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Planning Manual

For Sizing
Constanza Rainwater Catchment Projects

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Prepared for

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1. Introduction

Rainwater harvesting systems are highly modular and encompass a myriad of configurations. Rainwater systems are usually categorized as dry or wet. A dry system is one which the overhead conveyance system is dry between rains while a wet system is one which the underground pipes remain filled continuously (Graftman, 2017). The purpose of this report is to serve as a guide for the planning of dry, decentralized, rainwater catchment systems that can serve as a potable water supplement for individual households.

2. Project Site

Constanza is located in Dominican Republic, approximately 100 km northwest of Santo Domingo. Over 60,000 Dominicans live in Constanza, roughly 70% in rural areas. These rural areas span over 830 square kilometers where many residents have little to no access to basic amenities including water. The client, Puente Desarrollo Internacional (PDI), a 501(c)(3) nonprofit organization, identified lack of access to drinking water as one of the most urgent needs of the people of Constanza. Unreliable access to water is deleterious on community growth. The client explained that the locals currently obtain water from illegally tapped sources or local rivers of questionable water quality. More so, the client noted that locals travel long distances to haul water. Clean water is a crucial component of health and sanitation and the extra time and effort that families endure to obtain water from distant sources detracts from time spent on education and financial well-being.

Through a series of community surveys, PDI collected preliminary water availability data from over 2,000 households in Constanza. Results show that 42% receive water 2-3 times a week, 32% of residents receive water daily and 8% receive water only once a month, if at all (Figure 1). Survey results suggest that the western, more rural area of Constanza known as El Chorro, has the least reliable access to water. Historical climate data demonstrates that Constanza receives an average of around 960 mm of rain annually (Izzo et al, 2013). The high frequency of rainfall events provides opportunity for rainwater storage infrastructure that can provide year round water access reliability the community lacks. Houses in Constanza are also suitable for retrofitting rainwater catchment systems. Most houses in Constanza are similar to that shown in Figure 1. As such, this manual will use the house shown in Figure 1 as a case study for designing a decentralized rainwater harvesting system. In reality, each household will vary in terms of roof dimensions, water demand and current access to water and therefore house-specific calculations must be performed for each household. The main goal of this feasibility study report is to provide a design manual for decentralized water catchment systems. This manual includes 1) sizing instructions 2) operation and maintenance guidelines and 3) a need identification survey.

Figure 1: Typical house in rural Constanza with metal roof is an ideal candidate for rainwater harvesting. Photo credits: client Scott Coppa.

3. Fundamentals of Decentralized Rainwater Catchment Systems

To properly design a decentralized rainwater catchment system, one must first understand the purpose of each component. The proposed design includes four fundamental components depicted in Figure 2. These components are outlined in *To Catch the Rain* by Lonny Grafman and are adapted to meet the specific needs of Constanza, Dominican Republic in this report. The following subsections will provide an explanation of:

1) the catchment surface,
2) the conveyance,
3) special fittings to ensure sanitation, and
4) the storage tank.

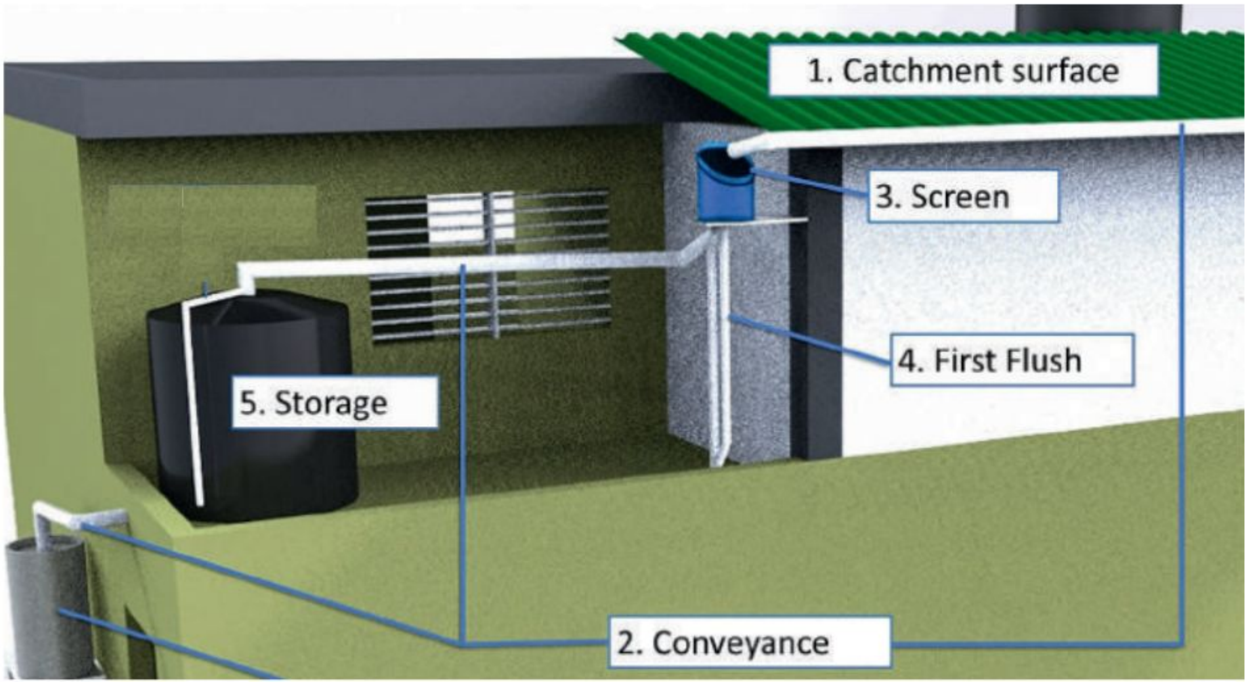


Figure 2: Adapted depiction of the anatomy of a decentralized rainwater catchment system from Grafman (2017)

While rainwater catchment systems can be designed as decentralized systems serving individual households, they can also be designed as centralized systems whereby multiple roofs are connected to a single cistern. The advantages and disadvantages of each are summarized below in Table 1.

Table 1: Pros and Cons of Centralized and Decentralized Rainwater Catchment Systems

	Decentralized System	Centralized System
Pros	• Easy to construct • Easy to maintain • Adaptable to user needs • Low impact failure • Low space requirements	• Promotes community involvement • Economy of scale • Decreased operation and maintenance training
Cons	• More expensive • Increased operation and maintenance training	• Must coordinate with neighbors for cost and maintenance • High impact failure • May be less convenient for end of use • Requires more space

A decentralized rainwater capture system is designed to capture rainwater from a single house and provide water to the residents at the point of use. The user can simply open a tap fitted to the storage tank upon successful water capture. Decentralized systems are ideal for isolated homes in rural areas or families who desire complete control over their water source. One benefit of rainwater systems is they are adaptable, so can be designed to fit most houses. In addition, close proximity to the owner facilitates ease of operation and maintenance. Since water is conveyed from an elevated roof to a storage tank, no electricity or pumping requirements exist.

The concepts discussed in this report can be used to size tanks for both centralized and decentralized tanks, but the authors advise familiarizing oneself by working with individual families than several per system for the first few projects.

4. Design Guide for Sizing of a Decentralized Rainwater Catchment System

4.1 Water Storage Potential

The catchment surface is the area of the rainwater catchment system which the rainwater falls unto to be captured and are typically the roofs of buildings. By knowing the rainfall capture potential for a specific house, the storage tank can be sized accordingly. Water quality and quantity is dependent on catchment surface material. In terms of water quality, some surface materials increase pathogen loading and detract from water quality more than others. Rougher surfaces lead to lower water quality than smoother surfaces (Grafman, 2017).

Before designing a rainwater harvest system, an initial inspection of the roof should be performed. First, the material and condition of the roof and the condition should be noted. If the roofs are thatched or shingled using asphalt, a corrugated sheet of metal should be fitted to serve as a catchment area. Repairs should be made where the roof leaks or where there is severe rusting of the roof material. The roof catchment area should also be calculated using measured dimensions of the roof. If decided that the roofing material is appropriate and in good condition, one can begin estimating the capture potential based on peak flow conditions from historical climate data.

A modified Rational Method formula, shown in Equation 1, can be used to calculate the volume of rainfall potentially captured using roof area, an assumed runoff efficiency coefficient, and the storm intensity derived from historical precipitation data.

$$Q = R \times A \times k \times e \tag{1}$$

Where:

Q is the volume of rainfall captured per unit time,
R is the precipitation in depth per unit time,
A is the area of the roof,
k is a conversion factor between SI and imperial units, and
e is the efficiency coefficient of the collection surface.

A spreadsheet has been developed to aid in calculating storage tank volume in Constanza, Dominican Republic. The steps for utilizing this spreadsheet can be seen below.

Step 1: Estimating the Total Water Demand and Preliminary Storage Volume

To calculate the total water demand for a given household, the following inputs are required:

1) water use per person per day,
2) number of residents in the household,
3) days that the household has access to a water provided by the municipality, and
4) the roof area.

Using the calculator, the total volumes per month and per year per household are calculated. An example for the case study is shown in Table 2.

Table 2: Excel Calculator User Interface for Case Study Inputs for Step 1

Input	Value	Units
Water Use per Person per Day	30	Liters/person/day
Number of People to be Served	3	People
Number of Days with Water Access (provided by municipality)	3	days/month
Existing Roof Area	24	m^2

Using Equation 1, the capture potential for a given household can be estimated. The storage tank can be sized to accommodate the maximum average yearly precipitation based on that shown in Figure 3. Using an assumed roof area of 24 m^2 and the maximum monthly rainfall rate of 170 mm for the month of May, the tabulated results are shown in Table 3.

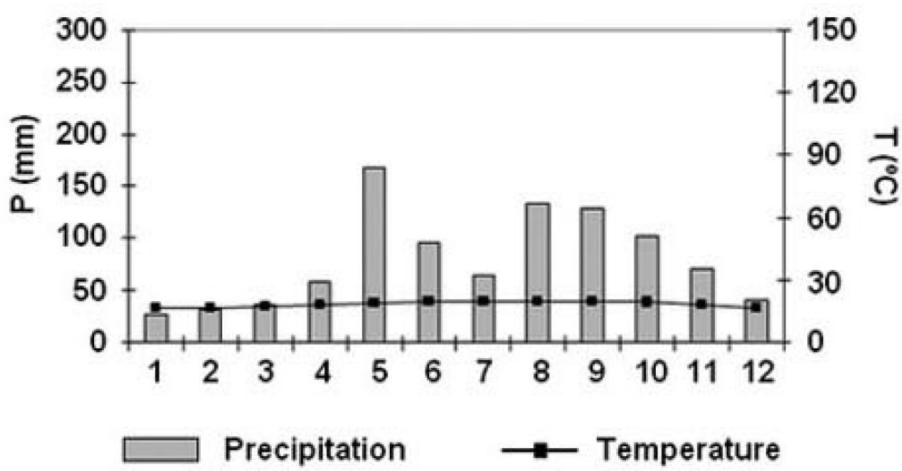


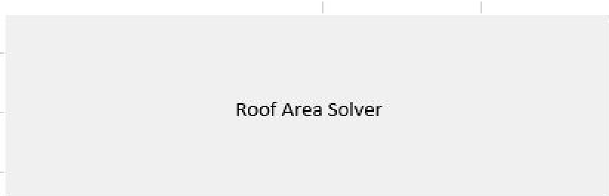
Figure 3: The average monthly rainfall of Constanza, Dominican Republic is shown above. (Izzo et al, 2013)

Table 3: Excel Calculator User Interface for Case Study Outputs for Step 1

Output	Value	Units
Water Volume Required (month)	2,430	Liters/month
Water Volume Required (year)	29,160	Liters/year
Storage Volume	3,264	Liters
Total Water Volume	18,432	L/year
Percent of Water Need Met per Year	63%	

The novelty of this calculator is that it not only enables proper sizing of the water storage tank, but it allows the user to gauge whether or not the water requirement of a household could be met based on the roofing area. As shown in Table 3, the yearly potable water demand can be met by over 63%.

To calculate roof area and tank sizing to meet water demand, the user clicks the "Roof Area Solver" button and roof area is minimized and storage area is calculated based on the roof area to ensure water demand is met. See Figure 4 below for the User Interface from the Excel Spreadsheet.



Output	Value	Units
Roof Area	42	m^2
Storage Volume	5,764	Liters
Water volume Provided	32,551	L/year
Percent water need met	112%	
Yearly Shortage	-	L

Figure 4: User Interface to solve for roof area and storage tank sizing to meet water demand.

Assuming similar monthly precipitation rates shown in Figure 3, a roofing area of 42 m^2 would be needed to capture enough water to meet 100% of the daily water demands for a three person household. In Figure 4, percent water need met exceeds 100% to account for spill. Options for expanding the roof area to accommodate demand include using a tarp, constructing a covered patio, or stand-alone corrugated metal structure.

4.2 Conveyance System Sizing

4.2.1 Gutters

Gutters and downspouts convey rainwater from the roof to the storage tank. To maximize the volume of rainfall captured, the gutters should span the length of the roof. Due to its robustness and easy handling, PVC pipe is an appropriate gutter and downspout material as shown in Figure 5. It is available locally, economical, and installed easily. The required piping for gutters is the length of one side of the roof because the pipe is cut in half horizontally, with each half servicing each side of the house. For the case study, 6 meters of piping is required for the gutters, with each half pipe capturing an area of 12 m^2.

Figure 5: This gutter is constructed of PVC pipes cut in half to capture runoff from a tile roof. (Grafman, 2017).

Galvanized sheet metal is an alternative material for the construction of gutters (Figure 6). Sheet metal can be cut and shaped into gutters that have more capacity to convey runoff. Sheet metal is widely accessible in Constanza and is relatively inexpensive. However, it can be difficult to connect multiple sheets together over a long roof span and losses can occur at the gutter and downspout junction (Grafman, 2017). It is recommended to overlap two sheets of sheet metal, with the upstream sheet overlapping the downstream sheet.

Figure 6: Galvanized sheet metal adapted to function as a gutter (Grafman, 2017)

A slope of 0.5% (0.005 m/m) is recommended for the gutters. A shallower slope will not convey the water fast enough and will result in ponding and overflow. A steeper slope will depart from the roofline and will intercept a smaller percentage of runoff from the roof. Equation 2 is used to calculate the vertical departure expected.

$$Drop = Slope \ x \ Roof \ Length \qquad (2)$$

Case Study calculation:

$$Drop = (0.005 \ m/m) \ x \ (6 \ m) = 3 \ cm$$

For the case study house, the deviation from the roofline is a tolerable 3 cm.

Pipe diameters of 3 and 4 inches were analyzed for maximum flow capacity using rainfall intensity data from Miami, Florida due to lack of rainfall intensity data from the region (NOAA National Weather Service). The results are in Table 4; storms over these intensities will exceed the gutter capacity and begin to spill over the gutters. Although the efficiency of the system is decreased in intense rain events due to gutter spill, heavy rain tends to occur during wet months when water availability exceeds storage volume and demand is fully met.

Table 4: Maximum storm events conveyed in gutters without overflowing.

Pipe diameter (inches)	Gutter Capacity (m^3/sec)	Storm Characteristics	
		Storm Recurrence	Storm Duration
3	0.0010	1-year	> 6 hours
4	0.0023	2-year	> ½ hour

4.3 Sizing the Sanitation Fittings

4.3.1 Screens

Preventative measures such as first-flush systems and screens minimize the required cleaning of the entire system and ensure higher water quality. First, screens minimize debris entering the conveyance system and subsequent storage tank. They can either be bought commercially to match a particular pipe size or made using available materials such as wire screens or meshes to cover the entrance of a down spout. An example of a screen in shown in Figure 6.

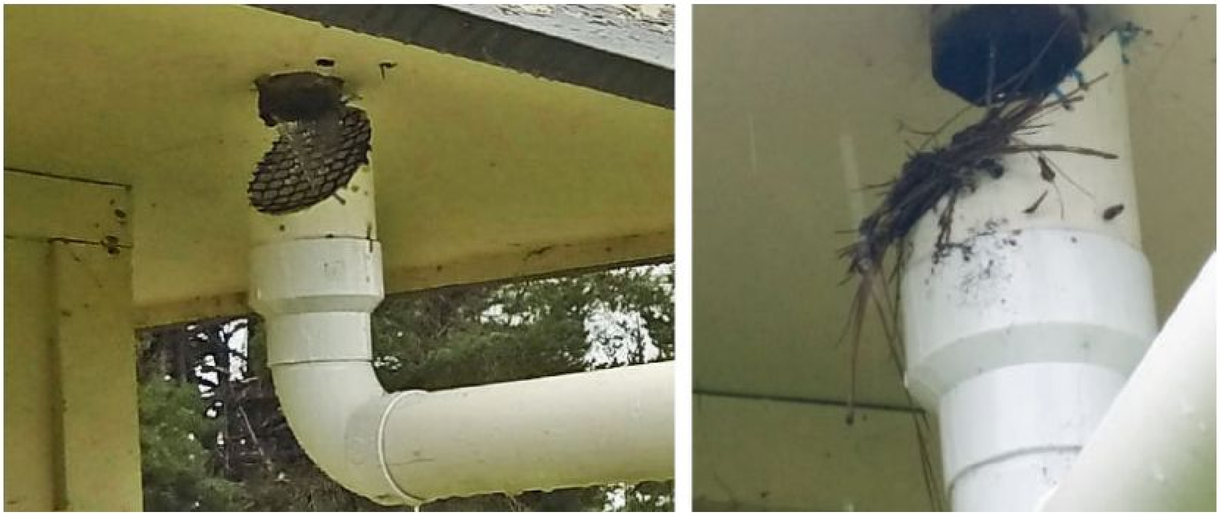


Figure 6: Adapted from approppedia.org, this figure depicts a plastic mesh screen on the left and debris accumulation on the right.

4.3.2 First Flush

While screens are simple to size, first-flush systems need to be carefully sized. First-flush systems, shown in Figure 7, divert the dirtiest portion of the water away from the storage tanks. Between rain storm events, dust, ash and animal droppings accumulate on the roof surface. The initial rainfall in contact with these contaminants fills the first-flush chamber first. When the first-flush device fills, a floating ball seals the chamber entrance, and allows the clean water to pass over the first-flush device and enter into the storage tank.

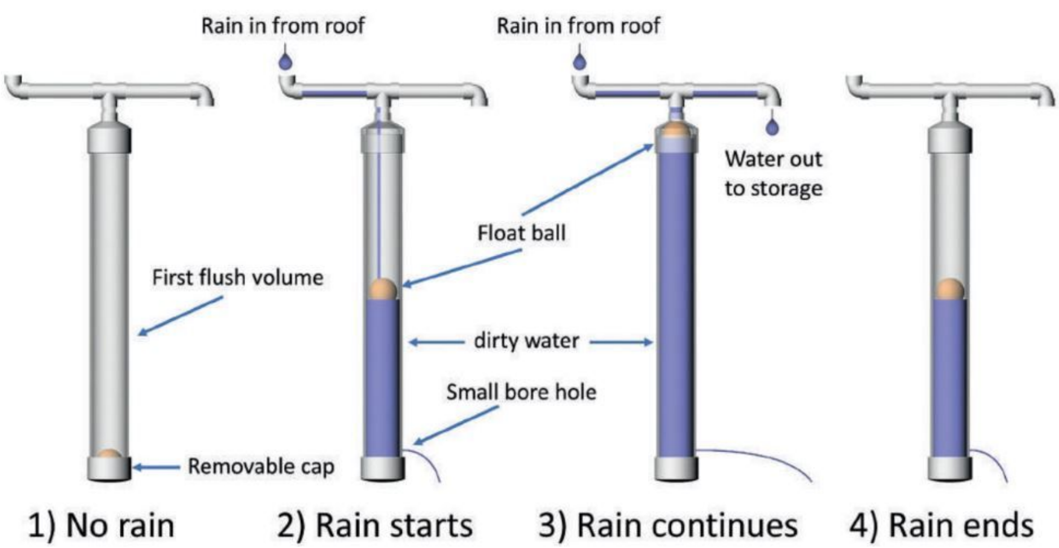


Figure 7: A sample floating-ball first flush system (Grafman, 2017)

4.3.3 Availability and Cost of First Flush

First Flush systems are available commercially as kits to accommodate 3 or 4 inch piping used for conveyance. Rain Harvest Systems, a retailer of first flush devices, sells kits for 3 and 4 inch diameter pipes for approximately $40 per unit and a 12 inch diameter kit for $120. Partnerships with US organizations could help subsidize these systems to reduce the cost for Constanza residents.

Before importing from the United States, local plumbing manufacturers and hardware stores should be investigated for a similar system that could be cheaper, logistically simpler, and be a better fit for the local design. If first flush devices are not available in the Dominican Republic, it could be a business opportunity for local entrepreneurs.

4.3.4 Sizing First Flush

The volume of the first-flush chamber is unique to each house as it varies with catchment area. As such, for every system designed, the volume of the first-flush system should be calculated. The volume required can be calculated using a modified version of an area-based empirical method such that 0.41 L of water is diverted per square meter of roofing area prior to collection (Grafman, 2017).

$$First\ Flush\ Capture\ Device\ Volume\ [L] = 0.41 \times Roofing\ Area\ (\ in\ m^2) \tag{3}$$

First Flush volume is calculated in the Excel calculator developed for storage sizing. An image of the user interface can be seen in Table 5 below.

Table 5: Excel Calculator User Interface for First Flush Device

First Flush		
Output	**Value**	**Units**
First Flush Volume	10	Liters
Chamber Height 3" PVC	88	cm
Chamber Height 4" PVC	50	cm

From Eq. 3, a summary of pipe lengths required for first flush systems are shown in Table 6 below. For smaller roofs, a 3 inch diverter will suffice, whereas for larger roofs, a 12 inch diverter is recommended to avoid an excessively long first-flush system. Where possible, use a smaller diverter to minimize cost, since larger diameter pipes are more costly.

Table 6: Length of PVC required to accommodate various first-flush system sizes based on roofing area

Roofing Area	Water Volume Diverted	Length of 3" PVC Required	Length of 4" PVC Required	Length of 12" PVC Required
m^2	L	in	in	in
5	2.05	17.7	10	-
10	4.1	35.4	19.9	-
15	6.15	53.1	29.9	-
20	8.2	70.8	39.8	-
25	10.25	-	49.8	-
30	12.3	-	59.7	-
35	14.35	-	69.7	7.7
40	16.4	-	-	8.8
45	18.45	-	-	10
50	20.5	-	-	11.1
55	22.55	-	-	12.2

Note: Null values are not recommended for first flush due to inconvenient height.

4.4 Material Considerations of the Water Storage Tank

To ensure sufficient water quantity and practicality, water storage, cost, volume and footprint must be analyzed. The three cistern materials considered in this manual are:

1) Ferrocement - cylindrical shape constructed using cement and rebar
2) Plastic - manufactured plastic tanks available in discrete sizes locally
3) Cinder block cistern - cubic shape constructed using cinder blocks, cement, and rebar

Information for each type of storage tank is given in Table 7, and tank examples are shown in Figure 8. In the foreground of Figure 8, a ferrocement cylindrical cistern made from rebar and concrete is shown. The blue barrel is used for convenient daily storage and often found near kitchens and latrines. Adjacent to the barrel is a cistern comprised of cinder block and mortar. Lastly, a larger plastic storage tank on the roof allows for a gravity fed system. Tank location, including elevation and distance from the house will affect on the functionality of the design.

Table 7: Pro's and Con's for three storage tank options.

	Ferrocement	Plastic	Block Cistern
Pros	● Customizable Sizing ● Ideal for larger tanks	● Easy to install ● Ideal for smaller tanks	● Customizable Sizing ● Can be underground to reduce footprint
Cons	● Skilled Labor Required ● Concrete can crack	● Expensive ● Fixed Volumes ● Not ideal for larger storage requirements ● Shortest lifespan	● Cubic shape not ideal ● More expensive

Figure 8: Examples of water storage. Biehl (2012)

5. Operations and Maintenance Guide

Rainwater harvesting systems require little training and supervision to operate making it economically desirable. Aside from preventative design measures such as screens and first-flush systems, the primary maintenance objective is to avoid pathogen contamination from animal droppings, insects and air pollution that may contaminate the piping system. Some ways to deter contamination include clearing the catchment area of debris and periodically cleaning first flush devices, storage tanks, and pipes. The user must disinfect the water source regularly to prevent disease.

5.1 Recommended Disinfection Method Prior to Use

A major concern of rainwater catchment systems is ensuring that the harvested water is safe to drink. Ideally, water quality testing should be regularly performed as a safety check, but access to laboratories in developing areas is difficult. Chlorination is recommended to sterilize rainwater collection systems (Mosley, 2005). While commercial chlorination and iodine water disinfection tablets exist, these tablets are designed to low water volumes and no commercial treatment tablets exist for water storage tanks. Further, commercial reagents designed for the disinfection of airline potable water storage tanks exist, but are costly. As shown in Table 8, while water disinfection tablets such as Aquatab are popular for small-scale use, it costs $18 per 100 gallons treated. On the other hand, sodium hypochlorite, which can be sourced from common household bleach, is a cheap and effective means of providing disinfection (Mosley, 2005). Of the commercial products considered, Aquaprime Neoklor is the most cost effective option at $0.10 per 100 gallons. Despite scholarly and government recommendation, if residents are not comfortable with using bleach, using Neoklor remains a viable and cost-effective disinfection option at $0.10/100 gallons treated or see Table 9. A summary of the costs of several disinfection options are listed below in Table 8.

Table 8: Comparative Water Treatment Chemical Reagent Costs

Disinfection Options	Commercial Name	Unit Cost ($)	Cost per 100 Gallon ($/100 gal)
Bleach	Generic 6% m/m active ingredient	$4.50	$0.03
Water Disinfection Tablets	Aquatab	$9.00	$18.00
Water Disinfection Reagents	Purogene Biocide	$29.00	$6.00
	Water Preserver	$11.95	$22.00
	Aquaprime NeoKlor	$72.00	$0.10

Based on the active ingredient concentration and the size of the tank, the proper dose can be estimated. Different brands of bleach have varying concentrations of the active ingredient, sodium hypochlorite, but a 4% m/m (mass of active ingredient per mass of solution) concentration is typical. Scholars such as Mosley (2005) have devised a table that can be used to dose a storage tank with 4% sodium hypochlorite bleach based on its volume. The authors have adapted the information and extrapolated the data to estimate the dosage required using bleach solutions of varying concentrations as shown in Table 9.

Table 9: Suggested Bleach Dosing Requirements Based on Storage Tank Size

Volume of Water in the Storage Tank (L)	Bleach Dose (mL) with Active Ingredient as Sodium Hypochlorite				
	4% m/m Active	**5% m/m Active**	**6% m/m Active**	**7% m/m Active**	**8% m/m Active**
1000	125	100	83.3	71.4	62.5
1500	187.5	150	125.0	107.1	93.8
2000	250	200	166.7	142.9	125
2500	312.5	250	208.3	178.6	156.3
3000	375	300	250.0	214.3	187.5
3500	437.5	350	291.7	250.0	218.8
4000	500	400	333.3	285.7	250
4500	562.5	450	375.0	321.4	281.3
5000	625	500	416.7	357.1	312.5

Residents must wait 24 hours after dosing prior to potable water use. In addition to a graduated cylinder for volumetric dose measurements, residents operating a rainwater catchment system should use latex gloves and safety glasses as personal protective equipment for handling and preparing chlorine solutions, if available. The cost of personal protective equipment is negligible relative to the cost of the conveyance system, maintenance, and disinfection. If residents run out of chlorine, the water should be boiled before its use for cooking, cleaning, and drinking.

5.1.1 Water Treatment Alternatives

Harvested water should always be disinfected and or treated prior to potable use. In addition to the alternatives discussed above, there are a number of treatment methods available, though they may be cost prohibitive or energy intensive. A broad list adapted from Grafman (2017) is shown below:

1. **Canister filters**-rely on sedimentation and a combination of ceramic and carbon filters. While effective, are relatively expensive.
2. **Activated carbon filters**-use chemical adsorption to remove organic compounds, tastes, and odors, but are ineffective at removing viruses and bacteria.
3. **Ceramic filters**-uses a labyrinth of microscopic holes to filter contaminants of various sizes. While they can be manufactured locally, these filters have low flow rates and can clog easily. Ceramic filters do not reduce the pathogenic load.
4. **Slow-sand filters**-involve a gravity fed system of gravel and sand with a developed biofilm layer at the top. They are inexpensive to construct, are reliable, and offer some degree of pathogen removal, but entail a slow flow rate.
5. **Boiling**-the simplest treatment option that can be used when bleach is unavailable for disinfection prior to use. While effective, it is energy and time intensive.
6. **Ultraviolet (UV)**-relies on an electrical lamp to disable microorganisms by damaging their genetic material. While excellent at pathogen reduction, it requires an energy source.
7. **SODIS** (Solar disinfection)-uses solar radiation and heat to treat water stored in clear water bottles. While potentially useful in small-scale situations, its long treatment time and low capacity makes it unsuitable to provide a supplementary water supply.

For a detailed summary of treatment times, capacity, and pathogen removal performance, refer to Table S1 in the appendix adapted from Imani et al. The authors recognize that the locals may not trust in the effectiveness of a particular treatment or disinfection method and may require extra disinfection steps. Or, the locals might prefer improved water quality beyond simple chlorination. According to the client, the locals already trust the use of ceramic filters as a means of treatment (Figure 9). Those who already have a ceramic filter can use it as an additional treatment measure prior to consumption.

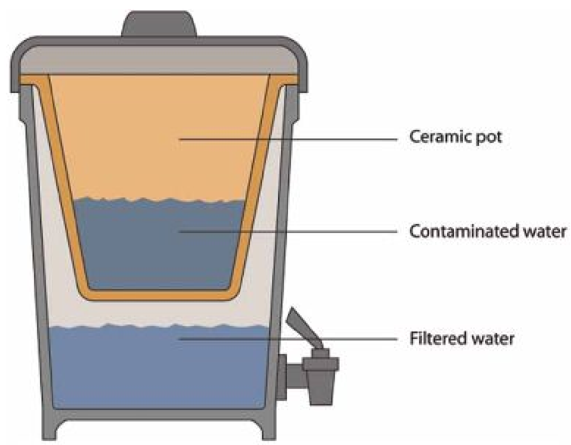


Figure 9: A concept schematic of a ceramic filter (Soppe et al. 2015)

5.2 Cleaning Procedures

5.2.1 Catchment and Conveyance System Cleaning

Cleaning the rainwater catchment system is simple and should be done on an as-needed basis (Grafman, 2017). Well-designed systems with an adequate screen and first-flush device will require less storage tank cleaning than a system without these measures (Grafman, 2017). Mostly, the common cleaning methods include regular visual inspects of the gutters and screens that can catch debris, which should then be removed by hand. The first flush devices should be inspected for clogs, leaks and cleaned accordingly. Lastly, the roofing should be checked for rust, leaks or excessive exposure to animal droppings, dirt, or dust and repaired and cleaned off if necessary.

5.2.2 Storage Tank Cleaning

The storage tank should be checked every year for build-up and deposits (Grafman, 2017). Build-up should be removed by hand or by vacuum and the tank should be scrubbed after. Deep cleaning of the water storage tanks are also needed when an animal or floodwaters enter the storage tank. While the United Nations and the World Health Organization do not have guidelines for maintaining rainwater harvesting tanks, the United States CDC provides recommendations. The CDC recommends that once the catchment area including the rooftops and gutters are cleared of debris, the water storage tanks are to be drained of water and debris. Once cleared, the inside of the tank should be scrubbed with a stiff brush and a solution of 0.25 L of household bleach mixed with 38 L of water. Once cleaned, the tank should be rinsed, drained, and standard operations can be resumed. It is recommended to clean the storage tank in April, as higher precipitation is expected in May. A deep cleaning guide from the CDC is attached in the Appendix section. Hand and eye protection should be worn when scrubbing the tanks with a bleach solution.

6. Participatory Approach through Community Surveying

Using a participatory approach means to include the end users of a water system in the planning of the system from the start. This contrasts from traditional planning methods where the needs of users are dictated by officials who may have a different perception of the actual needs and desires of the users. In the case of a centralized water system whereby a single storage tank accumulating rainfall from the roofs of multiple neighbors, participatory planning is useful in that it can increase feelings of ownership and community empowerment (akvopedia.org).

Through a comprehensive survey, a planner can decide whether or not a group of neighbors will be willing to maintain a system together. In the case of a decentralized system, a community survey will help verify that individual homeowner has the financial ability to own the system and if the aesthetics of the system are acceptable. Systems perceived to be inconvenient, difficult to operate, or do not correspond to the true needs of the users have an increased risk of neglect. On the contrary, ensuring community acceptance will increase the chance for a successful project.

A participatory planning approach guide for international development is attached in the Appendix section. The attached manual describes how to develop a communication strategy among various stakeholders through surveys and group discussions to identify user priorities such as current sanitation practices, cultural beliefs, household income vs. cost of system, and potential water uses. The following subsections will include a discussion about sample questions that should be included in future water demand surveys as adapted from the World Health Organization.

6.1 Core Survey Questions from the World Health Organization (WHO)

For complete guidance on implementation, analysis, quantification, and definitions on conducting the drinking water survey, refer to the core questions brochure attached in the appendix. This section is to serve as an introduction to materials presented elsewhere. Surveys should be prepared simultaneously in Spanish and English and checked with each revision for continuity between translations (Biehl, 2012).

Each question should have predetermined answers for locals to select the most appropriate option for their situation. These predetermined answers will be numerically ranked in terms of need, and all answers will be compiled to quantitatively estimate each household's need.

Question 0: Consent to Participate.

Obtain written proof of consent to participate in the community survey.

Question 1: What is the main source of drinking-water for members of your household?

Adapted from the World Health Organization Core Questions list, the purpose of this question is to identify the main source of drinking-water for members of the household. To quantify this, record the number of household members using improved sources of drinking-water such as piped water into dwelling, piped water to a yard, a public tap, tube well or borehole, protected dug well, a protected spring, bottled water, or rain water. Unimproved sources include unprotected springs, unprotected wells, a street vendor with a water drum, a tanker truck, and surface water. For detailed definitions, refer to the core questions brochure in the appendix.

Question 1A: What is the main source of water used by your household for other purposes, such as cooking, and hand washing?

The WHO poses this question to only those whose response to Question 1 was "bottle water". The purpose of this question is to identify the main water source used by household for potable us. It is important to identify the main secondary source to be able to classify the household as having access to an improved or unimproved water source.

Question 2: How long does it take, round trip, get water?

The purpose of this question is to assess whether the main drinking-water source is sufficiently close to the household to ensure that there is an adequate daily water supply.

Question 3: Who collects the water?

The purpose of question 3 is to know who (adult man, woman, female child, male child) fetches the water to identify whether there are gender and generational disparities with respect to water-hauling responsibilities.

Questions 4 and 5: Do you treat your water to make it safer? If so, what do you do to make it safer to drink?

The purpose of questions 4 and 5 is to identify whether the household treats the water as an indication of the quality of the drinking water used in the household. To quantify these questions, record the number of household members who treat their water using an adequate treatment method and record the total number of household numbers surveyed.

6.2 Recommended Survey Questions Beyond that Provided by the WHO

Question 6: Do you think it is worthwhile to begin or improve rainwater harvesting projects?

The purpose of this question is to gauge whether or not the respondent even wants a rainwater capture system installed on their property. Knowing is the first step to deciding which respondents to work with on developing a project.

Question 7: Above which price would you definitely not subsidize the project, because you can't afford it or because you didn't think it was worth the money? (Breidert et al., 2006)

Scholars believe that there is a maximum and minimum price for each product which can be determined by a direct approach to measure willingness to pay. (Breidert et al., 2006). Because funding may be limited, besides identifying water needs, the client should identify who could afford to maintain the rainwater catchment system or fund its construction.

7. Appendix

The items listed below are attached in the following order.

1. CDC Water Cistern Cleaning Factsheets
   https://www.cdc.gov/healthywater/emergency/drinking/disinfection-cisterns.html
   https://www.cdc.gov/healthywater/emergency/pdf/cistern-factsheet-eng-H.pdf
2. NETSSAF Participatory Planning Approach Guideline
   https://sswm.info/sites/default/files/reference_attachments/NETSSAF%202008%20Participatory%20Planning%20Approach%20Guideline_0.pdf
3. WHO Core Water Survey Questions
   https://www.who.int/water_sanitation_health/monitoring/oms_brochure_core_questionsfinal24608.pdf
4. NOAA National Weather Service- Precipitation Frequency Data server
   https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ne

Table A1: Adapted summary table of cost, maintenance, and capacity of various treatment methods from Imani et al.

	Chlorination	Biosand Filter	Ceramic Filter	SODIS	Hollow Membrane	Boiling Water[9]	Biosand + Biochar Filter
Capacity	1,000 L / bottle[2]	123L[5]	20L/day	1-5L (depends on what is available)	100 L	30L boiling pot	1200L (500L biosand concrete tank + 500L biochar concrete tank + 200L storage bin[6]
Treatment Time	30 minutes	50L/hr	2L/hour	6 hours (sunny) or 2 days (cloudy)	12 L/hr	20 minutes @ 100°C	12 L/hr
Cost per Unit	$0.28 / bottle	$20 for locally made concrete vessel	$30	Marginal	$200	N/A	$35 per 200L bin < $100 for biochar[7]
Total # of Units Needed[1]	90 bottles per school year[3]	3 biosand filters ($60)	25	100+	1	5	1 system
Safe Water Storage	Add 3 200L bins ($35 per bin)[4]	Add 3 200L bins ($35 per bin)	Included	Included	Included	Add 3 200L bins ($35 per bin)	Included
Maintenance	Daily chlorine dosing	Daily refilling, periodic agitation of biolayer	Refill every 4 hours, brush clean filter every 3 months	Constant filling and placing in sun, replacement of bottles when cracked	Backwash filter daily, replace filter every 3 years	Constant refilling and transferring of water	Periodic biolayer agitation, yearly biochar replacement
Water Efficacy[8]	3-6 log removal of bacteria, 3-5 log removal of protozoa	98.7% bacteria, 85.9% viruses, 99.88% cryptosporidium	2-4 log removal of bacteria, 2-6 log removal of protozoa, 1-2.3 log removal of viruses	3-5.5 log removal of bacteria, 1-3 log removal of protozoa, 2-4 log removal of viruses	99.99% removal of bacteria and protozoa. Limited removal of viruses	86-99% removal of bacteria and viruses	98.7% bacteria, 85.9% viruses, 99.88% cryptosporidium, heavy metal removal
Total Capital Cost	$105	$165	$750	<<$200	$200	$105	$105
Operational Cost	$25.20 per school year	N/A	N/A	N/A	$20 per 3 years (filter replacement)	N/A	Yearly cost to replace biochar

[1] Technologies have been scaled to treat 500L of water per day (2.5 L drinking water per person for 200 people)

[2] Bottle refers to one bottle of WaterGuard, which is locally produced and widely available in Kenya

8. References

Abdulla, Abdelkader. "Rainwater Harvesting in Tobruk, Libya". 2010.

Aiken, Benjamin A., Christine E. Stauber, Gloria M. Ortiz, and Mark D. Sobsey. "An Assessment of Continued Use and Health Impact of the Concrete Biosand Filter in Bonao, Dominican Republic." American Journal Of Tropical Medicine And Hygiene 85.2 (2011): 309-17. Web.

Biehl, Ryan M. "Suitability comparison of rainwater harvesting and piped water systems in the Dominican Republic." (2012).

Breidert, Christoph, Michael Hahsler, and Thomas Reutterer. "A review of methods for measuring willingness-to-pay." *Innovative Marketing* 2.4 (2006): 8-32.

Dos Anjos, Nelson Da Franca Ribeiro. "Source book of alternative technologies for freshwater augmentation in Latin America and the Caribbean." International Journal of Water Resources Development 14.3 (1998): 365-398.

Grady, Caitlin, and Tamim M. Younos. "Water Use and Sustainability in La Altagracia, Dominican Republic." (2010).

Grafman, Lonny. "To Catch the Rain: Inspiring stories of communities coming together to harvest their own rain, and how you can do it too." (2018).

Izzo, Michela, Carmen. Rosskopf, Pietrop. C. Aucelli, Antonio Maratea, Rafael Méndez, Caridad Pérez, and Hugo Segura. "A New Climatic Map of the Dominican Republic Based on the Thornthwaite Classification." Physical Geography 31.5 (2010): 455-72.

Mosley, Luke. Water quality of rainwater harvesting systems. South Pacific Applied Geoscience Commission, 2005.

Soppe, A. I. A., et al. "Critical parameters in the production of ceramic pot filters for household water treatment in developing countries." *Journal of water and health* 13.2 (2015): 587-599.

Water Conservation Methods, http://www.neoakruthi.com/blog/index.html

World Health Organization. “PHAST step-by-step guide A precipitory approach for the control of diarrhoeal diseases.” 1998.

US Department of Commerce, Noaa, Nws, & Office of Hydrologic Development. (2005, November 07). Retrieved from https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ne