increased water demand can cause the water supply to be insufficiently treated (Safe Water for Families Project). This points out that the use of a chlorination device can be very beneficial.

4.2 Flow Dependent Chlorination

To avoid issues with dosing, a flow-dependent device can be used. A flow-dependent device ensures that the water is automatically and appropriately dosed as water flows through the device. This type of device can reliably dose a water supply, and requires less operator dependence. The Pennsylvania State University has developed a low-cost flow-dependent device for use in developing communities. The device is to be placed in-line with the influent water pipe into a reservoir. When water flows through the device, it is automatically chlorinated. Bernoulli's Principle is utilized to create a pressure differential that draws sodium hypochlorite (NaOCl) solution into the water from a small chlorine reservoir. This is done with the use of an orifice plate, shown in Figure 4.1 (Schuhmann & Karlheim, 2012).

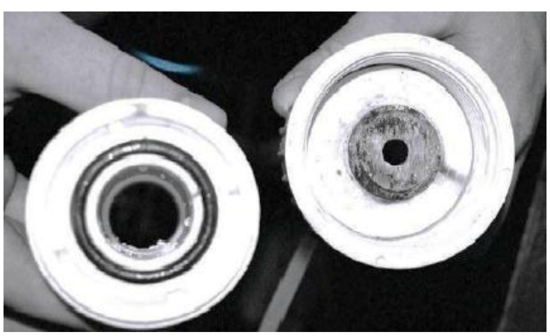


Figure 4.1: Orifice plate (Shuhmann and Karlhelm, 2012)

The orifice plate restricts the diameter of the flow, which increases the flow velocity. The increase in velocity causes a decrease in pressure, so that the pressure is actually negative at a location directly after the orifice plate. The vacuum pressure pulls sodium hypochlorite through a small tube and into the influent water pipe. A schematic design of the device is shown in Figure 4.2 (Safe Water for Families Project; Schuhmann & Karlheim, 2012).

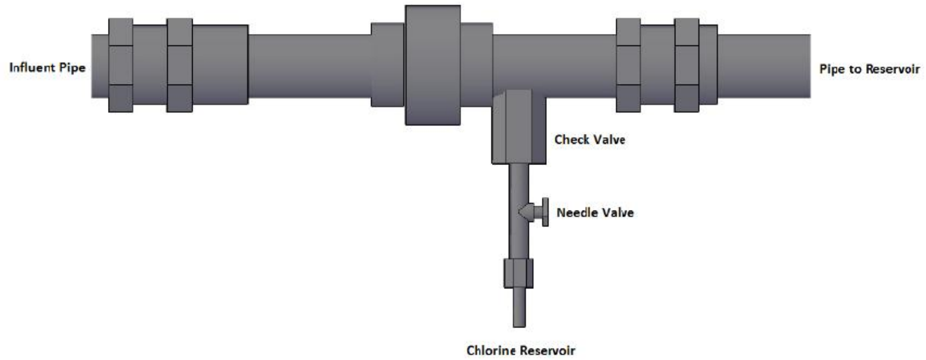


Figure 4.2: Flow dependent chlorination device (Schumann and Karlheim, 2012)

The device is constructed of easily available PVC pipes and fittings. However, there are two parts that are not as readily available. These are the check valve and the needle valve. The check valve allows chlorine solution to be pulled into the pipe during flow, and also prevents water from exiting the pipe when there is stagnant water in the device (periods between filling a reservoir). The needle valve controls the diameter of the chlorine inlet tube, and thereby allows the dose of chlorine to be adjusted. For use in developing countries where these parts are not available, replacement parts may be supplied (Safe Water for Families Project; Schuhmann & Karlheim, 2012).

Figure 4.3: CTI-8 Chlorinator (Safe Water for Families Project)

A similar device is available from Compatible Technology International. The device is called the CTI-8 Chlorinator, shown on in Figure 4.3. This device is being used in parts of Nicaragua. Similar to the chlorinator designed at the Pennsylvania State University, the CTI-8 is a flow-dependent device constructed of PVC pipe. The device is placed at the influent water pipe, and can appropriately dose a water reservoir. Instead of using sodium hypochlorite solution, the CTI-8 uses calcium hypochlorite tablets to treat the water (Compatible Technology International). In areas where tablets are not readily available, this is a disadvantage to using the device.

4.3 Chlorine Generation

Chlorine is often scarce in developing countries (Morganti, 1999). All of the previously described methods of treatment require the use of chlorine as a disinfectant. Chlorine can be generated on-site using salt water and electricity. This is becoming an increasingly common practice in developing communities. There are numerous devices that can generate some form of chlorine. The most common of these devices generate sodium hypochlorite. For this to happen an electrolytic cell is placed in brine solution, and reactions take place at the anode and cathode to produce sodium hypochlorite. A detailed explanation of the chemical process can be seen in *La Gonave Water Project,* a report produced by Corvinus University of Budapest and the Pennsylvania State University in 2011 (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011).

A case study performed in Haiti by the Massachusetts Institute of Technology in 2001 found that chlorine generation using brine solution and electricity is the most appropriate method for Haiti. Salt was found to be readily available and is expected to continue to be. Additionally, it was determined that impurities in Haitian-produced salt were not problematic for sodium hypochlorite generation (Zyl, 2001).

A case study using this type of device has been performed in Nepal by the Massachusetts Institute of Technology. In this case study, the device that is used is the SANILEC-6. Shown in Figure 4.4, this is a portable device that can generate sodium hypochlorite as needed. It consists of an electrolytic cell and a power source. The electrolytic cell is placed in a reaction tank containing brine solution. After the reactions take place, a sodium hypochlorite solution remains. This device can produce about 2.7kg of available chlorine in 24 hours. The concentration of the sodium hypochlorite solution produced is not considered hazardous, which is ideal for safety purposes (Morganti, 1999).

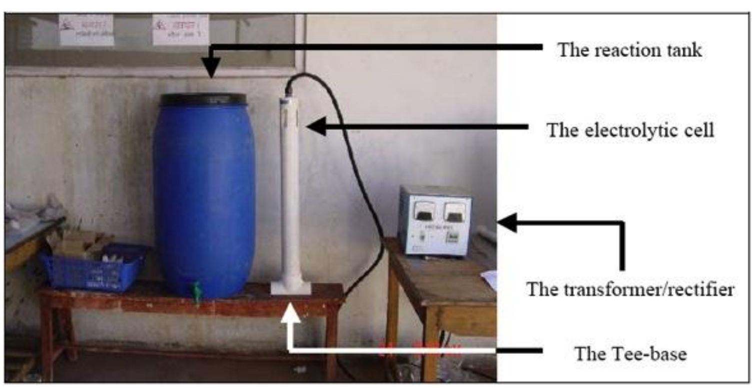


Figure 4.4: SANILEC-6 sodium hypochlorite generator (Morganti, 1999)

Many other similar devices are available, including the AquaChlor chlorine generator that was previously mentioned. The devices vary in size, efficiency, and availability. If a sodium hypochlorite generation device is desired for use in a specific developing community, the driving decision behind which device to use will likely be product availability and cost.

4.4 Current System in Gran Sous

The New Life McGuire Purifier both generates disinfectant and treats the water. The McGuire device is a different type of chlorine generator. The type of chlorine generated is chlorine gas, which allows the device to easily treat the water as the chlorine is generated. A schematic design of how the device is implemented in a system is depicted in Figure 4.6. As shown, brine solution made from available salt and water is added to the device. With the introduction of electricity from a battery, the device produces chlorine gas. As this is happening, water is being pumped through a pipe that runs above the gas production chamber. At this point, gas is automatically introduced into the water (PEACEwater - 3).

Figure 4.5: New Life McGuire purifier (PEACEwater – 3)

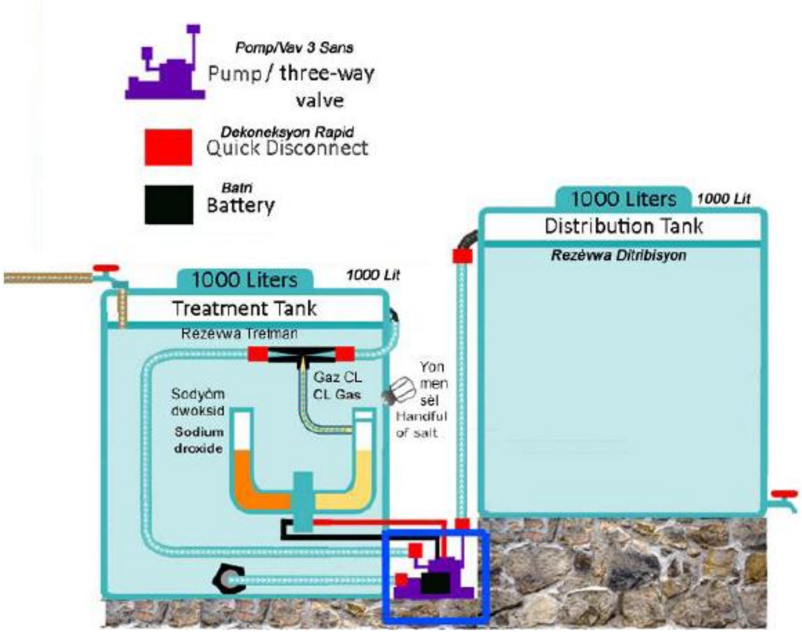


Figure 4.6: McGuire device system integration (PEACEwater – 3)

The water in the treatment tank is circulated through the McGuire device with the pump. The pump will continue to run until adequate dosage is reached. PEACEwater has provided a complete instruction set for the device, including the determination of chlorine dosage. To determine when the dosage has reached the appropriate level, a water testing kit is used. The recommended dosage is 5 mg/L, which is not to be exceeded to ensure that WHO standards are met. If the dose is too high, more untreated water needs to be introduced into the treatment tank. If the dose is too low, the water should continue to circulate through the McGuire device. Once the dosage is determined to be correct, the power should be disconnected from the McGuire device, and the pump should continue to run for one hour. At this point the water should be tested again. If the remaining dose is less than 2 mg/L, the device should be turned on and more chlorine should be introduced to bring the water to the 5 mg/L mark. The process should continue until the dose after one hour is 2 mg/L or more. At this point the three way pump should be switched on so that it pumps water from the treatment tank into the distribution tank (PEACEwater - 3).

There are several advantages to using the McGuire device. One advantage is that a comprehensive manual written in Haitian Creole has been developed. Although this manual is picture intensive, it is still necessary to be able to read or to be trained to properly use the device and test the water. Additionally, having the chlorine generation and water treatment integrated into one device is beneficial because it allows for ease of use. There is no need for the chlorine solution to be transferred; this is done using chlorine gas. However, while chlorine gas is effective, it is also dangerous to deal with. Even at concentrations as low as 0.1% air by volume, chlorine gas can be deadly.

Additionally, there are disadvantages to using the McGuire device. The main disadvantage is that the device does not allow for flow-dependent dosing. The actual dosage is variable and cannot be accurately predicted without testing. Because of the difficulties associated with training and education in developing communities, the device may also be susceptible to improper use. This is especially concerning when dealing with chlorine gas (National Drinking Water Clearinghouse, 1996). Additionally, the use of a pump is energy intensive and may lead to problems for large systems. The device is also costly at around $2,000 USD, according to the Site Engineer, Yee Chen.

4.5 Treatment Methodology Decision

The two treatment systems that will be considered for use in water facilities in Nan Plim are the McGuire purification system and the flow-dependent chlorination system developed at the Pennsylvania State University. Another similar chlorination device discussed was the CTI-8 Chlorinator. This device uses chlorine tablets, which are not always readily available, therefore the device is not considered for use. The McGuire device is considered because of its effectiveness and familiarity at the water facility in Gran Sous. The flow-dependent device developed at the Pennsylvania State University is considered because it is an inexpensive and effective system.

To quantify the above comparison, a Pugh decision matrix is used. The current system, the McGuire Purifier, is set as the baseline for analysis. The alternative options are compared to the current system. The categories considered for comparison are feasibility, cost, long-term benefits, maintainability, and effectiveness. If an alternative is considered to be better than the current system, it is assigned a value of one. It the system is not better or worse a zero is assigned. A negative one is given for categories where the alternative is worse than the current system. The baseline is given all values of zero. Table 4.1 shows this analysis. Manual chlorination is also analyzed for comparative purposes.

Table 4.1: Pugh Decision Matrix for water treatment

	Baseline	Alternatives	
Criteria	Current Solution (McGuire Purifier)	Manual Treatment	Flow-Dependent Device
Feasibility	0	-1	1
Cost	0	1	1
Long Term Benefit	0	-1	1
Maintainability	0	1	0
Effectiveness	0	-1	1
Positive Sum	0	2	4
Negative Sum	0	3	0
Neutral Sum	0	0	1
Total	**0**	**-1**	**4**

In this analysis it is shown that the use of the flow-dependent device developed by Dr. Schuhmann of The Pennsylvania State University is the best option. This device is considered to be more feasible than the McGuire Purifier since the design is simple, the parts are expected to be readily available, and no electricity is necessary. The cost is also expected to be much lower than the current system in Gran Sous. The device also ranks higher than the McGuire device in the long-term benefit category. The simplicity of the design allows it to be a more sustainable device and also allows for easy reproduction. Since the system needs to be monitored and refilled, and the check valve may not be readily available in Haiti, the maintainability is the same as the McGuire Purifier. However, the flow-dependent chlorinator is more effective since it delivers a predictable and controllable dose of chlorine.

Taking everything into consideration, a system similar to that of the flow-dependent chlorinator designed at The Pennsylvania State University will be designed and recommended.

4.6 Summary

There are many different water treatment methods and devices that are used in developing countries. Commonly, point-of-use treatment is used because it is easily implementable. Although this can be effective, it is difficult to have quality assurance. The ideal method would involve treating the water before it is collected by the community members. This can be done with the use of a chlorination device. The devices use sodium hypochlorite solution, chlorine gas, or chlorine tablets. Sodium hypochlorite solution is the same as household bleach, which can be bought locally. It can also be generated using brine solution and a generation device.

Design decisions were made based on appropriateness of the solutions for the Island of La Gonave. The flow dependent chlorinator is most suitable, since it is a simple and dependable system. Therefore, this device will be designed and prototyped for Nan Plim.

5. Financial Review and Assessment

In order to provide financial recommendations, the current economic and infrastructural factors in Haiti must be considered. In addition, it is important to realize that this project is unique in terms of ownership and usage of the water facility. This will be addressed through a section detailing planning and management practices, which will define the approach required to establish a well-functioning management and financial system. Next, it is essential to focus on the various financial phases: funding the construction of water facilities and generating revenue to cover the costs of operation and maintenance. A comprehensive list of financial opportunities, ranging from traditional organizations to less conventional sources, is provided. Furthermore, our team will provide a collection of best practices to financially sustain the water facility in the future.

Based on literature research (National Drinking Water Clearinghouse, 1996), there is a set of key principles that can lead to a state of financial sustainability. In order of importance, these factors are the following:

1. Identifying the cost implications of the project's characteristics and the environment
2. Maximizing the willingness to pay
3. Clarifying financial responsibilities
4. Optimizing operation and maintenance costs
5. Setting an appropriate and equitable tariff structure
6. Developing an effective financial management system
7. Organizing access to alternative financial sources

The project is complicated due to the second principle: willingness to pay. The users will not pay money for water, which means that a compensation package/method to finance the facility must be developed. The rest of the stages can be performed based on best practices in other developing countries.

5.1 Construction

After determining the initial costs, a method must be developed to provide the required funds. Based on the examples of other developing countries, the team reviewed a wide spectrum of organizations, ranging from NGOs to donation websites and more. Due to the high number of these various organizations, this list is not comprehensive, but rather details opportunities with the most potential.

Crowdfunding

"Crowdfunding describes the collective cooperation, attention, and trust by people who network and pool their money and other resources together, usually via the Internet, to support efforts initiated by other people or organizations" (Crowd Funding). Crowdfunding websites are divided into three main categories:

- Websites for creative, for-profit projects (Kickstarter, RocketHub)
- Websites for donations and nonprofit projects (Firstgiving, Crowdrise)
- Microcredit crowdfunding websites (Kiva, Zidisha)

For-profit Crowdfunding (Kickstarter, RocketHub)
The general process required by this category is the following:

Step 1: Someone has a good idea but needs money to make it a reality. They put their project on a crowdfunding website such as Kickstarter.
Step 2: People are surfing on the web and find the aforementioned project. They watch the pitch video and if they like the idea, they can immediately support the project.
Step 3: The donation money is put on an escrow account. If donations reach the set limit at the end of the funding period, then the project gets all the money. If it doesn't, then all money is sent back to the individual contributors. This is called all-or-nothing funding.
Step 4: The project owners can start working on their ideas and when the final product is ready, pledgers get their reward; depending on the amount they donated, usually a copy of the product.

However, only for-profit projects can be listed on these websites. Therefore the project must be described as a business with the intention of making a profit. The project must also provide compensation to those who pledge.

Donations and Non-profit Crowdfunding (Firstgiving, Crowdrise)
The process here is very similar. The main difference is that the website only publish as nonprofit projects. Also, the donors usually don't get a reward, only some kind of

recognition. These websites offer the possibility to raise funds for projects, nonprofit organizations, and special events.

Examples of these websites include:

- Justgiving.com
- Bmycharity.com
- VirginMoneyGiving.com
- Firstgiving.com
- Startsomegood.com
- Crowdrise.com
- Causes.com

The aforementioned websites list a number of successful water projects and nonprofit organizations. Some notable projects include:

- Help Charity: Water provides clean and safe water in Ethiopia - $128,300
- Access to Safe Water and Sanitation in Bangladesh - $45,000
- Support safe water micro-enterprises in Ghana - $35,200

Microcredit Websites

This peer-to-peer lending is usually not made in the form of a single, direct loan, but rather as the aggregation of smaller loans with a negligible interest rate (Microcredit).

The most notable web-based microlenders include (Microcredit):

- Kiva
- Zidisha
- Lend for Peace
- Microloan Foundation
- iMicroInvest
- United Prosperity

In 2009, the US-based nonprofit Zidisha became the first peer-to-peer microlending platform to link lenders and borrowers directly across international borders without local intermediaries (Zidisha).

Figure 5.1: The lending process of Zidisha (Zidisha)

Peer-to-peer lending enables social entrepreneurship. These small loans can help poor people start their own business. This way they can make money and support the water facility project.

Foreign Direct Investment

This option is greatly dependent upon the profitability of the mechanism that will ensure the maintenance of the facilities; investors will eventually expect a return on their investment. Even though the investment is relatively small, a solid return expectation will have to be met. Speaking generally about the involvement of foreign sources, on the other hand, is much clearer. Most of the donation channels are based and founded in the developed world. Furthermore, they are mainly used by North Americans and Europeans.

Agencies

Agencies are typically internationally known organizations. Their financial position is strong and they have the ability to give loans and financial aids to less developed countries. Agencies generally include interest rates, durations and sources, but these rates are lower than those available open market. As a result, these agencies are preferred when funding investments which support essential resources like clean water. There are numerous agencies, nevertheless they all have a common theme: helping start-up a project. This can be done through direct sponsorship, helping gather donations on their own website, and much more. Two major agencies include the United Nations and Powered by Action.

Table 5.1 shows several agencies which provide help to water resource projects. These governmental/institutional agencies differ in terms of cost recovery, subsidies, and the role of the private sector. Nevertheless, these institutions are potential auxiliary financial service providers.

Table 5.1: Potential funding or supplying agencies (Technical Advisory Services, 2007)

Agency	Cost recovery	Subsidies	Role of the Private Sector
Danida (rural WS)	O&M cost and a proportion of investment cost	Subsidies are legitimate in achieving benefits for the poor- however criteria for use of subsidies should be transparent and in no cases exceed present government subsidy level	Can support strengthening the collaboration between the public and private sectors and channel funds for investments through public-private partnerships provided guarantees for social equity and services for the poor
DFID[8]	O&M cost as a minimum	Subsidies may be applied based on careful analysis	Private sector has a role in mobilizing new finance for WS.
SIDA[9]	Cost recovery systems ensuring sustainable yet affordable services	Cross-subsidization in favour of the poor may be required to ensure full cost recovery	Supports facilitation of international and domestic private banking sector lending to investments in public and private WS&S infrastructure for poor people in rural and urban settings
African Development Bank[10]	O&M cost	Social equity should be ensured	Based on community ownership to facilities, the private sector should provide goods and services required
GPOBA[11]	O&M cost + minimum 10% of investment	Explicit, output-based and targeted to the poor.	Key to ensure competitive pricing of investments and efficient operations

5.2 Operation & Maintenance

As detailed previously, the financial part consists of two segments. This chapter will discuss the second idea: revenue streams and potential income-generating mechanisms. As a result of considering the information contained in “Financing Mechanisms for Peri-Urban, Small Towns and Rural Water Supply,” (Technical Advisory Services, 2007) this section defines numerous financing mechanisms for projects similar to Nan Plim water facility.

Table 5.2: Potential financing options (Technical Advisory Services, 2007)

Financing Mechanism	Application in Water Supply
Tariffs including cross-subsidization	Tariffs are applied for all WS investments
Equity & user contribution	Applied for most WS investments
Grants	Grants funded by government or donors for capital cost are applied for most WS investments due to low cost recovery
Microfinance	Loans for individuals or groups for financing water connections as part of a piped scheme or hand pumps-Pilot stage
Output Based Aid	Pilot stage for piped water in small towns and rural growth centres
Risk guarantees	Pilot stage
Mixed credit	Used in urban WS
Commercial loans	Used for financing financially viable water supply investments-mostly in urban WS
Debt-Equity swaps	May be used for financing large urban WS
Bonds	Future option
Carbon credits	Future option

Table 5.2 contains many options to choose from, but there are nevertheless three which have the most relevance and potential. These will be explored in the following sections.

Public Private Partnerships (PPP)

Public Private Partnerships are a shift in terms of general responsibility between the public and the private sector (Technical Advisory Services, 2007). This kind of contract allows the public sector to transmit the general risks and responsibilities to a licensed private company, but the political responsibility has to be managed by the public sector. On the one hand, these partnerships are likely to generate additional financial resources, gain operational efficiency and innovation, optimize lifecycle costs or even mobilize management capacity at the private sector. On the other hand, PPPs mean a rise in transaction costs, and due to the long-term contracts signed at the beginning of the cooperation there is a loss of future flexibility as well. The PPP solution was successfully applied in Uganda, where several contracts were signed between private local firms, authorities, and the governmental ministry as well.

Microfinance Institutions (MFIs)

MFIs are aimed at low-income clients and/or solidarity lending groups, who cannot use banking and other kinds of financial services (Technical Advisory Services, 2007). As mentioned earlier, there is a gender balance issue in developing countries. Women, more than men, would be willing to pay for water and the MFIs' main target group is women who can establish and maintain a small business. It is important to emphasize the role of women in developing countries due to the external circumstances, which influence the economic development in rural and emerging areas. Specifically, these cultures have very low rates of female business owners and entrepreneurs and therefore have limited diversity.

"Fonkoze is Haiti's Alternative Bank for the Organized Poor, the largest microfinance institution offering a full range of financial services to the rural-based poor in Haiti. Fonkoze is committed to the economic and social improvement of the people and communities of Haiti and to the reduction of poverty in the country" (Building the Economic Foundations for Democracy in Haiti). The only problem with this option is the cultural behaviors mentioned by our sponsor, which entails people being reluctant to accept this opportunity. It is necessary to consider that the innovative financing mechanism would have to make profit in order to pay back the loan as well.

Output Based Aid (OBA)

OBA is a method to achieve development in rural areas through explicit output-based subsidies for essential service delivery. With this kind of financing possibility, service extensions may make poorer areas financially viable for companies (governmental or private) who are operating in the water supply sector. The name OBA comes from the timing of the subsidies given to the operators, because there are requirements that must be met in order to qualify for each additional component of the aid. Examples of these targets are outputs like household connections to a water piping system, which must be established and independently verified.

Other Financing Methods

- Risk guarantee: This is a tool that behaves like insurance, protecting the financial aid provided to the community against inappropriate applications. In particular, this would apply to loans intended to finance different infrastructural investments. Essentially, it functions as a risk mitigation tool for those involved in a given project (Technical Advisory Services, 2007).
- Growing coffee, cocoa and mango in order to sell them at the local or regional market: a given share of this revenue (e.g., 50%) could be the basis of the sustainable financing mechanism. The villagers could act collectively so they would have a better bargaining position, which means better prices for these goods. Main Haitian commodities include: apparel, oils, cocoa, mangoes, and coffee.

Figure 5.2: Coffee beans, cocoa beans, and mango

- Due to the lack of water resources, water means power and possibilities in this region. The people of Nan Plim could capitalize on their access to clean potable water by selling it to their neighbors, who also need clean water. While this looks a viable plan, there is an obstacle to implementing it. As a result of the community's stated belief that water is a given and essential right to the human race, they would never charge for it. However, they might pay for bottled or packaged (plastic bag) water products, since it contains materials that represent an added value. Other possibilities are so-called barter deals, where both parties pay with goods and no money is involved in the transaction.
- Kiva Microfunds is a nonprofit organization that works to connect lenders and borrowers through partner microfinance institutions. Personal stories detailing the need of those asking for a loan are provided, along with statistics regarding the particular Kiva field partner they are registered with. To date, $305 million has been lent to over 769,000 borrowers; 98.92% of which have repaid their loan as expected (Kiva). While this is not a direct solution to the water scarcity problem, it represents a possibility for intermediary support.

Part II: Solution Recommendations

6. Water Treatment Design Methodology

This section describes the calculation methods associated with the design of the recommended water treatment device. User manuals for the device have been developed and are discussed. In addition to the design of the chlorination device, methods for obtaining chlorine are evaluated and discussed. Furthermore, a contingency plan is recommended for unforeseeable events that may occur.

6.1 Design Development

System Demands

Before the device is designed, relevant information about the facility must be collected. For the Nan Plim facility, the information was obtained from the Site Engineer, Yee Chen. The information is shown below:

1. Flow rate from the source: Q_{in} = 10 gpm = 37.85 L/min
2. Capacity of water tank: V_{tank} = 20,000 Liters
3. Pipe Diameter: d = 2 inch
4. Vertical distance from source of reservoir to tank: Z = 100 feet
5. Tank refill rate under current demands: Once every 2 to 3 days
6. Initial Number of Users: 2000
7. Design Accommodation: 3500
8. Design Life: 25 years

With a given concentration of NaOCl in the disinfectant solution, the required flow rate of disinfectant can be calculated for any desired chlorine dose. The WHO recommends a maximum dose of 5mg/L. By using the maximum dosage, it is assumed that there will be an safe amount of residual chlorine at the time of consumption. For this reason, a dose of 5mg/L is recommended and used for calculations. Typical household bleach is about 5% NaOCl. The required flow through the device is very small, and may become difficult to control. For this reason, it is recommended that bleach be diluted to a concentration of 1% NaOCl. At this concentration, the required flow rate is calculated to be 0.019 L/min. With this flow rate, the following information is obtained:

Required volume of 1% NaOCl solution per tank = 10.0 L/tank
Required volume of 5% NaOCl solution per tank = 2.0 L/tank

The system must be designed to accommodate the demands described in this section.

Design Calculations

Although this device can be easily described using Bernoulli's Principle, the induced vacuum cannot be so easily calculated. Karlheim and Schuhmann have tested this device and provided graphs with the test data. These graphs were used to aid the design of the device. The device used in the tests consisted of 1 inch diameter piping (Schuhmann & Karlheim, 2012). For comparative purposes, the device designed will also consist of a 1 inch system. Since a large amount of head is present at the source (about 102ft) the head loss experienced when moving from a 2 inch diameter pipe to a 1 inch diameter pipe is expected to be small when compared to the total head. For this reason, it is not considered for design.

Using the methods presented by Karlheim and Schuhmann, the following results are obtained:

Upstream pressure of water = 187.8 kPa
Vacuum pressure downstream of the orifice = 15.86 kPa
Maximum volumetric flow of NaOCl solution = 1.16 L/min

Since the required flow rate is much lower than the maximum flow rate that is predicted using the empirical data, it can be concluded that the design of a chlorination device with 1 inch diameter PVC piping can provide sufficient vacuum pressure for the Nan Plim facility.

Device Design and Prototype Construction

Based on the above calculations, it is has been shown that a chlorinator modeling that of Karlheim and Schuhmann with a one inch diameter PVC pipe will induce a sufficient vacuum pressure to appropriately dose the water in Nan Plim. Additionally, a disinfectant reservoir that can accommodate the demands of the system needs to be developed. A refill system that has the ability to keep the level of solution in the disinfectant reservoir constant needs to be implemented to maintain a constant dose (Schuhmann & Karlheim, 2012).

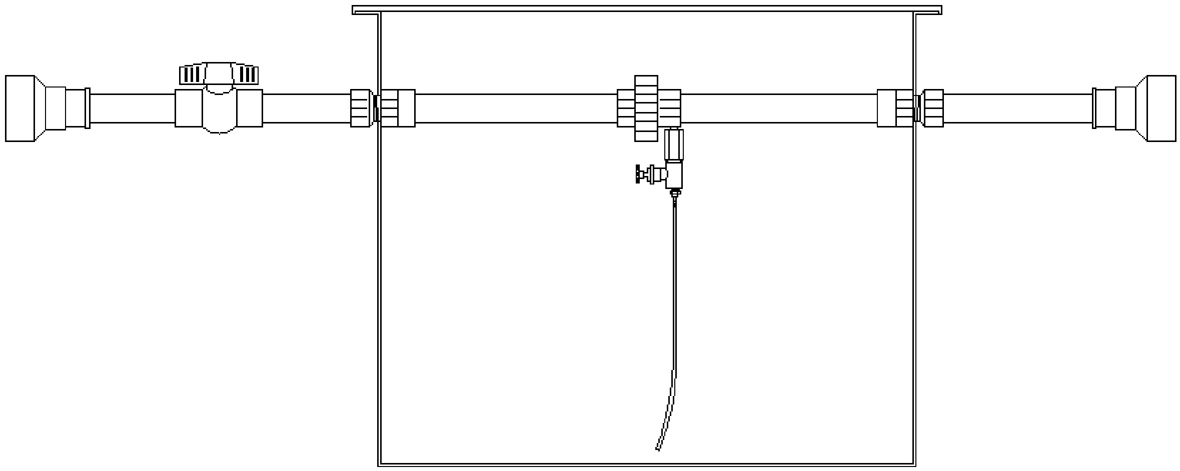


Figure 6.1: Chlorination prototype

The design prototype of the chlorinator and disinfectant reservoir is shown in Figure 6.1. The reservoir consists of a plastic tub, which has holes cut in the sides to allow the chlorinator pipes to pass through. The reservoir and device are protected by the lid of the plastic tub. Details of the prototype and a parts list can be seen in Appendix A.
The refill mechanism has to be simple yet functional. The mechanism must allow for a relatively constant level of sodium hypochlorite solution to be maintained in the disinfectant reservoir. To do this, an upside down bottle can be used as shown in Figure 6.2.

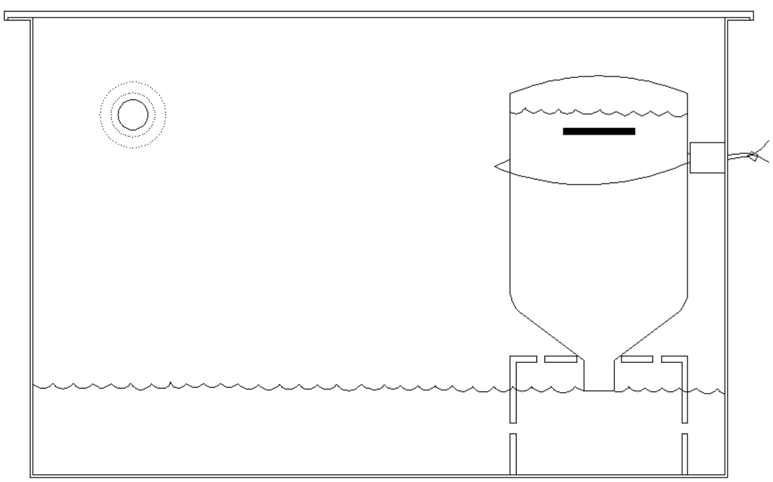


Figure 6.2: Disinfectant refill mechanism

When turned upside down and placed level with the surface of the solution, the bottle will not drain. This is because the atmospheric pressure that is acting on the surface of the reservoir is great enough to overcome the gravitational force that acts on the solution in the bottle. If the bottle is fixed at a constant height, the solution will drain from the bottle once the surface level of disinfectant in the reservoir drops below the opening of the bottle. The bottle can be fixed using a locally available item similar to that shown in Figure 6.2, such as a flower pot or other container. Holes should be cut in the container as shown to support the bottle at the neck and allow movement of solution across the reservoir. The bottle can be held in place using locally available string, and tying it to the tub through small holes in the side as shown in Figure 6.2. The bottle has not been provided for inclusion in the prototype, as it may be important to buy these parts locally. The bottle must be able to hold enough solution for at least one complete water tank refill. For the calculations provided in this section for a 1% sodium hypochlorite solution, the bottle would need to be a minimum of 10 Liters.

The disinfectant reservoir needs to be supplied with sodium hypochlorite solution to keep the level of disinfectant constant. This means that there should always be solution in the reservoir, and the bottle should never be empty.

6.2 Instructions and Manuals

It is important that any proposed solution be feasible to implement. This requires considering cultural appropriateness for design. While the community members are intelligent, communicating across different backgrounds and cultures can be a difficult task. As mentioned, many of the community members on the Island of La Gonave do not have a formal education. Also, the literacy rate is rather low. For the design to be feasible and appropriate, these factors must be considered in design.
For this reason, instruction manuals have been created. These manuals are pictorial in nature, and are easy to understand. The manuals included are:

1. Parts and construction manual (Appendix A)
2. Disinfectant refill manual for proposed design (Appendix A)
3. Device Calibration Method (Appendix A)

6.3 Sodium Hypochlorite Source

With the demands of the system calculated, it is now necessary to assess the options for obtaining sodium hypochlorite. The two options for the source of sodium hypochlorite are on-site generation and purchasing commercial bleach.

Generating sodium hypochlorite can be done using salt water and electricity. Generation devices use an electrolytic cell to turn salt and water into sodium hypochlorite. These devices are discussed in Chapter 4. As previously mentioned, the main factors for making a decision on which generation device to use are 1) availability of device, 2) amount of chlorine that can be generated, and 3) cost. Through market research, the most readily available devices were determined to be the AquaChlor devices manufactured by Equipment & Systems Engineering, Inc. This company is located in Miami, Florida, and has numerous AquaChlor systems being used in Haiti, among many other countries of the World. The AquaChlor models are advantageous because the company location is close, the systems have been implemented in Haiti, and there are several different AquaChlor models available at different prices. The difference between the models is the amount of NaOCl that can be generated (Equipment and Systems Engineering, Inc.).

The least expensive of the models is $1,250 USD, and can generate chlorine at a rate of 30 grams/hr (Equipment and Systems Engineering, Inc.). The current system demands 10.0 Liters of 1% sodium hypochlorite solution as calculated previously, or 10 grams NaOCl per liter of solution. The current demands would require 100 grams of chlorine to be generated each time the tank is refilled. For this device, that would require 3.33 hours of generation. AquaChlor also has devices that can achieve this amount of chlorine in one or two hours. The costs of these devices are $2,350 and $1,550 respectively. Additionally, the cost of the solar panels needed to produce electricity should be considered. Since the cost of salt is low, it is not considered for the analysis.

Purchasing commercial bleach should also be considered as an option since it is an easily implementable solution. The average concentration of commercial bleach is about 5% NaOCl. As calculated previously, the required amount of bleach for each refill would be 2.0 Liters. At the initial demand state the tank is expected to be refilled every 2 to 3 days. This would require about 0.8 Liters of bleach per day. The cost of bleach in La Gonave is not easily obtainable because of price variability (Household Chlorination Options in Haiti). Based on prices of Clorox in the United States, it is conservatively estimated that the cost of bleach in Haiti is $1.40 USD per liter, which would result in a cost of $410 per year.

Comparing this annual cost of bleach to the initial cost of the least expensive AquaChlor device, it is seen that a generator that takes three hours of operation time before each refill will not start to be cost beneficial for over 3 years. For the devices that require 1 and 2 hours of operation, the return on investment would be extended to 5.7 years and 3.8 years respectively. The cost of solar panels and salt were not considered in this comparison, so the returns on investment would be even longer. It is also important to note that the return on investment would only be achieved if the device lasts for the calculated amounts of time.

Purchasing bleach is more cost beneficial than purchasing a sodium hypochlorite generator. Additionally, purchasing bleach does not require electricity. Assuming there is no shortage of bleach, this option is also more dependable than relying on an electronic device.

6.4 Contingency Plan

The proposed solution involves purchasing commercial bleach. It is understood that the supply of bleach in Haiti is variable; therefore it is necessary to develop a contingency plan to prepare for the occurrence of an unforeseen interruption in supply of commercial bleach. This plan recommends the following:

- Commercial bleach has a shelf life of about 6 months. It is recommended that a 5 month supply be kept in stock and stored on-site.

- If there is a permanent or long-term interruption in supply, it is recommended that an AquaChlor sodium hypochlorite generator be purchased. More information can be obtained using the contact information below:

Equipment & Systems Engineering, Inc.
14260 S.W. 136th St. Unit # 4, Miami, FL 33186
Phone: (305) 378-4101 • Fax: (305) 378-4121
E-Mail: jotoma1@earthlink.net
WWW.AQUACHLORESE.COM

7. Quality Assurance Calendar

The team recommends implementing a quality assurance calendar to maintain the water quality at the Nan Plim facility. This calendar serves as a long term monitoring system, as described in the final steps of the water safety plan (World Health Organization, 2011). An effective quality assurance calendar will enable the local manager to operate and maintain the water facility without continual aid or support from developed countries. In order to accomplish this task, the calendar must overcome several obstacles and provide sufficient instructional detail. The first obstacle to consider is that the readers of the calendar might be illiterate, so the calendar cannot rely on textual communication, rather it should focus on visual representation. The second obstacle includes financial and resource sustainability. Nan Plim has limited local resources, and therefore any facility testing or maintenance has limited funding. To address these concerns, the quality assurance plan is comprised of a monthly calendar, long term reminders, and a legend of instructions.

7.1 Monthly Calendar

The monthly calendar includes water quality or maintenance tasks that are performed at least once per month. Symbols represent each individual task on the calendar, and a check box accompanies each symbol. This allows the facility manager to indicate when each task is completed, and to develop a system to record maintenance and water tests. The monthly calendar includes the four primary maintenance and water quality tasks: Refill Reservoir, Test chlorine concentration, Inspect facility for leaks, and Inspect facility for cracks or damage. Figure 7.1 shows a week of tasks to be completed. See Appendix B for a full monthly calendar.

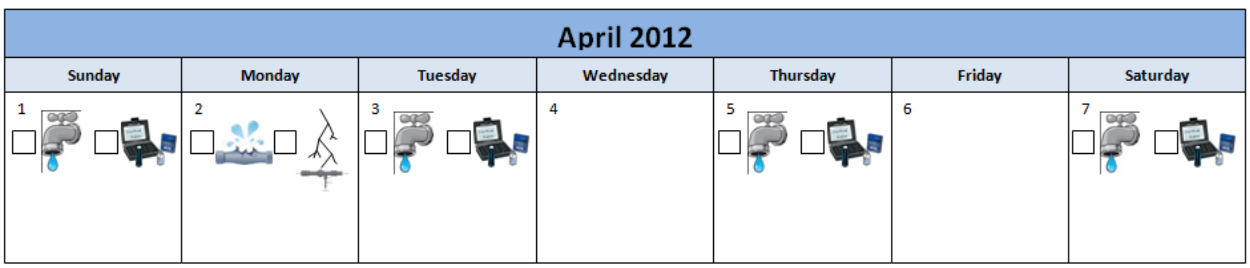


Figure 7.1: Weekly schedule from quality assurance calendar

Refill Reservoir

The water reservoir must be refilled every two days; during this process it also gets chlorinated. Throughout the rainy season the reservoir may be refilled less frequently, and the calendar can be adjusted to reflect this change of schedule.

Test Chlorine Concentration

After the reservoir is refilled, the water must be tested for free active chlorine (FAC) as recommended by the Haiti 2011 report. The 2011 report also recommends the facility manager uses the CHEMetrics chlorine testing kit due to its inexpensive cost and simplicity (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011).

Inspect Facility for Leaks

Once a week, the entire facility must be inspected for leaks. The facility manager must simply visually inspect the facility, while paying close attention for leaks around the piping system, chlorination device, and the reservoir.

Inspect Facility for Cracks or Damages

Once a month, the manager must inspect the facility for structural damages, cracks in the cement, or invasive vegetation. These hazards were identified by the 2011 report and can cause long term and costly damage if left un-attended.

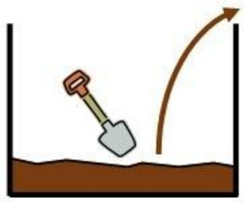
One significant drawback to a visual calendar is that new monthly calendars must be made each year. The current calendar was created using Microsoft Word's drawing tools and images from internet sources. Online calendars, such as Google Calendars, will update automatically and can implement tasks that occur on an irregular basis. However, these online calendars can only include text, not images. Therefore, in order to serve an illiterate user, each monthly calendar must be custom made. A simple template has been provided so new monthly calendars can be easily created. To do so, one must edit the month, renumber each day, and then click and drag each symbol onto the day the task is to be performed. Figure 7.2 shows an example of what a symbol looks like and how it can be added to the calendar.

Figure 7.2: Drag and drop template to create a monthly calendar

The team recommends that Roots of Development creates a fine-tuned version of the quality assurance calendar.

7.2 Long Term Reminders

Two tasks are excluded from the monthly calendar: removing sediment from the reservoir and testing the water at Port-au-Prince. These tasks are listed separately for two reasons. The first reason is to identify them as long term tasks, because they do not occur each month. The second is because their time of completion is on a more flexible schedule. If these tasks were included in the monthly calendar, they would be assigned to a specific day. Realistically, the task does not need to be completed on any specific day, rather within a large time frame. Figure 7.3 shows the long term reminder for removing sediment. The facility manager can mark off each month after the task is completed. Appendix B includes the Port-au-Prince water test.



2012	January	April	July	October
2013	January	April	July	October
2014	January	April	July	October

Figure 7.3: Long term reminder to remove sediment once every three months

Removing Sediment from Reservoir

Once every three months, sediment must be removed from the reservoir. The Haiti 2011 report explains that as the water sits idle in the reservoir, small particles drift to the bottom of the tank where they collect to form sediment. Based on calculations, the report also recommends the sediment be removed once every 5 years to prevent the level of the sediment from reaching the spigot pipes. However, the site engineer, Yee Chen, recommends the sediment to be removed once every three months. To clean the tank, the facility manager will get into the reservoir and use a shovel to dig out the sediment.

SNEP Test at Port-au-Prince

Once a year, the water is to be tested by Service National d'Eau Potable (SNEP) in Port-au-Prince. SNEP will test the water using more accurate equipment than the CHEMetrics test kit. SNEP will also test for other water qualities beyond chlorine levels to further analyze the quality of the water. The entire testing process is estimated to cost about $250 (Baskaran, Furtenbacher, McCullough, Peck, & Laszlo, 2011). Due to this cost, Yee Chen suggests that a more realistic testing schedule might be once every 5 years, as opposed to annually.

7.3 Legend of Instructions

The final component of the quality assurance calendar is the legend of instructions. The purpose of this legend is to emphasize what each symbol means and provide further visual instructions where necessary. As mentioned earlier, the users of this calendar are assumed to be illiterate, thus all instructions must be visual representations and include as few words as possible. Figure 7.4 shows the water symbol representing the refilling of the water reservoir. Please see the full legend in Appendix B.

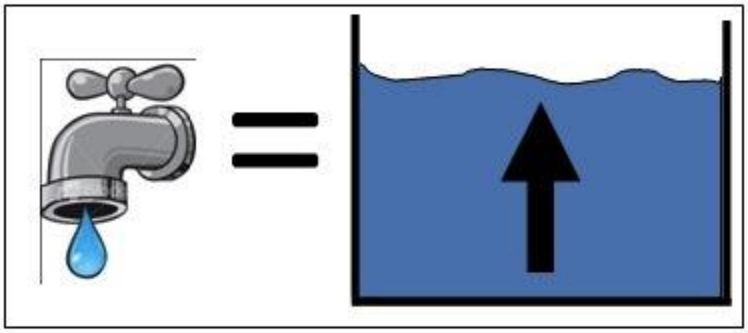


Figure 7.4: Faucet symbol represents refilling of the water reservoir

The team suggests that Roots of Development create more accurate legend instructions by taking pictures of the actually facility or task being completed. These pictures will reduce or eliminate any ambiguity caused by drawings or representative images.

8. Startup and Sustainable Financial Plan

8.1 Construction

Initial Costs

The total construction cost of a water facility serving 3,500 people is around $20,000, as detailed in Roots of Development's project description (Gran Sous Water Rehabilitation Project). Another document lists the price of a community water tank and the necessary pipes as $20,000 (World Bank, IFAD, 2007). By examining the first estimate, the approximate construction costs consist of the following:

- Airfare and domestic travel expenses, food, and accommodations for the site engineer and colleagues (assuming that they offer their services free of charge): $1,940
- Food to feed 15-30 volunteers and construction bosses per day for about 4 weeks of construction (all preparation and cooking to be done by volunteers also offering their services for free): $1,141
- Costs to employ 16 local managers/leaders, and their assistants, to help community volunteers with the various construction projects (more than five weeks of work): $2,664
- Cost of the materials needed to capture the water source, purchase the chlorination device, and build a public latrine, areas to bathe and wash, the cistern, and a small house for the chlorination device (using rocks gathered by community members): $14,185

The preliminary budget of the Nan Kafe-Nan Plim project estimates the cost to be $25,000. This document explains that most of the costs are associated with materials (roughly 70%), while food and labor only account for 30% of the costs. A reason for this might be that some participants of such projects work for free. The cost drivers are the main pipeline (38%), the reservoir (13%) and the barrier walls, stairs and floor (9%).

"While these figures might be appropriate for a water facility construction in La Gonave, it is important to bear in mind that costs may not only vary between countries, but they can differ tremendously, even within the boundaries of a country, depending on factors such as remoteness or the availability of materials." (Harvey, 2006)

Evaluation of Financing Methods

Section 5.1 introduced several financing methods that could cover the construction costs of the facility. The 4F framework is used to evaluate these options (see Table 8.1).

Table 8.1: Evaluation of framework of initial funding alternatives

Lower is better	Initial funding				
	For Profit Crowdfunding	Nonprofit Crowdfunding	Online Microcredit	Agencies	FDI
Strategic fit	4	2	3	1	5
Feasibility	5	1	3	2	4
Finance	3	1	4	2	5
Future	2	4	1	5	3
Total	14	**8**	11	10	17

The evaluation criteria can be described as the following,

- Strategic fit represents how much an alternative fits into Roots of Development's current strategy.
- Feasibility describes whether the given funding is attainable or not.
- The finance criterion demonstrates whether enough money could be obtained from the sources.
- Future represents repeatability and sustainability.

The funding methods were evaluated based on all these criteria. The ratings used ranged between one and five, where the lower the number indicates a better performance. For the initial funding of the Nan Plim project the nonprofit crowd fundraising websites are the best options. As for funding of future projects the agencies are also a really good alternative. In communities where selling water is viable, Kickstarter and online microlending can also be recommended.

Best Financing Method in Detail

Nonprofit crowdfunding

The recommendation is that Roots of Development should join all crowd fundraising websites which allow charity projects. Some examples include Firstgiving.com, Startsomegood.com, Crowdrise.com and Causes.com. The biggest advantage of such sites is that they connect people with a similar mindset. All the people who visit these fundraising sites have the same intention: to help others less fortunate. All of these projects are competing against each other for donations.

Analyzing the fundraising websites showed that one of the most successful nonprofit organizations is Charity: Water. This organization managed to raise $260,000 on causes.com and most of its projects are successful too. They utilize a number of sales techniques in order to achieve these results. Based on these techniques the following tips can be given to Roots of Development:

- Focus on water projects only to create an integral portfolio.
- List top donors to encourage participation.
- Tell people where their money will go. “People are more likely to donate if they know exactly how the money they give will be used.” (Zeigler, 2011)
- Inform all donors after the project is finished and show them how many lives they have influenced.
- Introduce multiple revenue streams, such as a store with project-related merchandise.
- Make a well-informed, creative, and revealing pitch video since it can inspire emotion effectively (Zeigler, 2011)
- Don’t just encourage people to donate, encourage them to help raise funds from others.

This strategy has multiple results. First, Roots will have the chance to create a community of donors who care for disadvantaged people, are willing to donate, and are somewhat of an evangelist in the sense that they tell their friends about the projects. Second, these sites provide a sustainable and repeatable way of financing, if done correctly.

8.2 Operations and Maintenance

Costs

The costs incurred in the Operations and Maintenance (O&M) phase depend on various factors, and therefore a calculated value is unique to a particular project. This section will describe a cost model for the O&M of rural water plants, and will also calculate costs for the Nan Plim project.

O&M Cost Model
The O&M costs can be divided into three parts (Harvey, 2006):

- Direct O&M costs (maintenance, repair and asset replacement)
- Indirect O&M costs (institutional support costs)
- Rehabilitation and expansion costs

The most relevant aspects at this point in our work are the direct O&M costs. We can calculate these following the four-step guide provided in the paper entitled "Cost Determination and Sustainable Financing for Rural Water Services in Sub-Saharan Africa" (Harvey, 2006).

1. Recurrent O&M costs
2. Current replacement costs
3. Annuity
4. Average annual cost of O&M

Nan Plim Calculation
First, a facility operator must be employed. His average daily wage is $1 USD, and in a year his salary is approximately $260 (assuming he doesn't have to work every single day). The water has to be treated every other day, requiring salt and chemicals as part of the standard procedure (at a cost of $20). Also, frequent tests of the quality of water are essential; estimated costs of these quality checks are $200 per year. Additionally, once a year water samples must be transported to Port-au-Prince for a special test at a cost of $250. Lastly, an average of $150 per year is planned for supplying spare parts. Other materials like sand and rocks can be gathered by the community and therefore incur no cost.

The sum of these costs is $880. We can conclude that the average yearly direct cost of the Nan Plim water facility is about $900. Indirect, rehabilitation, and expansion costs cannot be calculated at this moment.

Evaluation of Financing Methods

According to the literature review several methods can be utilized to maintain the facility. As performed previously, it is possible to apply the 4F model. The table where all the criteria are included can be seen below:

Table 8.2: Evaluation of framework of operation and maintenance

Lower is better	Operation & Maintenance			
	MFIs	Output Based Aid	Growing Agricultural Goods	Selling Water in Jerry Cans
Strategic fit	3	4	1	2
Feasibility	4	3	1	2
Finance	2	1	4	3
Future	3	4	2	1
Total	12	12	**8**	**8**

In summary, the results strongly support growing agricultural goods and selling water in jerry cans as viable financial options.

Best Financing Methods in Detail

Growing Agricultural Goods

After accessing the local market or the main island's (Port-au-Prince), community members have the opportunity to sell these commodities and reinvest into the facility. After performing the analysis, a contribution of $0.75/year/cap is affordable and reasonable. This is the required amount which makes the facility financially viable.

Retail market prices of mango in the US, which is the biggest mango importer, are about $2.5/kg (approx. 5 mangos). Producers in Haiti can sell their products at a price of $0.5/count (approx. 12 mangos = 2.5kg) to wholesalers. Usually the transportation to the US starts at Port-au-Prince. The problem with this solution is that there are not enough established mango fields, and there is a lack of agricultural culture and skills. On the other hand, there is an increasing demand on the market, which means higher prices on the long run. The relative closeness to the US is an advantage compared to India, another mango exporting economy (Castañeda, Rodríguez, & Lundy, 2011). If the people living in Nan Plim could produce a relatively small amount of mango, or any other valuable agricultural product for that matter, they would be able to sustain the facility on their own.

Selling Water in Jerry Cans

This approach is unique because it aims to adapt to local customs and expectations. Namely, clean water is essential for a healthy life and residents of La Gonave will not sell or pay for water alone. Nevertheless, additional value can be created which is worth charging a fee, providing an avenue by which the money needed to sustain the facility can be obtained. Through culturally sensitive innovation and services, it is possible to approach this in a way that is more acceptable to the culture.

First, jerry cans must be obtained for containing, transporting and storing water; especially with regard to maintaining the cleanliness of the water. These cans can be bought in the US or at the main island of Haiti, and should fulfill the following characteristics:

- Made of plastic
- Refillable
- Capacity is between 5-10 liters
- Has a cap and handle
- Cost approx. $0.3/piece

It is not feasible to sell cans each time an individual visits the facility. Therefore, additional value-added services were explored. A detailed explanation of the system is as follows:

- When the facility generates drinking water people must be convinced to buy cans for approx. $2.5/can (this calculation assumes that every third person should buy one can per year). A jerry can is reusable for one year. After one year, due to hygiene requirements and recommendations, the new jerry can must be repurchased.
- Each time someone comes to the facility, operators can instruct them to clean the can in order to maintain the hygiene level. They would be provided with appropriate tools and chemicals to do this, which would be supported by a small fee that helps purchase materials and maintain the facility.

- As an alternative, the interval of jerry can replacement could be shortened to two months. In this case the price could decrease to approximately $1/can (including the original purchasing cost).
- Furthermore, clean water sold in jerry cans could be a valuable product on the local market. In the Nan Plim area there is a severe shortage of it, including the port located close to our facility's location. This means that selling water in jerry cans to other communities could be a profitable activity as importing clean water from the main island is inevitably much more expensive than buying it from Nan Plim or Gran Sous. The likelihood of general economic growth and welfare could increase through this process.

In summary, the options and methods discussed above are financially viable and have high potential. Based on associated calculations, the required $900/year can be easily achieved, and if there is any additional variable cost, this could be raised up to $1500/year to cover all expenditures.

8.3 Financial Conclusion

Project financials can be broken down into two distinct categories: initial funding of the construction and operation and maintenance of the facility. The initial costs are $20,000-25,000 and O&M costs are as low as $900 annually thanks to the effective and low-cost water sanitation device. A number of funding opportunities were examined that could fit this water facility project. The best option for construction is nonprofit crowdfunding, whereas growing agricultural products (coffee and mangoes) or selling jerry cans will address operation and maintenance costs. Exact strategies were detailed in the financial section on how to implement these methods.

9. Final Recommendations

To treat the water in the storage tank, a chlorination device has been designed and recommended. A chlorinator has been designed specifically for the facility of Nan Plim. Design calculations for this device has been provided (Chapter 6). It is recommended that this device be tested, calibrated to the system, and implemented. The data obtained from tests, which should include a water quality test, can aid the design of future devices.

A cost analysis shows that the use of commercial bleach as a disinfectant is a more viable solution than generating sodium hypochlorite on-site. It is recommended that commercial bleach be used in combination with the chlorination device, and that a five-month supply of bleach be maintained. Future considerations should include a detailed analysis to understand when commercial bleach should be used and when it would become more beneficial to use a generation device.

To ensure that the facility in Nan Plim remains safe, a quality assurance calendar has been produced. This calendar is pictorial in nature. The calendar reminds the facility operator of regular tasks that need to be completed. These tasks are inspecting the facility for cracks and leaks, refilling the tank, testing the water, and removing sedimentation from the tank. It is recommended that this calendar be used as a tool to ensure the maintenance and safety of the facility. Using check boxes for each task allows this calendar to also serve as a form of documentation, which is important for monitoring the system. For the future, it is recommended that an educational system be developed to inform the community members of safe water handling practices. An effort can also be made to include repair manuals along with the calendar for use in the event that a problem or deficiency is discovered.

A plan has been developed for the initial funding cost of the facility. The best way of initial funding is either getting funds from agencies or using crowdfunding websites. Crowdfunding websites are an efficient and effective way for covering construction costs. It is recommended that Roots of Development use crowdfunding websites, such as firstgiving.com or causes.com, to connect with potential donors. For this, a pitch video is needed, which should include information about how much the donation means to the community.

Recommendations for covering the operation and maintenance costs are organized around the idea of sustainability and self-financing. It is recommended that the community grow and sell mangoes and coffee, or sell jerry cans full of water (Chapter 8). These can be sold to other communities or to the people at the port of La Gonave. Selling fruit or coffee may be beneficial because they sell for a relatively high price. This can be done with minimal training.

10. Conclusion & Future Tasks

The designs, recommendations, and plans presented in this report address the issues of treatment methodology, quality assurance, and financial cost and sustainability. The root causes of the challenges associated with potable water in Haiti, specifically on the island of La Gonave, are a lack of formal education and a suffering economy. These regional factors are considered in the recommendations for water facilities.
Water quality and safety were researched to develop an understanding of the measures that must be taken maintain a water facility. Current standards and practices were also

reviewed. Based on the literature review, a quality assurance calendar was developed. This calendar serves to ensure that the water facility is properly maintained and operated.

A review of the current practices of chlorination in developing countries was also performed. This included numerous case studies as well as devices and methods that have been implemented. Based on this review, a water treatment methodology was recommended. A chlorination device was also designed and constructed to fit the Nan Plim facility. The device is flow-dependent and requires a supply of disinfectant. Different sources for obtaining this disinfectant were analyzed, and purchasing commercial bleach was recommended.

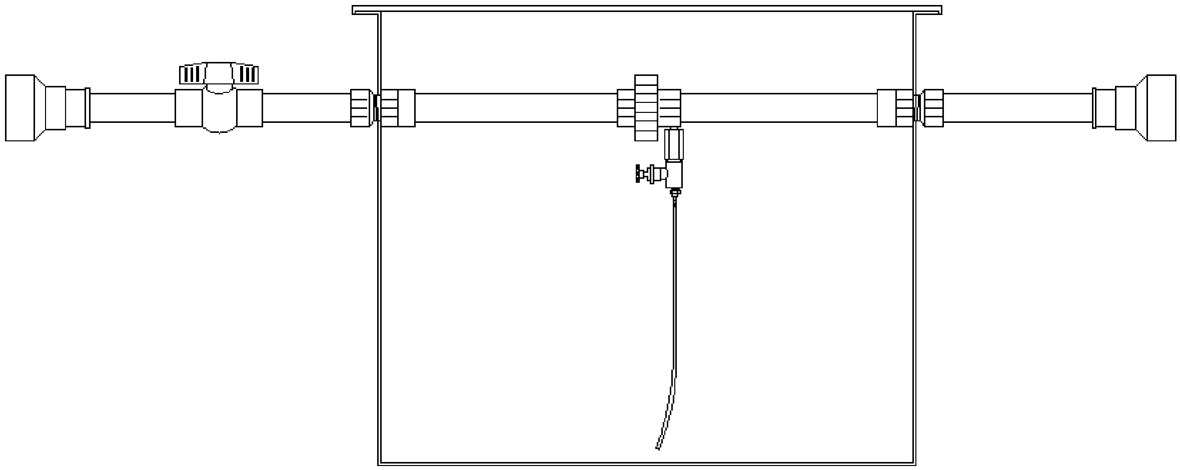
A financial plan has also been developed. This plan was based on a review and analysis of all applicable and available funding sources. The plan consists of two main sections, which include financing the initial construction and operation and maintenance. The recommended method for obtaining the initial construction cost is crowdfunding. To generate revenue for operation and maintenance costs, it is recommended that the community develops a business that sells jerry cans or coffee and fruit.

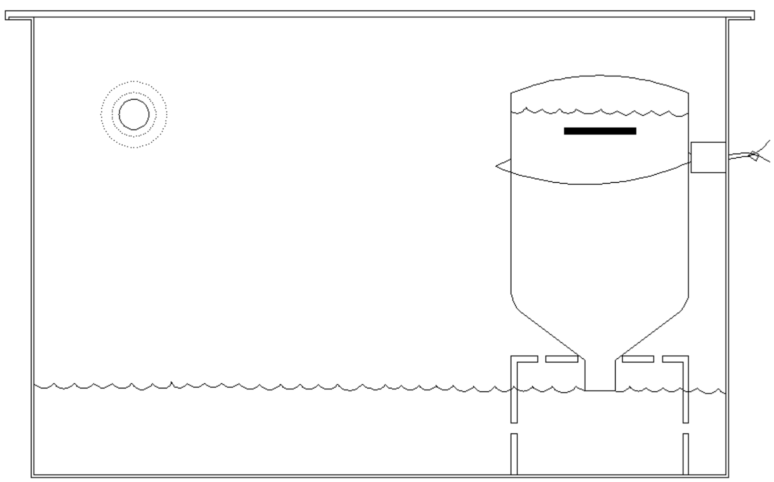
These designs, recommendations, and plans have improved the feasibility of constructing and maintaining drinking water facilities in La Gonave.

Appendix A: Device Documentation

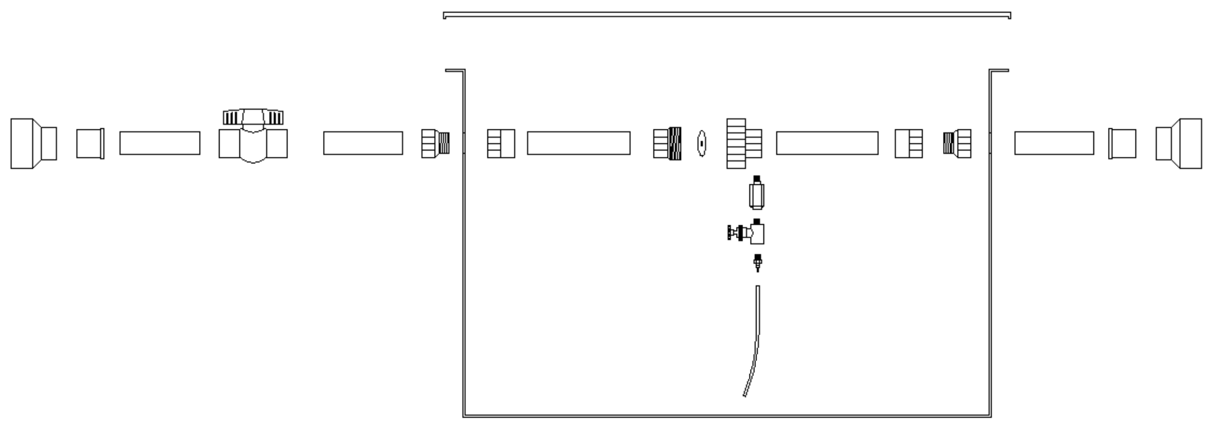
Parts and Design Manual

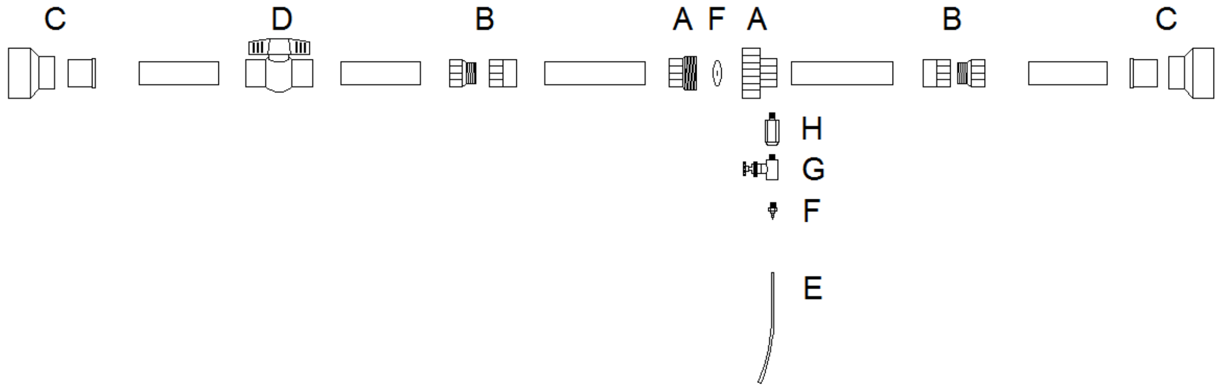
Design Drawings





Exploded Views





Parts List

Orifice coupler with hole drilled to fit check valve

Male and female 1 inch to 1 inch connector

1 inch to 2 inch connectors

1 inch shut-off valve

Vinyl tubing ($^1/_4$ inch)

1) Tube fitting
2) $^1/_4$ inch washer (Orifice)

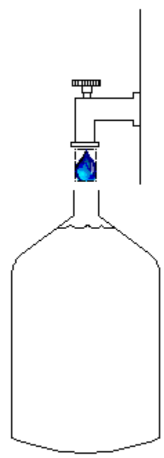
Needle Valve

Check Valve (one way flow)

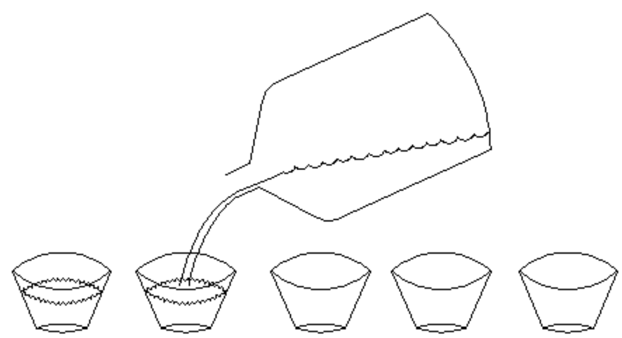
Refill Container Setup for Dilution

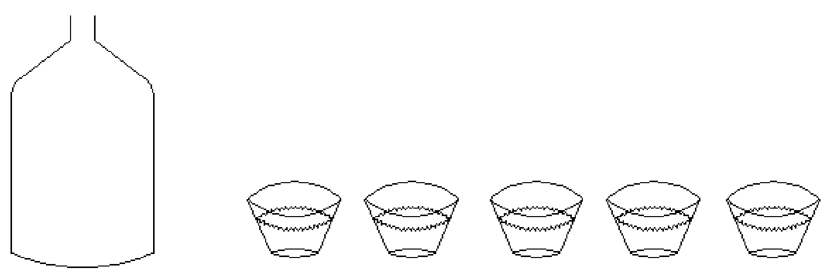
The images below describe the setup process for easy and accurate bleach dilution. The treatment methodology section suggests that bleach be diluted to 1% NaOCl solution from 5%. This requires a 1:5 dilution of bleach. These images show the process of marking the refill container for this specific dilution ratio.

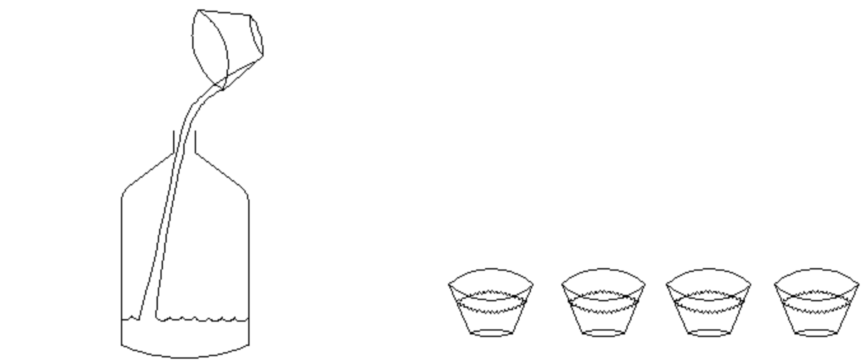
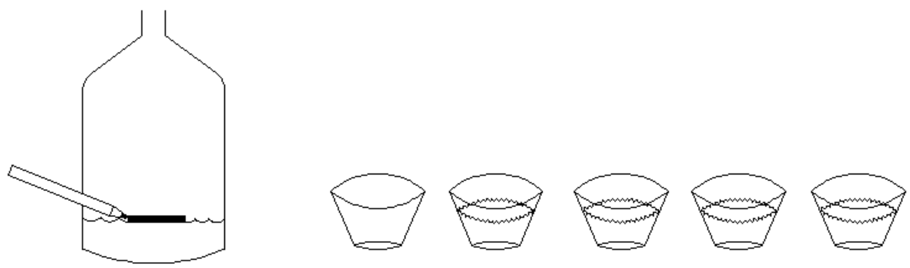
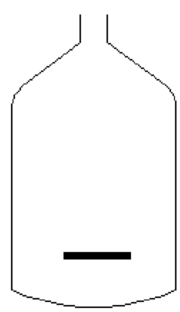
1. Fill the container with water



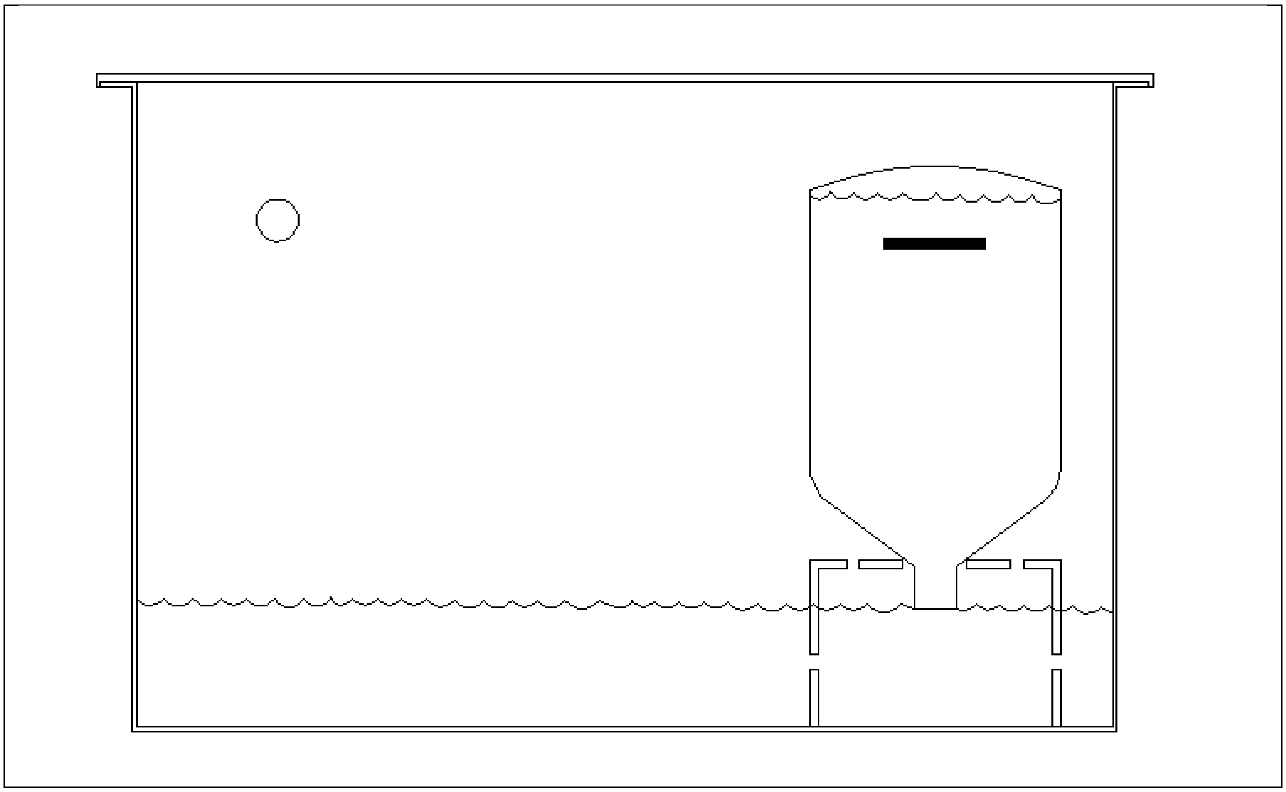
2. Pour an equal amount of water into 5 containers



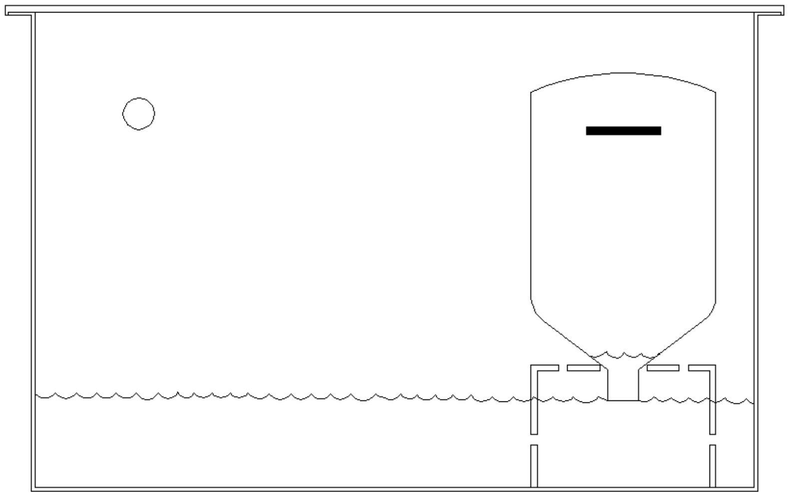


3. Pour one of the containers of water back into refill container

4. Mark this level with a permanent marker

5. The container is now ready to use for a dilution of 1:5. The disinfectant should be filled to the line. The rest is to be filled with water


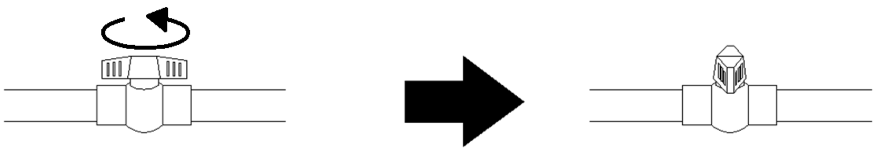
Container Refill Manual



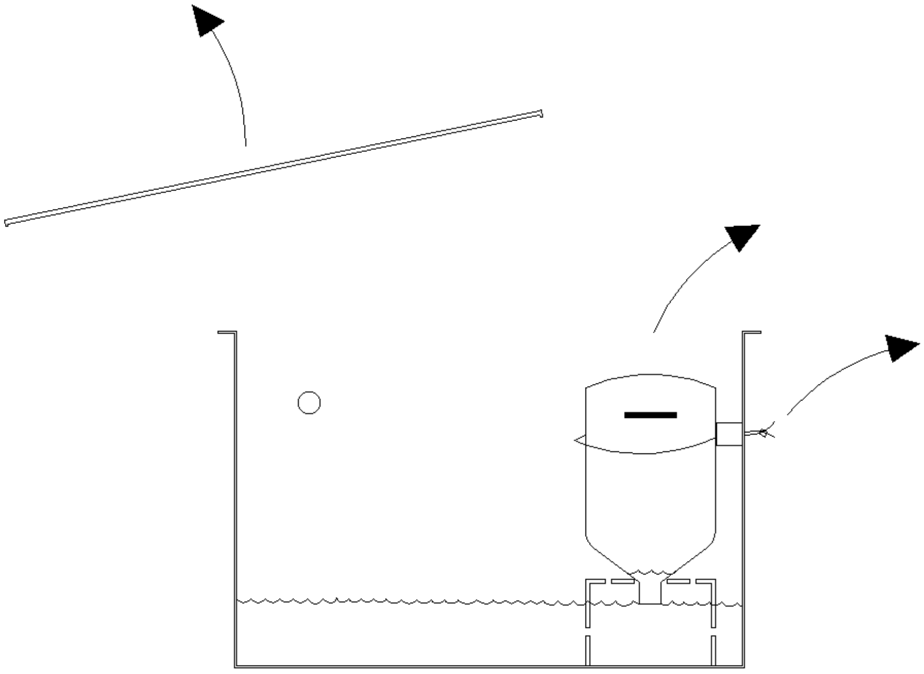
1. The container is empty and needs to be refilled



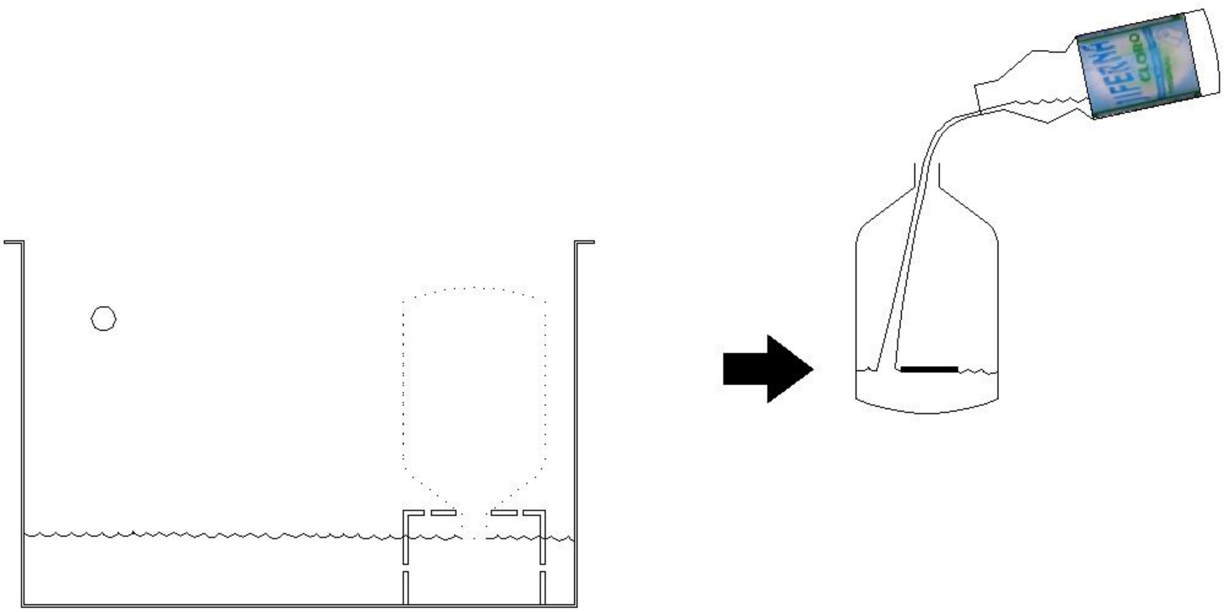
2. Turn the shut-off valve to the off position



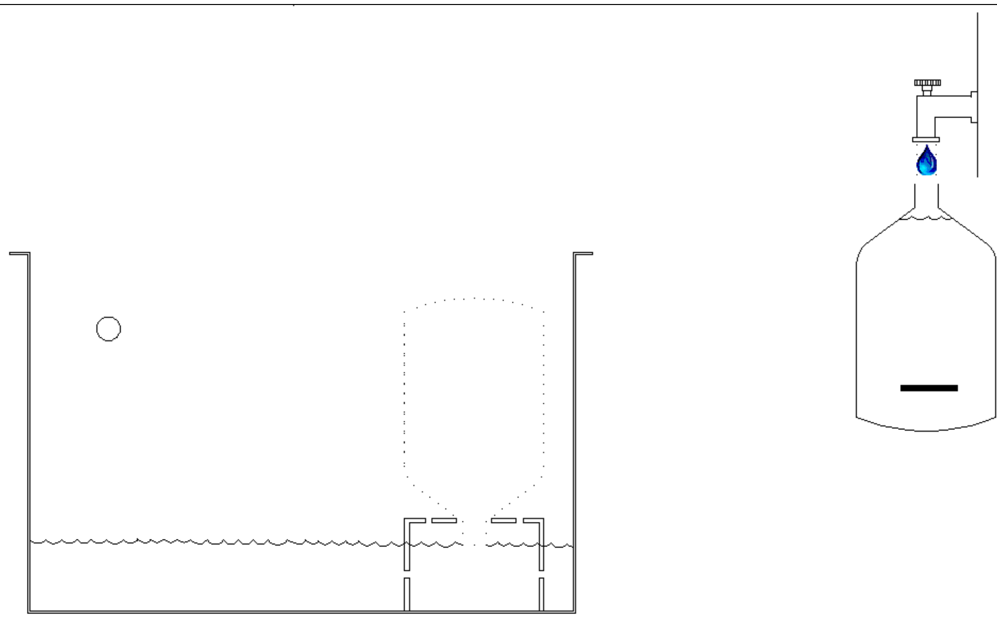
3. Remove refill container from system



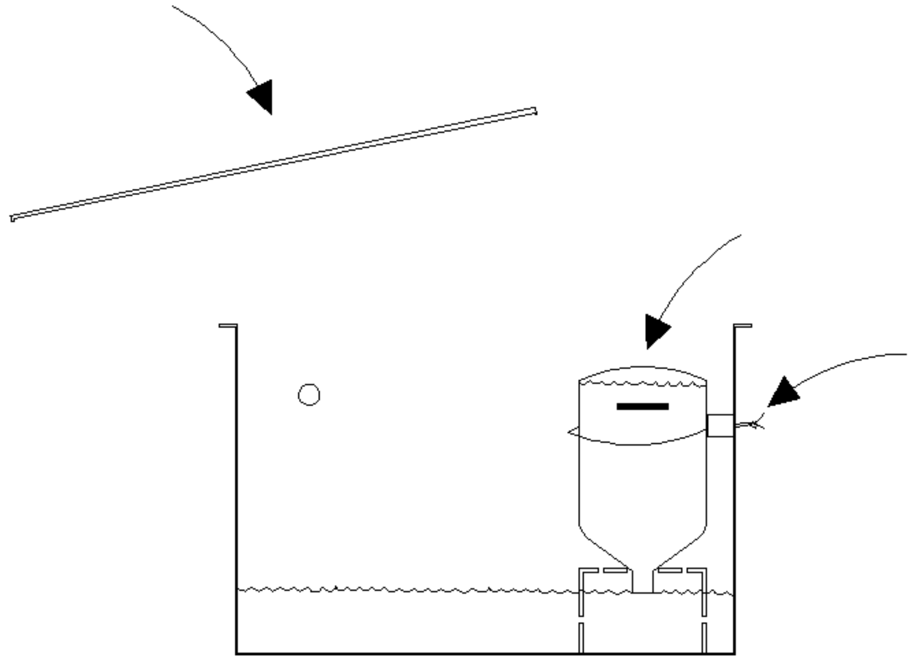
4. Fill the refill container with bleach to the marker line

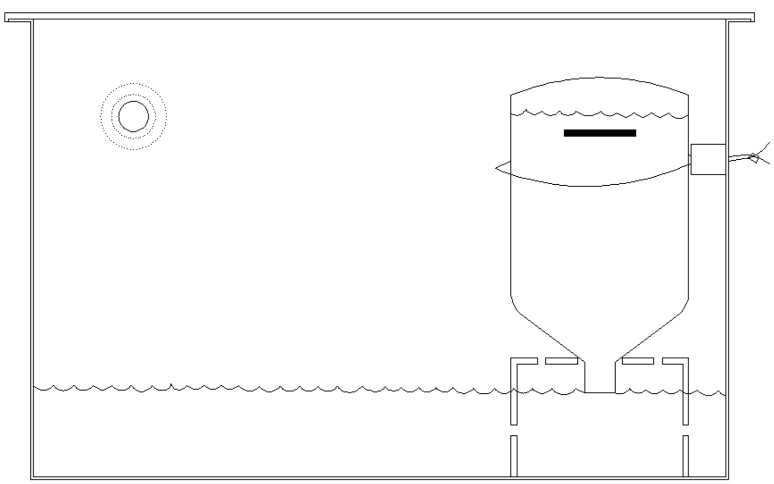


5. Fill the rest of the container with water

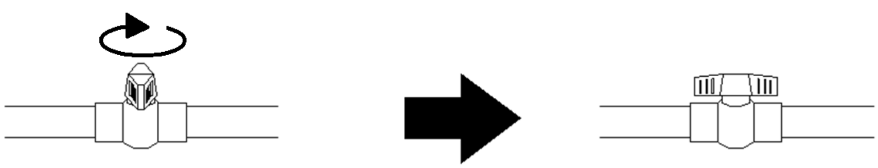


6. **QUICKLY** place the refill container back in the system





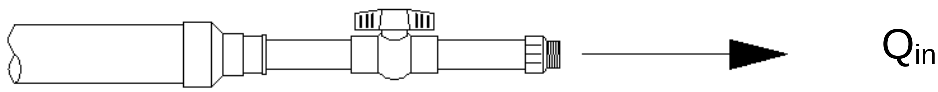
7. Turn shut-off valve to on position



Needle Valve Calibration Manual

1. Measure flow rate of water that will travel through device

Measure with fittings attached. Determine the flow rate, $Q_{in,}$ in units of volume/time by measuring the amount of time it takes to fill a container with a certain volume.



2. Calculate required flow rate of diluted bleach solution, Q_{cl}, through the device

$$Q_{cl}= (Q_{in}C_{out})/(C_{cl} – C_{out})$$

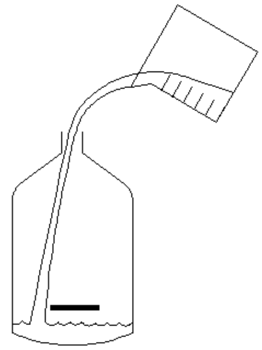
where,
Q_{in} = influent flow of water
C_{in} = concentration of NaOCl in the influent
Q_{cl} = influent flow of disinfectant
C_{cl} = concentration of NaOCl in the solution
Q_{out} = flow of water effluent the device
C_{out} = concentration of NaOCl in the effluent, or chlorine dose

3. Based on required flow rate of diluted bleach, Q_{cl}, calculate volume of solution that will pass through device in 10 minutes, V_{10}.

$$V_{60} = Q_{cl} \text{ x } 10 \text{ minutes}$$

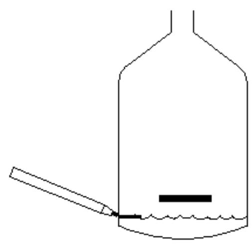
4. Measure V_{10} into a container, and pour into refill container

Note: This can be done with water

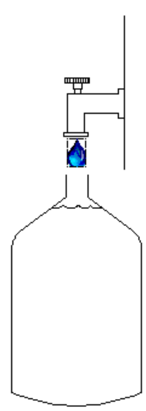


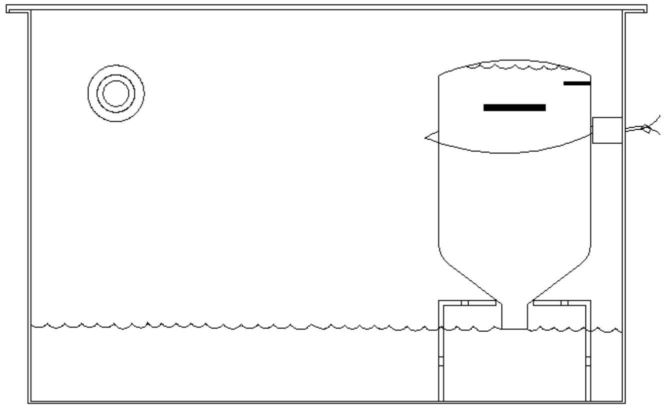
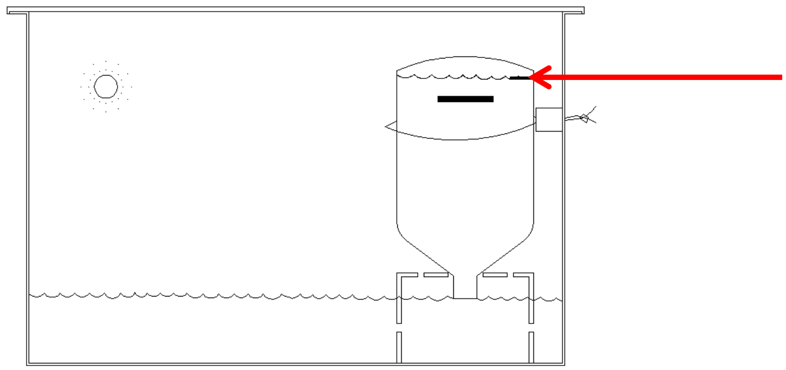
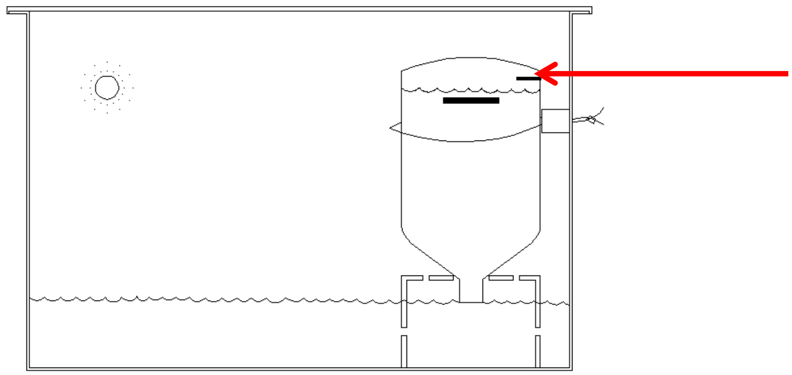
5. **Mark the level of V_{10} on the refill container**

   Note: This mark is different from the mark that indicates the refill amount of bleach

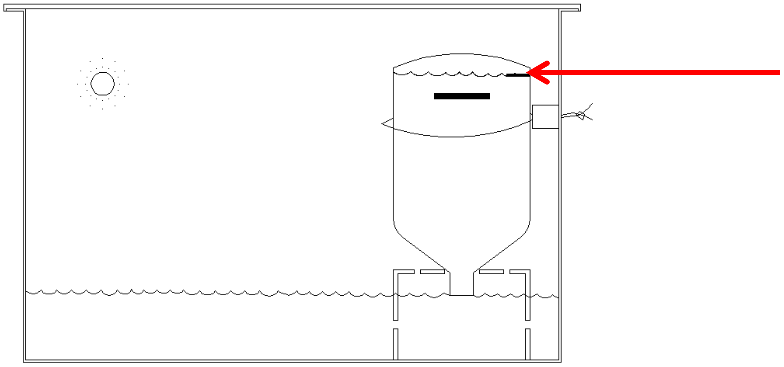


6. **Refill the container**



7. Setup System

8. Run the water for 60 seconds, and then shut the water off.
9. Adjust needle valve as needed
a. If the level of water in the refill container is even with the V_{10} line, move to step 10.

b. If the level of water in the refill container is below the V_{10} line, adjust valve and then go back to step 6.


c. If the level of water in the refill container is above the V_{10} line, adjust valve and then go back to step 6.



10. The above steps outline the process for **APPROXIMATE** calibration only. More time can be added for more accurate results. To fine tune the calibration, it is recommended that an additional calibration using NaOCl solution is performed. This would involve measuring the concentration downstream and calculating what the flow was using a mass balance. Before drinking the water, it should be tested to ensure there is a safe dose of chlorine (more than 0.2 mg/L, less than 5 mg/L).

Appendix B: Quality Assurance Calendar

April 2012						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

Figure 1B: Monthly quality assurance calendar

2012	January	April	July	October
2013	January	April	July	October
2014	January	April	July	October

Port-au-Prince 2012 2013 2014 2015 2016

Figure 2B: Long term reminders

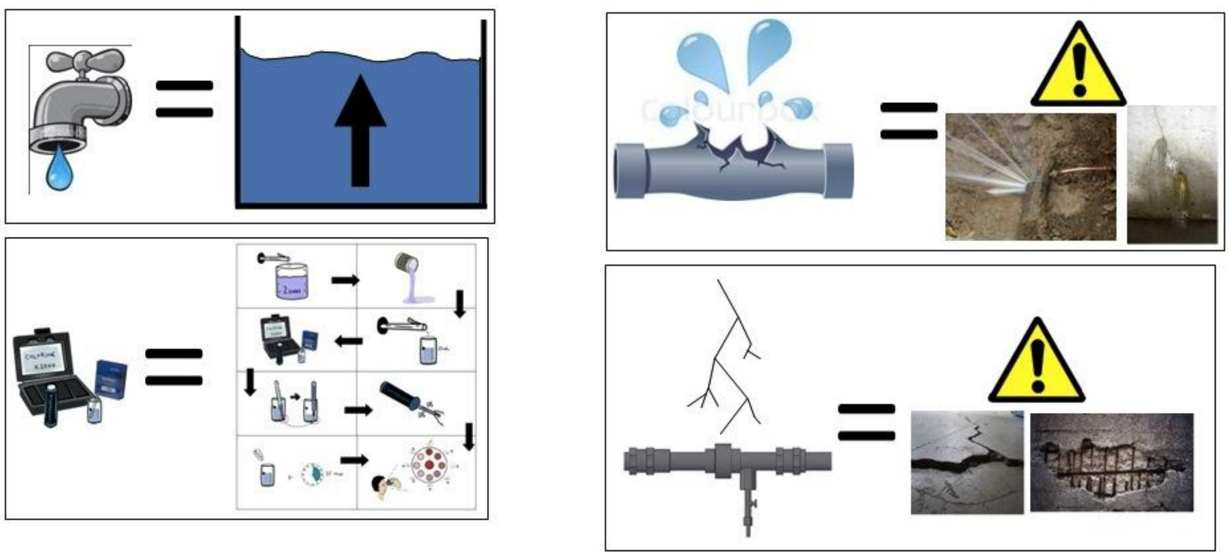


Figure 3B: Legend instructions

Appendix C: Root Cause Analysis

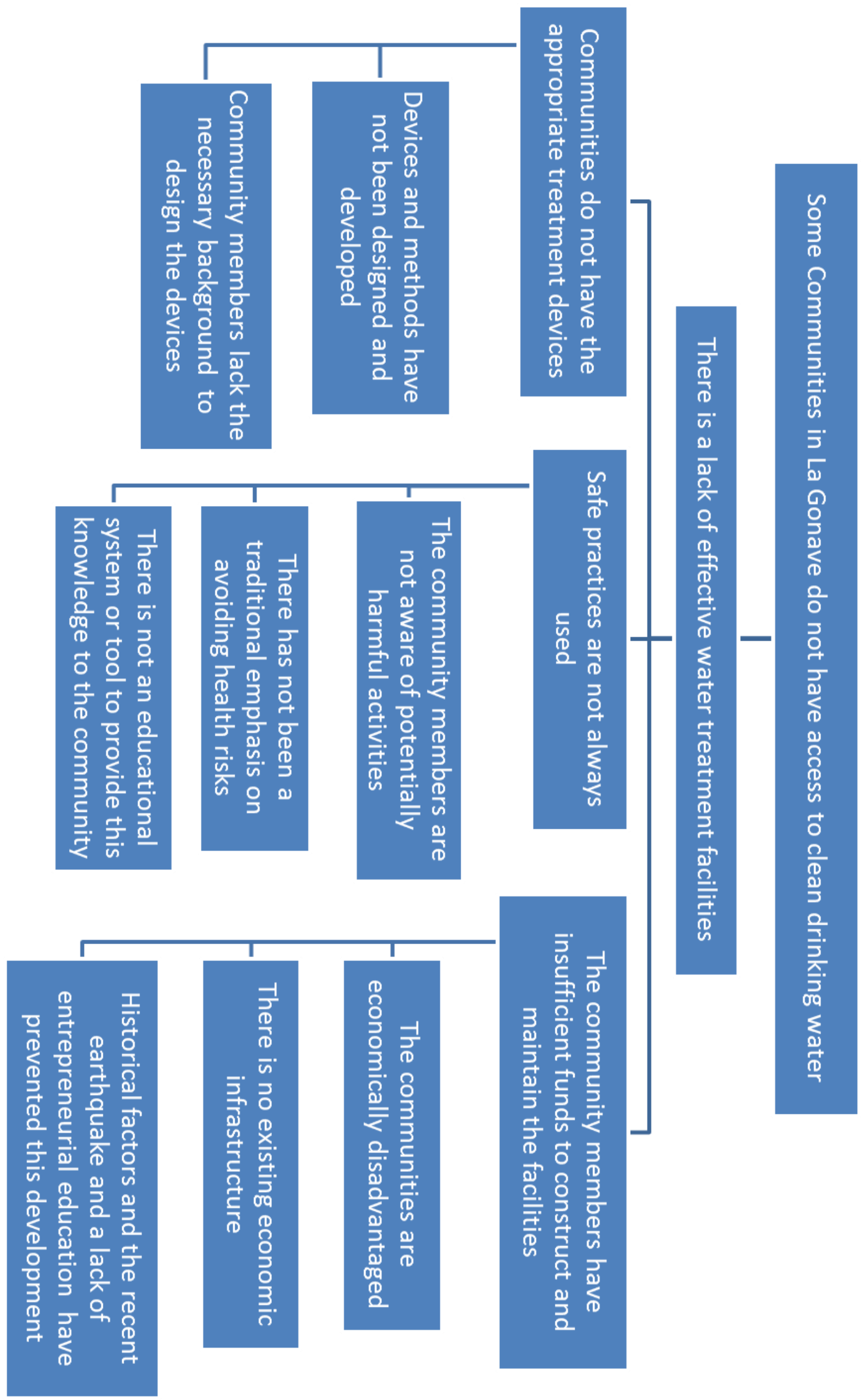


Figure 1C: RCA Diagram

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