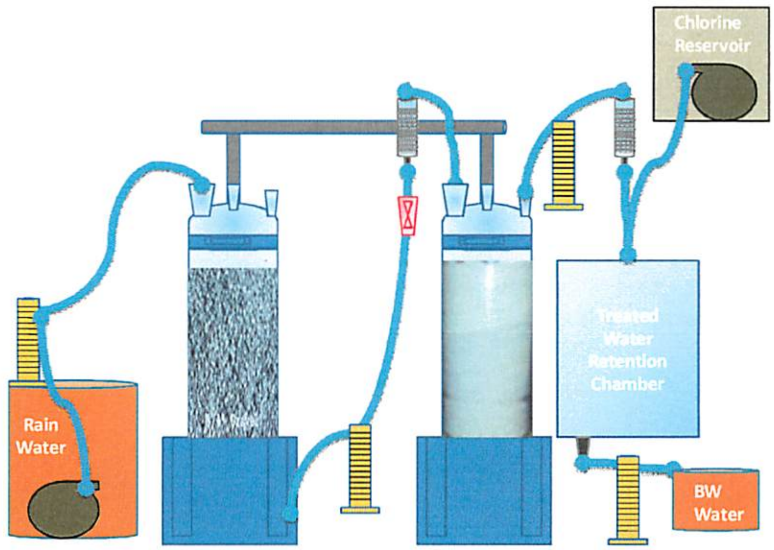
Final Report

Point-of-Entry (POE) Cistern Water Purification Units (CPU) Development

Project Year: Apr. 1, 2009 ~ Feb. 28, 2010



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February 28, 2010

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Problem Statement

Nearly 1.8 million people die every year due to diarrhoeal diseases (including cholera) in developing countries and 90% of which are children under five years. Approximately 88% of these diseases are attributed to unsafe water supply, inadequate sanitation, and poor hygiene practices. In fact, about 1.1 billion people worldwide do not have access to drinking water from improved sources, where as 2.6 billion people lack basic sanitation. With an improved water supply the diarrhea morbidity rate is reduced by 6% and with an improved sanitation by 32%. In the Caribbean, 77% of the urban and 37% of the rural population don't have access to an improved drinking water, whereas 20% and 44% of urban and rural population, respectively, have access to an improved sanitation (WHO/UNICEF, 2006).

Desalination supplies about 80% of the water used in the United States Virgin Islands (USVI). Despite this fact, greater than 50% of the residences in the USVI use rainwater cistern (Brin et al., 2003). Annual rainfall averages 40 inches in USVI and is very seasonal so that desalinated water is often transported to refill the cisterns. From that point, there is a potential for improved water supplies to get exposed to secondary contamination from pumps, pipes and the trucks, resulting in causing infectious diseases and other enteric illness (Sobsey et al., 2008).

In addition, there might be contamination of rainwater before collected to the cisterns due to urban pollution, bird and reptile waste materials and particulate matter deposited (Chang et al., 2004; Evans et al., 2006; Simmons et al., 2001). Also, if the cisterns are old and dirty due to poor maintenance, there is a potential of contamination of the stored cistern water. Another case of cistern water contamination can be due to aged cistern structure, thereby infiltration of contaminants from the surrounding contaminated soil and groundwater to the cisterns (Isquith and Winters, 1987).

Objectives of Research

The technology to be used for the provision of water services to communities and areas in specific characteristics is always challenging. When water purification technology similar to what is used in large urban areas is chosen, it will lead to high investments, which cannot be afforded by the majority of small remote communities. It is important to choose technologies that can easily be operated and maintained by local service providers or by community people.

This research aims to develop and evaluate a POE CPU which can be implemented in communities of the USVIs. To meet this end, low-cost, simple, POE sand filtration and disinfection unit was tested in a lab-scale. POE CPU to be developed in this proposed study will benefit many communities which rely on rainwater as their drinking water source (e.g., USVIs). POE CPU could be used by residents voluntarily with the expectation that the units can provide a protective measure if contaminations are present due to dirty rainwater or mismanaged cisterns. The POE CPU can also be used in a reactive mode, where the residents could take action in response to suspected or confirmed cistern water contaminations. In other aspects, the results of the proposed study not only strengthen the PI's research thrust on small drinking water system evaluation and development, but also significantly contribute to capacity building for USVIs through seminars and technology transfers in the future.

The proposed research was proposed with a budget of $19,750 during the period of April 1, 2009 to Feb 28, 2010. It encompassed lab-scale research, student training, results dissemination, and a seminar.

Materials

Three different sizes of sand were purchased from the Standard Sand & Silica, Co.. The sands were manufactured specifically for the compliance with AWWA Standard B100 and are listed with NSF Standard 61 as an approved filtration sand supplier and for the use of filtration systems. Commercial gravels in sizes of 0.25~0.75" was purchased for construction of the gravel filter. The lab-scale filtration unit was constructed with glass columns (7" in diameter and 12" long). For disinfection, 0.1% sodium hypochlorite (NaOCl) solution was applied to filtered effluent.

Rainwater was collected periodically and stored in a refrigerator at 4°C prior to use. It was analyzed for the key water quality parameters (Table 1).

Table 1. Characteristics of rainwater.

	Villarreal and Dixon (2005)	Appan (1999)	This Study
pH	5.2-7.9	4.1 (0.4)	5.8-6.2
BOD (mg/L)	7-24		
COD (mg/L)	44-120		77
TOC (mg/L)	6-13		
Turbidity (NTU)	10-56	4.6 (5.7)	0.7-1.3
Nitrate (NO_3^-, mg/L)			5.7
Phosphate (PO_4^-, mg/L)			0.025
TS (mg/L)	60-379		
SS (mg/L)	3-281	9.1 (8.9)	
Conductivity (uS/cm)			26-28
Total colifroms (#/100mL)		92.0 (97.1)	
Fecal coliforms (#/100mL)		6.7 (8.9)	2-10

Lab-scale POE CPU

Setup and Operation

According to the schematics of the POE CPU proposed (Figure 1), a lab-scale filtration and disinfection unit was constructed as shown in Photo 1. For the sand filtration column, three different sizes of sand were used, as shown in Table 2. Distribution and selection of sands were decided in accordance to another small drinking water system project that the PI is working on at a field (Hwang et al., 2009).

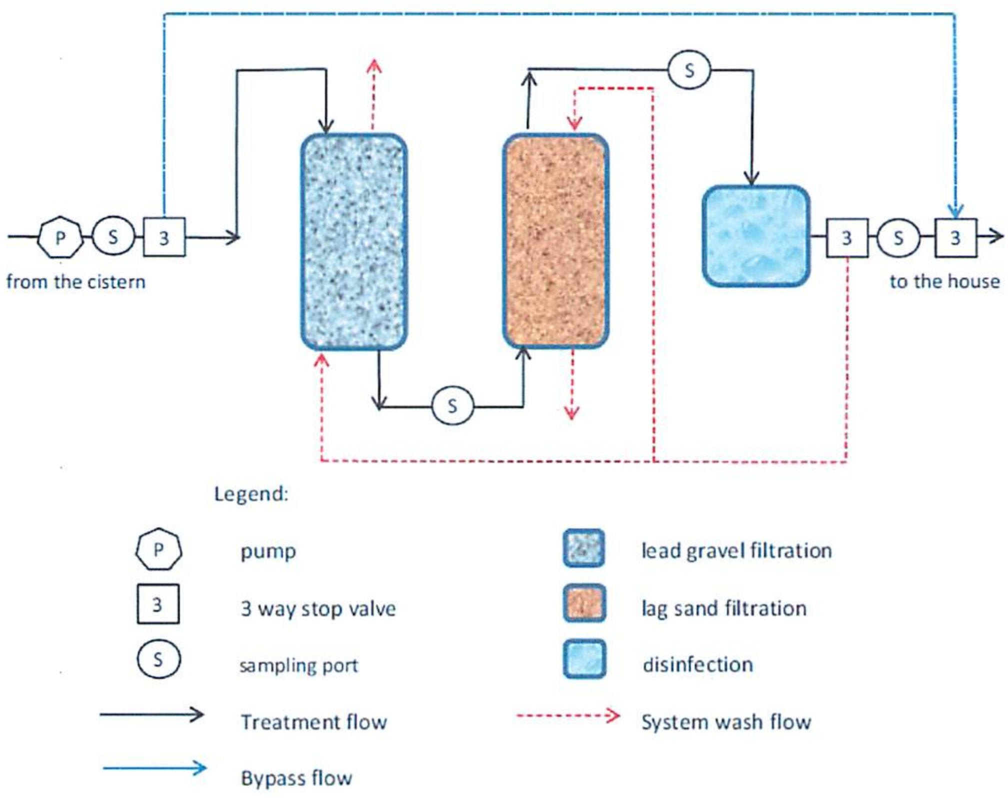

Figure 1. Schematics of POE CPU.

Photo 1. A view of the installed lab-scale POE CPU.

Table 2. Filtration media used for the sand filtration unit.

Media	Size	Total Weight (kg)
Sand	Global No. SS 30/65 Effective size = 0.18 mm	1.87
Sand	Global No. SS 20/30 Effective size = 0.55 mm	3.75
Sand	Global No. SS 6/20 Effective size = 1.10 mm	1.87

For the filtration, rainwater was pumped at 0.09 gal/min which is corresponding to 0.50 gal/min/ft^2 as shown below:

$$SFR = \frac{0.09\,\frac{gallon}{min}}{0.182\;ft^2} = 0.50\,\frac{gal}{\min ft^2}$$

For disinfection, a commercial liquid NaOCl solution (5.25%) was diluted to 0.1%. The solution was pumped to the effluent from the sand filtration unit at a flowrate of 0.03154 mL/min. The target disinfectant concentration was set at 0.5~1.0 mg/L in the effluent.

Backwash

Backwash of the sand filtration unit was conducted at a flow rate of 0.275 gal/min. The stored disinfected filtration effluent was used for the backwash. The flowrate was corresponding to 1.51 gal/min/ft^2 as shown below:

$$BWR = \frac{0.275\;gal/min}{0.182\;ft^2} = 1.51\,\frac{gal}{\min ft^2}$$

Analysis

Samples were collected for analyses of physiochemical and biological characteristics of water. For physiochemical water quality parameters, measured were total residual chlorine concentrations, pH, specific conductivity, particle counts and turbidity. Total residual chlorine (TRC) concentrations were monitored with HACH calorimetric method. The value of pH was monitored with Oakton pH Meter 300 series. Specific conductivity was analyzed with Orion Specific Conductivity Meter Model 162. Turbidity was measured with LaMotte 2020 Turbidimeter. Particle counts were measured with a particle counter (9703 Liquid Particle Counting System, Pacific Scientific, Co.).

For biological water quality parameters, measured were total coliforms (TC), fecal coliforms (FC) and total heterotrophic bacteria (THB) via a membrane filtration technique. Microbial analysis was done within 24 hours of sampling. TC was quantified with m ENDO Broth. All colonies that are red and have the characteristic metallic sheen are counted as TC after incubation for 24 hrs at 35±0.5 °C. For the FC, m FC broth was used. Tryptic soy broth was used for THB analysis. After incubation for 24 hours at 44.5±0.2 °C, all colonies developed in blue were counted for the FC. THB analysis was done with a72-hour incubation at 35°C.

Results and Discussion

Physiochemical Water Quality

Filtration and Disinfection

Rainwater was pumped at a loading rate of 0.50 gal/min/ft^2 to the lab-scale POE CPU for 10 mins. Samples were taken after 10 mins. Then, the POE CPU was run for 1 hour and samples taken after 1 hour and analyzed. It should be noted that different rainwater characteristics were observed in the cistern.

Water temperatures were measured to be 20 $\pm$ 1°C throughout the experiment. As shown in Figure 2 and Figure 3, the values of pH were maintained at a neutral level (~7) in the system. Conductivity in the final disinfected effluent was increased by ~2 times, but the value was still low enough at ~53 μS/cm. Reduction in turbidity was observed despite the initial increase during the first trial. Residual chlorine concentration was achieved in the range of 0.2~0.7 mg/L which was similar to the targeted concentration (0.5~1.0 mg/L).

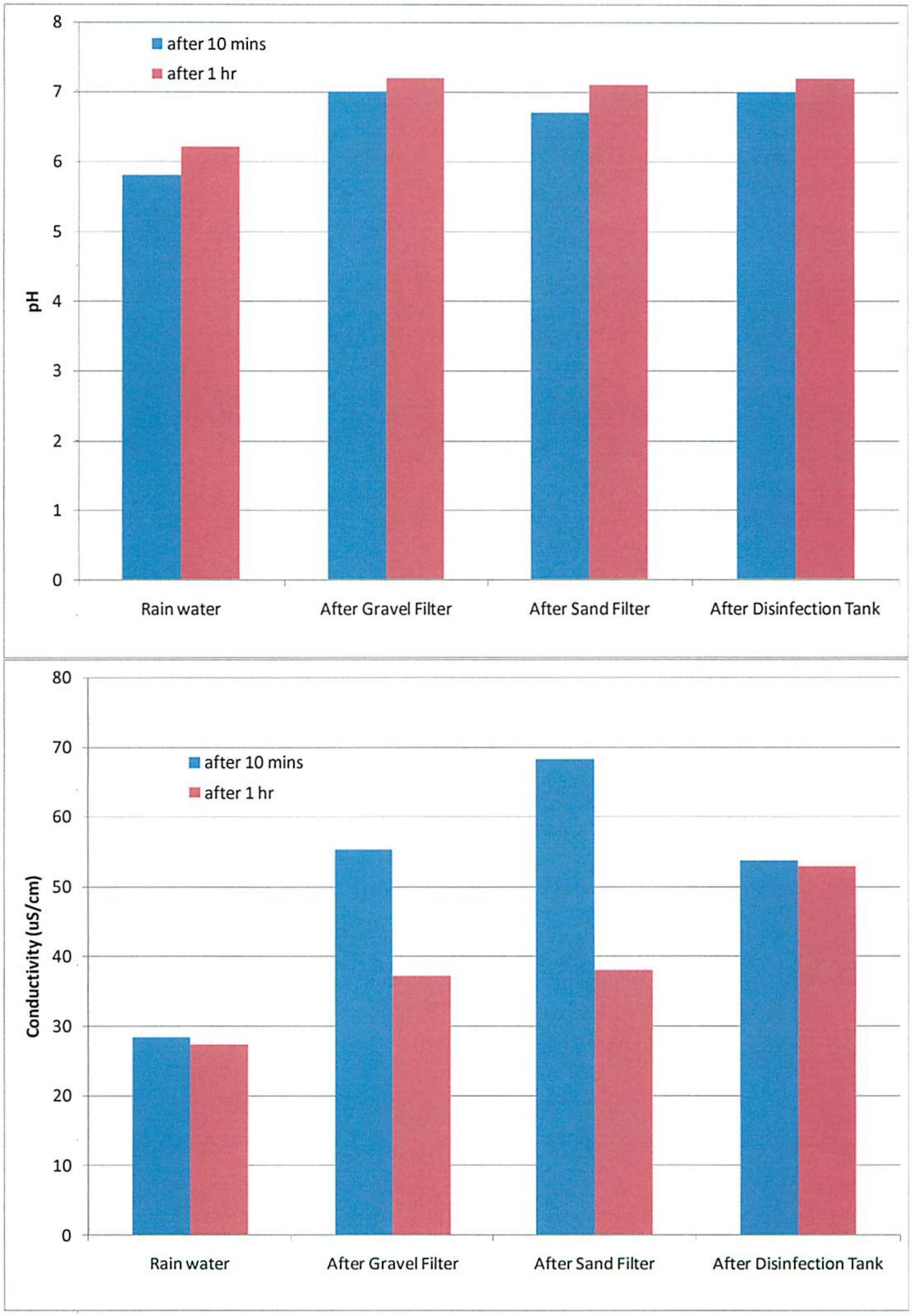

Figure 2. Trend of pH and conductivity during the lab-scale POE CPU run.

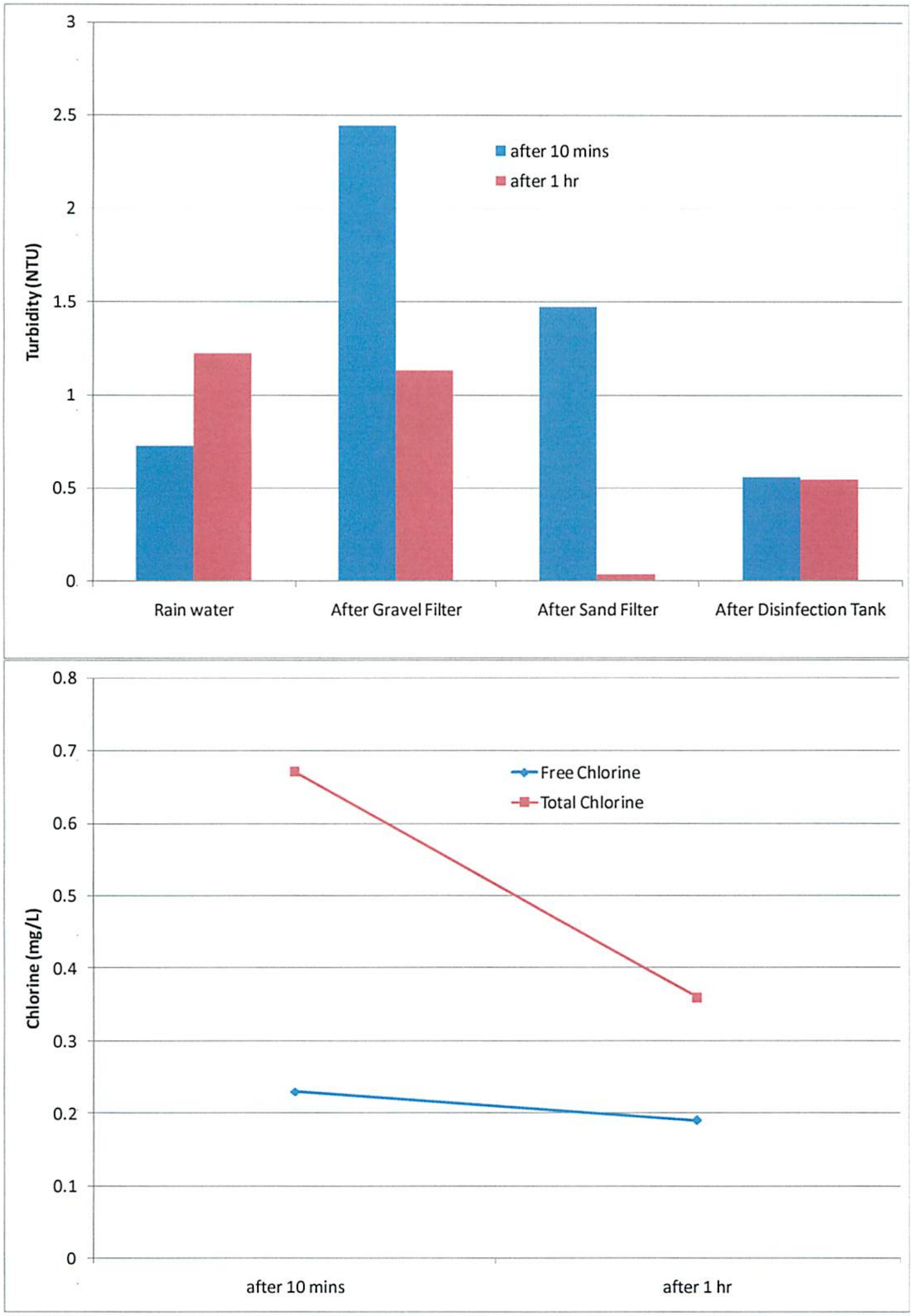

Figure 3. Trend of turbidity and residual chlorine during the lab-scale POE CPU run.

Backwash

During the backwash, 2.5 inches of bed expansion was achieved and the backwash effluent quality was analyzed (Table 3, Table 4, and Photo 2).

Table 3. Backwash duration and intensity.

Backwash Process	Duration (min)	Flow rate(gal/min)	Bed Expansion (inches)
Sand Column	6	0.275	2.5

Photo 2. Sand bed expansion during the backwash (left: before the backwash; right: after the backwash).

Table 4. Physiochemical water quality parameters of backwash.

Parameters	Backwash Influent*	Backwash Effluent	
		From Gavel Filter	From Sand Filter
Temperature (oC)	20.0	23.4	21.2
pH	7.1	7.0	7.0
Conductivity (uS/cm)	73.3	60.2	69.6
Turbidity (NTU)	0.6	53.1	4.9
Free chlorine (mg/L)	0.06	0.05	0.29
Total Chlorine (mg/L)	0.10	0.08	0.54
*: disinfected effluent from the sand filtration unit.			

Biological Water Quality

As shown in Figure 4, FC were detected at a concentration of 10 CFU/100 mL in the rainwater collected for the 1st trial (i.e., after 10 mins). However, no FC was found in the rainwater collected and used for the 2nd trial (i.e., after 1 hr). Differences in FC trend were due probably to the dissimilar properties of the influent rainwater with respect to FC concentrations. Unusually high FCs were detected from the gravel filter-backwashed water. However, no FC was found in the sand filter backwashed water.

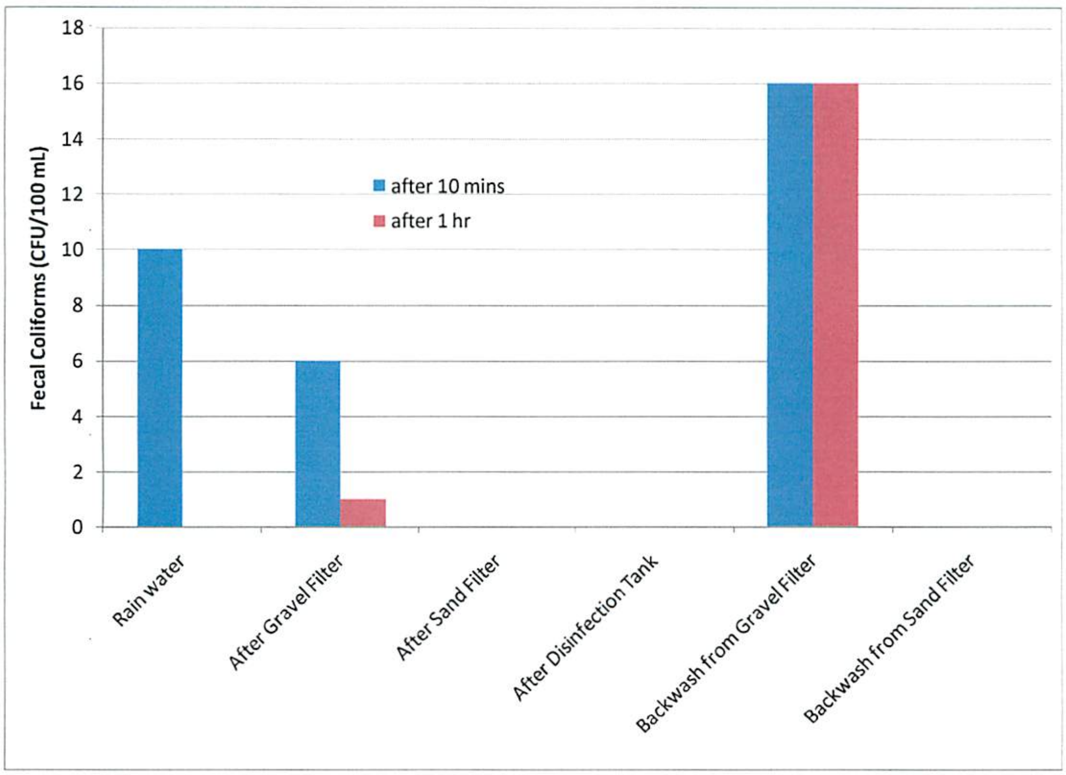

Figure 4. Results of fecal coliforms analysis.

THB was also analyzed for both 1st and 2nd trials. However, the CFU was too many to count for all the samples taken and analyzed, even with 100-time dilution of the samples. Additional run focusing on bacterial water quality is warranted to conduct.

CT Values on Microorganisms Removal

Microorganism concentrations (CFU/100mL) were artificially increased to assess the effect of CT values on microbial reduction. CT values are the product of disinfectant concentration (C) and contact time (T). Leachate of chicken manure was added to the rain water for this purpose. The initial concentrations of total coliforms and THB were measured to be 823 CFU/100 mlL and 42×10^3 CFU/100 mL, respectively.

Results from the disinfection of the influent water are shown in Figure 5. When the influent was disinfected with a chlorine concentration at 6 mg/L , smaller than 1-log removal was achieved for both total coliforms and THB despite 60-min contact time. Also, very low concentrations (<0.2 mg/L) of free chlorine was quantified after 20-min contact time.

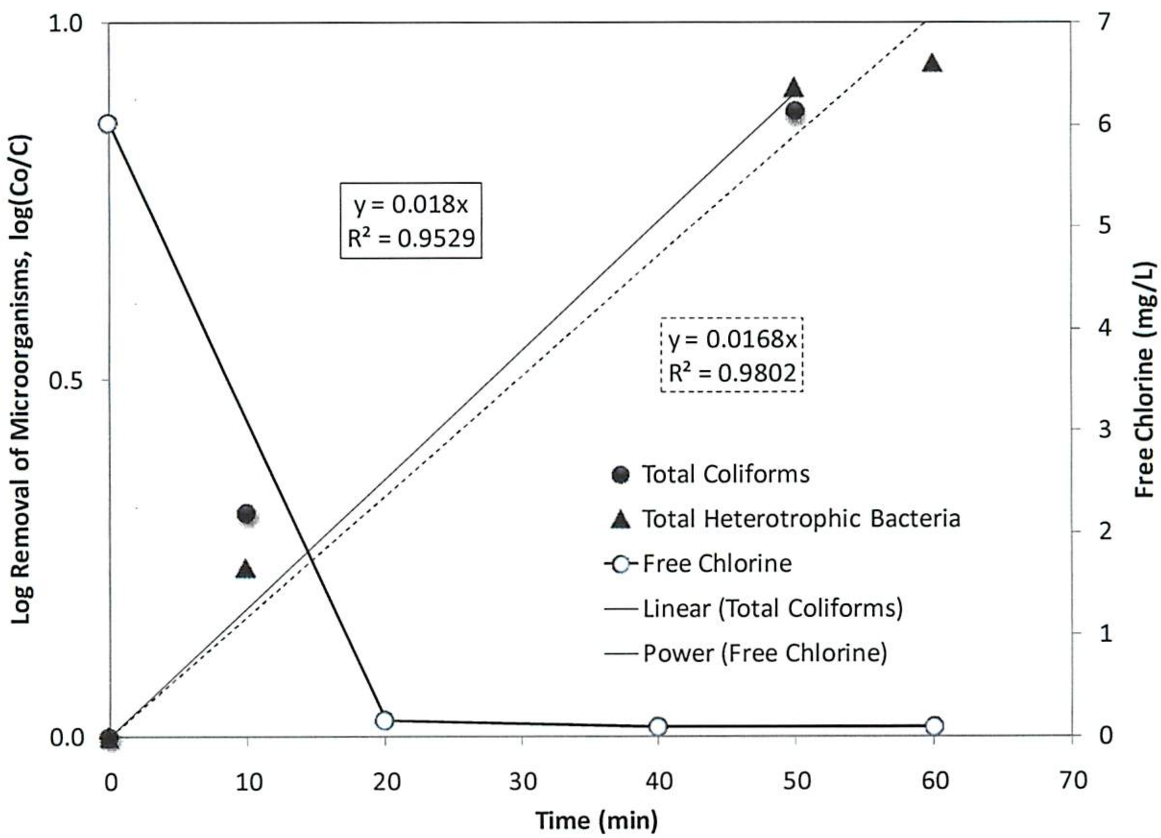

Figure 5. Effect of CT values on log removal of microorganisms in the influent amended with chicken manure.

However, when the effluent of the sand filter was disinfected with the same initial concentration of chlorine, 1-log removal and 1.5-log removal of both microorganisms was achieved with a contact time of 30 mins and 60 mins, respectively (Figure 6). Residual free chlorine concentration was maintained at 3 mg/L. It should be noted that the sand filtration reduced the concentrations of total coliforms from 823 to 400 CFU/100 mL and THB from 42×10^3 to 7.4×10^3 CFU/100 mL.

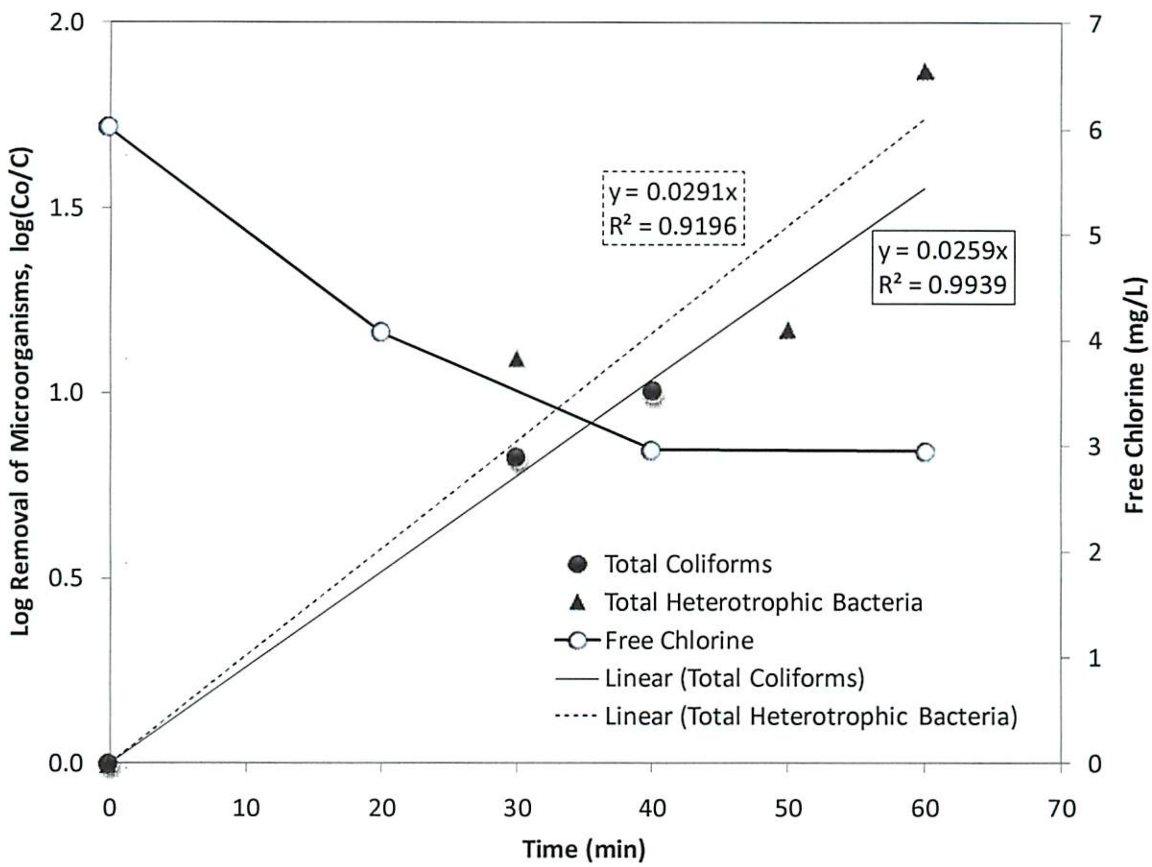

Figure 6. Effect of CT values on log removal of microorganisms in the effluent from the sand filter.

Student Training

The current project started administratively in April 2009. Prior to the kick-off, the project had focused on the training of two graduate students (Daniel Concepcion and Juan Falcon) with literature reviews with respect to filtration, disinfection and rainwater collections. They also helped to construct the lab-scale POE CPU. Later, two undergraduate students worked on the project (Laura Rodriguez and Maria Sevillano).

Seminar at the USVIs

A seminar was given by the PI (Dr. Hwang) to the science students in the Division of Science and Mathematics at the University of the Virgin Islands at St. Thomas on February 19, 2010. The title of the seminar was "Reclamation and Reuse of Rainwater". The seminar addressed both conventional and advanced technologies for rainwater reclamation and subsequent reuse. Biochemical quality of rainwater collected and stored was emphasized. Fundamentals of engineering design and operating parameters of sand filtration, chlorination, and ultra violet/peroxide were explained and applications of those fundamentals to real-case scenarios were demonstrated.

Future Studies

The goal of the first-year project was to develop and evaluate the performance of a POE CPU with respect to physiochemical and bacteriological water quality. To stretch the first-year project' goal, the second-year project is proposed to execute, focusing on the disinfection byproducts (DBPs) production potential in the final effluent from the POE CPU. Pathogens, such as Giardia, are often found in source water, and can cause gastrointestinal illness and other health risks (e.g., diarrhea, cramps, vomiting). To kill (or inactivate) these pathogenic microorganisms, water needs to be disinfected. However, disinfectants like chlorine can react with naturally-occurring materials (NOM) in the water to form DBPs. These byproducts include trihalomethanes (THMs), haloacetic acids, chlorite and bromate.

The second-year research will also focus on how these DBPs production can be minimized in the system, while ensuring microbial water quality. These byproducts may lead to increased health risks as potential carcinogens and the cause of reproductive and development defects in laboratory animals and human, if consumed in excess of EPA's standard over many years (Hamidin et al., 2008; Wang et al., 2007). The second-year work will encompass a series of lab-scale research on potential of DBPs occurrence in the effluent of the POE CPU, engineering approach to minimize DBPs production in the system, construction of a pilot-scale POE CPU, and a technical seminar by the PI to the students and professionals in the USVIs

Results Dissemination

Results obtained from the current research were presented at a regional professional conference as follows:

Hwang S., Concepcion D., Falcon J. "Small Filtration and Disinfection Unit for a Point-of-Entry Cistern Water Purification", 2009 CWWA Conference, October 4-10, St. Thomas, USVI.

Acknowledgments

This research was made possible with financial support by the United States Geological Survey 104B Program through the US Virgin Islands Water Resources Research Institute. We appreciate Mrs. Elsa Arce at the Puerto Rico Water Resources and Environmental Research Institute for her sincere administrative supports.

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