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Improving Implementation of a Regional In-Line Chlorinator in Rural Panama Through Development of a Regionally Appropriate Field Guide

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Environmental Engineering
Department of Civil and Environmental Engineering
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Abstract

Access to safe drinking water has a direct effect on improving human health and their quality of life. One country still struggling with providing access to safe drinking water to all of its population is Panama. Panama’s largest indigenous group, the Ngöbe people, is disproportionately affected by lack of access to safe drinking water. One way Panama’s Ministry of Health (MINSA) is attempting to increase access to safe drinking water to the Ngöbe people is by disinfecting the water already captured by rural gravity fed water systems constructed within in the Ngöbe-Bugle reservation. This is accomplished using an in-line chlorinator specifically designed to accommodate locally manufactured calcium hypochlorite tablets as a source of chlorine. However, in this study it was hypothesized that the current way MINSA is implementing the in-line chlorinator was ineffective both at educating communities on knowledge of chlorination and in chlorinating water in their water distribution systems.

This study investigated MINSA’s implementation method and then compared it to a new method of implementation that was based on a newly developed disinfection field guide created by the author of this thesis. The motivation of this study was to improve this process of implementation which could lead to more effective chlorination thereby decreasing illness caused by waterborne pathogens. Each implementation method investigated attempted to disseminate knowledge of chlorination to community members through a seminar. The MINSA seminar was presented by a MINSA health practitioner and a newly developed seminar was presented by this thesis’s author. A survey was developed to assess the knowledge of chlorination of community members after they attended a seminar. Results showed that

community members who attended the new seminar on average answered 20 of the 22 questions of the administered survey more correctly than community members attending the MINSA seminar. Additionally, based on the average correct response of community members to survey questions, participants in the new seminar answered more questions correctly compared to participants in the MINSA seminar in all sections of the survey, 32% greater in the “General Knowledge” section; 43% greater in the “MINSA Specific” section; and 36% greater over the total survey. This higher score by new seminar participants suggests that the new seminar is better at educating community members on knowledge of chlorination.

An assessment of each implementation method to effectively chlorinate the studied community’s water distribution systems was also completed. This was done by measuring the free chlorine residual of water leaving the studied community’s storage tank and entering the distribution system over one week. These concentration values were multiplied by a calculated chlorine contact time of the studied system’s distribution system to determine Ct values. Measured Ct values were compared to literature guidelines that provide information on what Ct values will kill commonly found waterborne pathogens in the region. Calculated Ct values above a critical literature value of 40.0 min-mg/L Cl_2 were determined to be effectively chlorinating a system’s water. Results showed that when using the MINSA implementation method the required Ct level of 40.0 min-mg/L Cl_2 was never met at any time during the week. However when using the new implementation method, the required Ct level of 40.0 min-mg/L Cl_2 was met at all points during the week except one when tested on the last day where the Ct value was found to be 35.9 min-mg/L Cl_2. These results suggest the new implementation method is more effective at chlorinating rural gravity fed water systems in the region compared to the previous implementation method.

Chapter 1: Introduction

1.1 The Need for Safe Drinking Water

Access to safe drinking water has a direct effect on improving the health and quality of life of consumers. The World Health Organization has defined safe drinking water as “water with microbial, chemical and physical characteristics that meet WHO guidelines or national standards on drinking water quality” (WHO 2013). The importance of access to safe drinking water can be seen by its inclusion as the target of one of the Millennium Development Goals (MDG). The MDGs are eight international development goals that were developed at the Millennium Summit of the United Nations (UN) in 2000 and were agreed upon by all 189 UN members. The seventh MDG is to ensure environmental sustainability and within this goal Target 7.B is to: “Halve, by 2015, the proportion of people without sustainable access to safe drinking water” relative to the year 1990 (UNICEF, 2012). This target was met in 2010 however 11% of the world’s population or 783 million people still remain without access to an improved source of drinking water (UNICEF, 2012).

One country still struggling with providing access to safe drinking water to all of its residents is Panama. Panama is located in Central America between Colombia and Costa Rica and has a population of approximately 3.6 million with roughly 75% of the population living in an urban setting (WHO and UNICEF, 2013). In 2013 it was estimated that 94% of the total population had access to an improved water source but only 86% of rural population had access to improved water sources (WHO and UNICEF, 2013). Table 1 provides a comparison of what is considered an improved versus an unimproved drinking-water source.

Table 1: Drinking-Water Source Categories: Improved vs. Unimproved

DRINKING-WATER SOURCE CATEGORIES	
Improved Source of Drinking-Water	**Unimproved Source of Drinking-Water**
Piped water into dwelling	Unprotected spring
Piped water to yard/plot	Unprotected dug well
Public tap or standpipe	Cart with small tank/drum
Tubewell or borehole	Tanker-truck
Protected dug well	Surface water
Protected spring	Bottled Water
Rainwater	

(Adapted from WHO and UNICEF, 2013)

Minority groups in Panama are disparately affected by lack of access to improved drinking water. The main minority groups in Panama are the Afro-Panamanians, Ngöbe-Bugle, Kuna, Chocó (Embera-Wounan), Bri-Bri, Naso and Chinese. The indigenous Ngöbe-Bugle people are the largest of these minority groups with an estimated total population of approximately 200,000-250,000 (Minority Rights Group International, 2008).

The Ngöbe-Bugle live in a “Comarca” or reservation that was formed from parts of several provinces (Bocas del Toro, Chiriquí, and Veraguas) in 1997 (Figure 1). 96.3% of the indigenous population lives below the poverty line with 85% in extreme poverty. This is considerably higher than the national average of people living in poverty and extreme poverty at 33% and 14% respectively (World Bank, 2011 and Ailigandi, 2011). The majority of the Ngöbe-

Bugle live off of a combination of subsistence farming and government welfare. The reservation where the Ngöbe-Bugle live is split into 2 distinct geographic regions due to the Cordillera mountain range (Cordillera Central) which bisects the area. There are seven districts within the Comarca, two on the Caribbean side of the mountain range and five on the Pacific side.

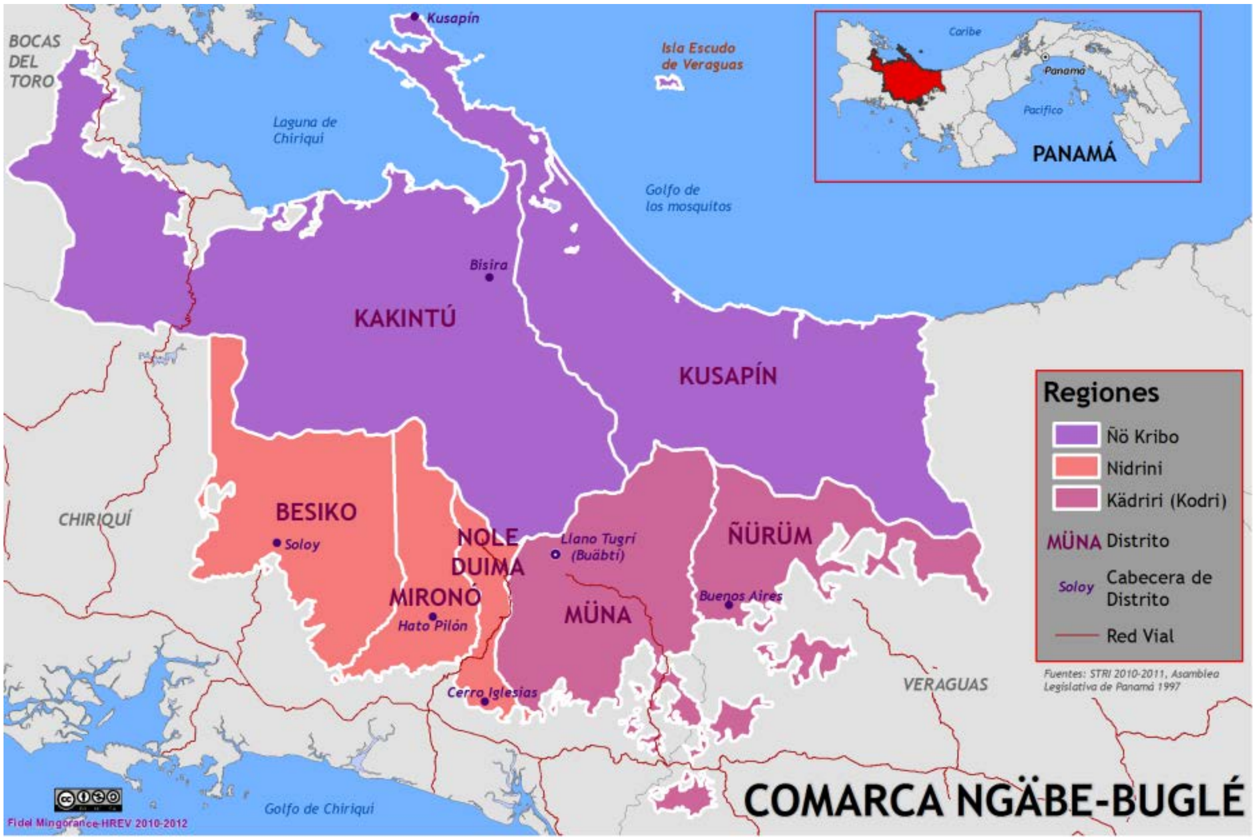

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Figure 1: Map Displaying the Comarca Ngöbe-Bugle's Seven Districts

The Caribbean side of the Comarca Ngöbe-Bugle is referred to as ÑoKribo and consists of 2 districts: Kankintú and Kusapin. The majority of water used in households in ÑoKribo is taken from either streams, unprotected shallow water wells or rainwater. Inland communities closer to the mountain range normally obtain water from streams while it is more common for communities closer to the Caribbean coast to obtain water from shallow water wells or rainwater harvesting. Inland communities at the base of the Cordillera Mountain range that have improved water sources almost universally obtain water through gravity fed water supply systems. Unfortunately due to lack of capital and trained personnel the source water for these systems is normally the closest large stream that is not being used by any inhabitants. These streams often flow down the mountain from springs for several kilometers before being captured. As a result the water quality of these supply systems have a greater potential to be contaminated than water captured directly from a spring source.

Recently the government has sponsored a chlorination program that provides solid chlorine tablets free of charge to communities to use in chlorinating their water. The Ministry of Health (MINSA) sells a self-designed chlorinator to communities for $25 that chlorinates gravity fed water systems with these free tablets. MINSA currently only employs two health practitioners (locally called technicians) to work in ÑoKribo, one in each district, and as a result communities have difficulty implementing their chlorinator as they are only able to receive one to three days of technical assistance from a MINSA employee to install and monitor their chlorinator. More commonly communities are unable to receive any help from a MINSA employee and are left completely responsible for properly chlorinating their own water supply systems without any guidance. Currently no field guide or manual exists to educate communities of the importance of chlorination and instruct communities on how to properly chlorinate using the government subsidized chlorine tablets. Additionally the two health practitioners in the area lack the adequate knowledge to determine if a system is being properly chlorinated.

In a 2007 census only 51.8% of the Ngöbe-Bugle population was found to have access to an improved drinking-water source (MINSA, 2007). A census conducted by a second organization in 2010 put this figure at 61.4% (INEC, 2010). These numbers however do not take into account the quality of drinking water but rather identify the source of the water. For example most of the piped water on the Caribbean side of the Comarca is obtained from streams. This would be considered an improved water source as the water is piped to households (refer to definition of improved supply in Table 1) but not necessarily a *safe* water source as the water may or may not meet WHO guidelines for water quality. During the last few decades there has been a huge investment in obtaining improved water sources in Panama's indigenous Comarcas but until recently there has been little investment in providing *safe* drinking water through some type of water treatment to meet WHO guidelines or national standards. MINSA's chlorination program is investing in providing *safe* drinking water to communities by treating gravity fed water systems with their chlorinator.

However this is not to say that increased access to water alone does nothing to improve health. On the contrary it has been estimated that "increased quantities of water alone reduces the risk of diarrhea by 20-25%" (Fry, 2010). This is because increased access to water allows for more frequent washing which reduces water-washed diseases, literally diseases caused by the inability to wash, and improves overall general hygiene. MINSA's chlorination program is aimed at reducing a different class of water related diseases, water-borne, or those that are cause by consuming water contaminated by pathogenic organisms normally from human or animal waste.

One study has been performed in the Comarca Ngöbe-Bugle by a former Peace Corps Volunteer assessing the effectiveness of MINSA's regional in-line chlorinator as part of the Master's International program at the University of South Florida (Orner, 2011). That study found that the in-line chlorinator could be effective at killing waterborne pathogens (according to measurements that met Ct values for various pathogens) but was unable to identify a chlorination regimen that successfully chlorinated a gravity fed water system for more than one day.

Unfortunately due to ineffective dissemination of information from Orner’s thesis to health practitioners in Panama the knowledge and recommendations developed in his study remain unused by MINSA technicians.

This thesis builds off of the research of Orner (2011); investigating if the current chlorination implementation method is effective and if not, how the knowledge developed in Orner’s thesis and the field studies of that research thesis can be used to help individual communities effectively chlorinate their own systems.

This study has several key differences when compared to Orner’s:

1) This thesis is investigating the implementation of MINSA’s in-line chlorinator where Orner’s thesis investigated the effectiveness of the chlorinator.
2) The Caribbean side of the Comarca (where the field studies in this thesis are conducted) has no distinct dry season and communities tend to live further away from the mountain range while the Pacific side (where Orner’s field studies were conducted) has a distinct dry season where there is little to no rain for several months and communities tend to live very close or on the mountain range. As a result communities on the Caribbean side of the Comarca normally capture water from stream sources that provide a constant large quantity of water with potentially poorer quality whereas the Pacific side of the Comarca normally captures water from spring sources that provide varying quantities of water depending on the season but with potential higher quality water.
3) The design of the chlorinator has been standardized in the past two years by MINSA and is slightly different from the design Orner used during his field studies.
4) The chlorine tablets used in this thesis are different from the ones used in Orner’s. This is due to MINSA purchasing the tablets from a different manufacturer.

1.2 Selection of Study Site

The site studied in this thesis is a community named Kuite. The reason this site was studied was because it is located on the Caribbean side of the Comarca Ngöbe-Bugle, the gravity flow water system in this community captures water from a spring source and the author lived in this community for two years during his Peace Corps service. Having the study site on the Caribbean side of the Comarca Ngöbe-Bugle was an important selection characteristic because no previous studies have been done on this side of the Comarca Ngöbe-Bugle investigating the effectiveness of MINSA’s in-line chlorinator in this region. A gravity flow system that captures water from a stream source and then uses MINSA’s in-line chlorinator to treat the water was an important selection characteristic as this also has not been previously investigated. Finally the author living in the community weighed heavily on the selection of this site for logistical and cultural reasons: the ability to take water samples in a rural location that often has harsh weather every day for three consecutive weeks and the ability to effectively administer oral surveys with community members after two years of building a relationship of trust and confidence with the community. Additionally soliciting for assistance from a regional MINSA health practitioner is a process that often takes up to six months making soliciting for a practitioner to visit multiple sites logistically prohibitive.

1.3 Motivation, Objectives, and Hypotheses

The motivation of this study is to decrease illness caused by waterborne pathogens in the Comarca Ngöbe-Bugle. This will be done by improving the process of implementing MINSA’s in-line chlorinator. The process of improving implementation will be accomplished through performing research and developing a field guide that educates users with no technical background on chlorination and instructs them on the proper installation, use and monitoring of

MINSA’s chlorinator. This improved process of implementation will lead to more effective chlorination thereby decreasing illness caused by waterborne pathogens. The objectives of this study are to:

1) Assess the effectiveness of the current chlorination seminar given by MINSA technicians to educate communities on general knowledge of chlorination and specific knowledge of MINSA’s in-line chlorinator.
2) Assess the current chlorinator implementation method as described in the MINSA chlorination seminar to effectively chlorinate rural gravity fed distribution systems.
3) Develop an appropriate field guide for the regional in-line chlorinator.
4) Assess the effectiveness of the new chlorination seminar which is derived from the newly developed chlorination field guide to educate communities on general knowledge of chlorination and specific knowledge of MINSA’s in-line chlorinator.
5) Assess the chlorinator implementation method developed in the new field guide to effectively chlorinate rural gravity fed distribution systems

This study has the following four hypotheses:

1) The current chlorination seminar given by MINSA technicians is ineffective at educating communities on general knowledge of chlorination and specific knowledge of MINSA’s in-line chlorinator used in Panama.

TASK: Develop a survey to assess the effectiveness of current learning material to be administered after a MINSA technician gives their current chlorination seminar. Ineffective education will be qualified < 2/3’s of respondents answering a given question correctly.

2) The current chlorinator implementation method as detailed in the MINSA chlorination seminar ineffectively chlorinates gravity fed water distribution systems.

TASK: Have a MINSA technician recommend a chlorinator operation regimen for a water distribution system. Assess the effectiveness of the chlorination regimen proposed by taking measurements of free chlorine residual in the field. Then use the Ct method and literature guidelines, guidelines that provide information on what Ct values in field conditions will kill commonly found waterborne pathogens, to determine if the system is being effectively chlorinated.

3) The new chlorination seminar developed in the new field guide effectively educates communities on general knowledge of chlorination and specific knowledge of MINSA's in-line chlorinator.

TASK: Use the same survey developed to assess hypothesis 1 to assess the effectiveness of the developed field guide to educate communities. This survey is to be administered after the author of this thesis presents the newly developed chlorination seminar developed in the field guide. Effective education will be qualified ≥ 2/3's of respondents answering a given question correctly.

4) The chlorinator implementation method developed in the field guide allows communities to effectively chlorinate their gravity fed water distribution system.

TASK: Develop a chlorination regimen with a community using the newly developed field guide. Assess the effectiveness of the chlorination regimen proposed by taking measurements of free chlorine residual in the field. Then use the Ct method and literature guidelines, guidelines that provide information on what Ct values in field conditions will kill commonly found waterborne pathogens, to determine if the system is being effectively chlorinated.

Chapter 2: Literature Review

2.1 Assessing the Efficacy of Chlorination using the Ct Approach

Proper chlorination is important to protect human health. Inadequate chlorination of water can lead to harmful microorganisms remaining in water and causing disease. However, over chlorination can lead to water that contains disinfection by products (DBPs), some of which are known carcinogens (White, 1999). One way to determine the relative effectiveness of a specific disinfectant to eliminate a specific microorganism through disinfection is by using the Ct approach. In this approach the effectiveness of the disinfectant is assessed through knowledge of the chlorine concentration (i.e., C) and the contact time (i.e., t) in water. This approach will be discussed in greater detail later in this chapter. First some background on water disinfection and chlorine chemistry is presented.

2.1.1 Water Treatment – Location and Method of Treatment

Water treatment describes the process of purifying water to a guideline or regulatory standard. Raw water from springs or rivers might be treated to be used for drinking water or wastewater may be treated before being discharged into the environment. Water treatment can be categorized by the location of the treatment. If treatment is performed in a single location for multiple users the treatment is referred to as centralized treatment. When treatment is performed at the household level treatment is referred to as point of use treatment (or household water treatment). Water treatment can also be divided based on the treatment method. The seven types of treatment methods are presented in Table 2 (Crittenden et al, 2005).

Table 2: Description of Different Treatment Methods

Treatment Method	Description
Mechanical Separation	Treatment by gravity, screening or adhesion
Coagulation	Treatment by chemical that aggregates matters to be mechanically separated
Chemical Purification	Treatment by softening, iron removal, neutralization or chlorine addition
Poisoning processes	Poisoning organisms with ozone or other poisonous compounds
Biological Processes	Death of organisms due to unfavorable environmental conditions and antagonistic organisms
Aeration	Evaporation of gasses or carbonic acids. Supply oxygen to aid in purification reactions.
Boiling	Treatment by heating

(Adapted from Crittenden et al, 2005)

Treatment by chemical purification specifically through the use of chlorine as a disinfectant has been established as an effective process to remove pathogens in both the developed and developing world. Table 3 provides a review of the attributes and cost of chlorine in the developing world.

Table 3: Attributes and Costs of Water Purification by Use of the Chemical Disinfectant Chlorine in the Developing World

Technology	**Chemical Disinfection by Chlorine Bleach or Hypochlorite**
Source Water Requirements	Relatively effective with <20 NTU
Pretreatment Requirements	Prefiltration may be needed for turbid water
Life of Technology	20 years (assumption)
Treatment Efficiency	99% bacteria, virus and protozoa removal

Table 3 (Continued)

Operating Power Requirements (during operation life stage)	None to minimal
Operating Labor Requirements	Minimal
Operating Material Requirements	Chlorine, chlorine delivery mechanism
Operating Knowledge Requirements	Skilled and/or trained labor
Capital Cost per 1,000 people ($US)	~15,000
Operation and Maintenance Cost per 1,000 people ($US/year)	~2,400 - 2,500

(Adapted from Hokanson et al, 2007)

This information suggests that chlorination is a viable method for water treatment in certain developing world contexts.

2.1.2 Chemical Disinfection History

Chlorine was discovered in its gaseous form in 1774 and in its liquid form in 1805 (White, 1999). In 1854 it was discovered that a cholera epidemic in Soho, London was caused by contaminated water. This finding spurred the creation of the modern scientific branch of epidemiology and formed the basis for identifying disinfectants to use in treating contaminated water (Markel, 2013). Currently chlorine is used extensively in water treatment in the developed world with an estimated 99% of all municipal water supplies disinfecting water with chlorine (White, 1999). The wide use of chlorine is attributed to the following reasons (White, 1999): potency and range of effectiveness as a germicide; ease of: application, measurement, control; persists well in water supplies; and, comparatively inexpensive.

In the developed world chlorine is almost universally added in the form of a gas for the disinfection of drinking water (Hodges, 1977); however, in the developing world in rural locations use of liquid bleach or hypochlorite salts is more commonly observed. This is because to use chlorine gas requires a larger capital investment, has higher operation and maintenance costs, and requires more technical training than the use of hypochlorite salts (White, 1999). Also storage and transport of chlorine in its gaseous form is difficult and impractical in many rural locations. Hypochlorination refers to chlorinating water with hypochlorite normally added in the form of the salts: sodium hypochlorite (- $NaOCl$) and calcium hypochlorite (- $Ca(OCl)_2$).

2.1.3 Chemistry of Hypochlorination

When sodium or calcium hypochlorite is added to water they disassociate according to Equations 1 and 2, respectively (White, 1999):

$$NaOCl + H_2O \rightarrow HOCl + NaOH$$

Equation 1

$$Ca(OCl)_2 + 2\ H_2O \rightarrow 2\ HOCl + Ca^{2+} + 2\ OH^-$$

Equation 2

The hypochlorous acid (HOCl) that is generated is one of the two disinfecting or germicidal agents for water supplies. Hypochlorous acid is a weak acid (pKa = 7.53) and undergoes partial hydrogen disassociation producing the base hypochlorite ion (OCl^-) as shown in Equation 3 (White, 1999):

$$HOCl \leftrightarrow H^+ + OCl^-$$

Equation 3

The distribution of hypochlorous acid and hypochlorite ion in solution is a function of pH and temperature. Of the two compounds hypochlorous acid is a better germicidal agent (Mihelcic and Zimmerman, 2010).

When chlorine is introduced to water it reacts with other dissolved compounds in the water. The most important is the reaction of chlorine with forms of nitrogen naturally occurring in the environment (White, 1999). Nitrogen can be present in inorganic forms (e.g., ammonia, nitrites, nitrates) and organic forms (e.g., amino acids, proteins). The most important of these is when chlorine interacts with inorganic nitrogen in the form of ammonia (or the positively charged ammonium ion) to form chloramines. The following three equations show the formation of mono-, di-, and tri-chloramines respectively (White, 1999):

$$HOCl + NH_3 \rightarrow NH_2Cl + H_2O$$

Equation 4

$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$

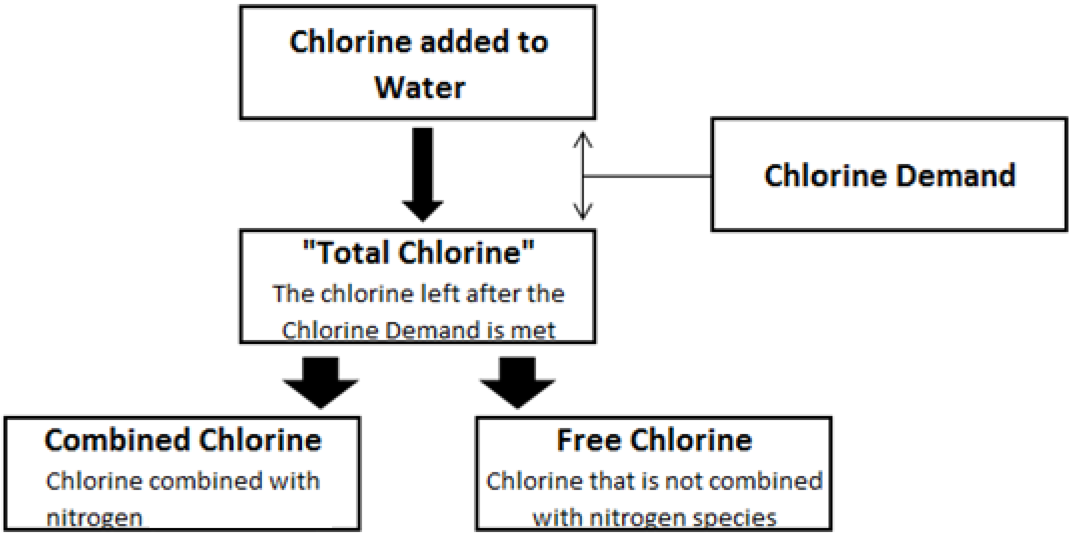
Equation 5

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

Equation 6

The importance of Equations 4 to 6 is because chloramines are not as effective at destroying waterborne contaminants as hypochlorous acid or the hypochlorite ion (White, 1999).

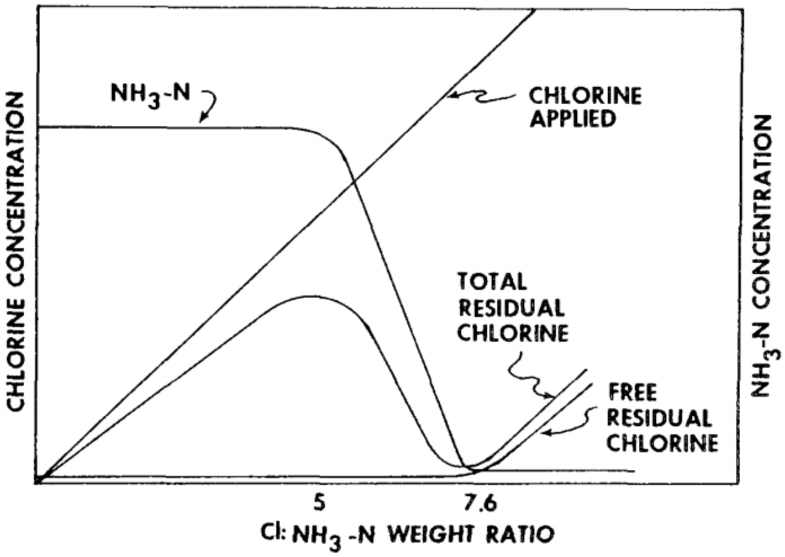
Figure 2 details what happens when chlorine is added to water with associated technical terms. When chlorine is added to water there is a chlorine demand (units of mg/L) that must first be met. This chlorine demand is due to the reaction of chlorine with organic materials and metals (CDC, 2013). The chlorine that is available after this demand is met is called total chlorine (units of mg/L). As shown in Figure 2, total chlorine is the sum of the combined chlorine (chloramines) and free chlorine (hypochlorous acid and hypochlorite ions).



(Adapted from CDC, 2013)

Figure 2: Chlorine Addition to Water

The relation of how much combined chlorine and free chlorine are in a water system is a function of the amount of total chlorine applied to the system and the amount of ammonia found in the system. This relationship is visualized in the breakpoint chlorination curve shown in Figure 3.



(Reproduced from Westrick, 1978; Public Domain, EPA Publication)

Figure 3: Breakpoint Chlorination Curve

The breakpoint chlorination curve shows that initially when chlorine is added or applied (after the chlorine demand is met) all of the available chlorine goes to form monochloramines with the available ammonia in the water. When enough chlorine is added the chloramines reach a maximum concentration (shown in Figure 3 at a Cl:NH_3-N weight ratio of approximately 5). After this, additional chlorine is added so the chloramines that are in the form of monochloramine start to form dichloramines and trichloramines. The curve starts to dip down as the additional added chlorine starts to destroy some of the chloramines in the water. At the "breakpoint" (shown at a Cl:NH_3-N weight ratio of approximately 7.6) the chlorine has completely reacted with the nitrogen compounds in the water and the rest of the chlorine added forms the free chlorine residual. In practice it is desirable to pass the chlorination breakpoint so that there is free chlorine residual in the water, which is a potent germicidal agent, to effectively eliminate waterborne pathogens (White, 1999).

2.1.4 Chlorine Delivery Systems in the Developing World

There are several different chlorine delivery systems that are available in the developing world to chlorinate small water systems. Skinner (2001) details these different types of chlorinators which he divides into three categories: 1) gravity driven, 2) water-powered, and 3) diffusion. This reference further lists six types of gravity driven chlorinators, six water-powered chlorinators, and three diffusion chlorinators as presented in Table 4. The type of chlorinator used by the Panamanian Ministry of Health (MINSA) is a diffusion chlorinator and more specifically a continuous flow diffusion chlorinator. Continuous flow means that water is continuously flowing over the solid or powdered chlorine that is being applied to the system. One problem with the continuous flow chlorinators is when solid tablets are used they often erode irregularly even with steady flow. This can lead to uneven dosing of chlorine (Skinner, 2001). This may not be a problem if a storage tank is sufficiently large to average out the unequal dosing over a period of time (Skinner, 2001).

Table 4: Description of the Types of Chlorinators Used in the Developing World

Type of Chlorinator	Examples	Description
Gravity driven	Mariotte jar, Inverted bottle, Constant-head tank, Inverted bottle + valve, Floating draw-off, Vandos feeder	The chlorine applied flows naturally through the device by gravity
Water-powered chlorinators	Wheel feeder, Float-powered, Hydraulic drive, Venturi systems, Direct suction, Displacement bag	Moving water powers the mechanical chlorinator or creates a pressure differential which is used to apply chlorine to the system
Diffusion	Pot / floating units, Continuous flow, Intermittent flow	Chlorine is applied to the system by water contacting a solid or powdered form of chlorine

2.1.5 Free Chlorine Residual Testing Options in Developing World Situations

The Centers for Disease Control and Prevention (CDC) list three “methods” (also referred to as testing units) to measure free chlorine in the field in developing countries. Table 5 summarizes these “methods” with their associated advantages and disadvantages. The CDC describes scenarios when each testing unit would be appropriate to use. Currently in Panama MINSA uses a color wheel test kit (i.e., test kit product number 1454201) or digital colorimeter (i.e., test kit product number 5870000) to measure chlorine residual in the gravity fed water systems in the indigenous Comarca Ngöbe-Bugle. The color wheel test kit and digital colorimeter in use by MINSA are both manufactured by HACH Company (Loveland, CO). For more information on HACH testing kits consult the HACH “Chlorine Test Kit” webpage (HACH, 2013).

Table 5: Testing Options for Chlorine Residual Field Monitoring

Method / Testing Unit	Description	Advantages	Disadvantages
Pool Test Kits	Uses liquid orthotolidine (OTO) as to test for chlorine by changing the color of the solution. Tests for total chlorine only.	Low cost Very easy to use	OTO solution degrades if not used causing inaccurate readings over time
Color Wheel Test Kits	Uses powder or tablet N,N diethyl-p-phenylene diamine (DPD) as test for chlorine by changing color of solution Test for free chlorine and total chlorine (range 0-3.5 mg/L)	Readings are accurate if properly used Low cost	Possibility for user error (matching color in sample to that on color wheel) Lack of calibration and standardization

Table 5 (Continued)

Digital Colorimeter	Use N,N diethyl-p-phenylene diamine (DPD) tablets or powder as test for chlorine by changing color of solution and then measure color intensity (chlorine intensity) by wavelength absorption Test for free chlorine and total chlorine (range: 0-4 mg/L)	High accuracy of readings Fast determination and display of results	Expensive in comparison to other methods Necessary to calibrate with standards

(Adapted from CDC, 2013)

2.1.6 Chlorine Residual Monitoring in the Field in Developing Countries

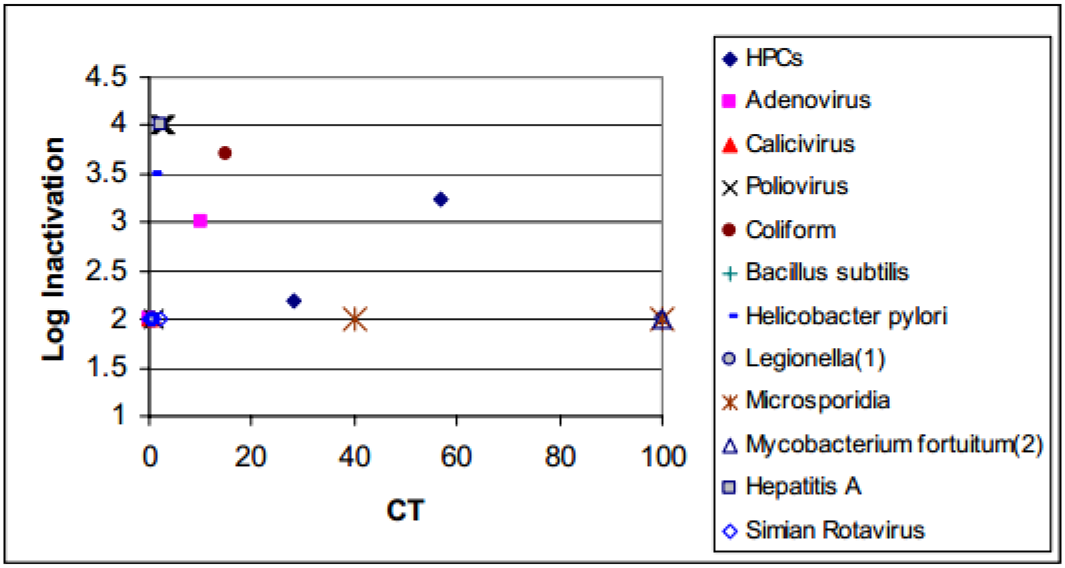
Monitoring of chlorine residual is important to ensure beneficiaries are provided safe drinking water. The U.S. Environmental Protection Agency (EPA) lists a maximum total chlorine residual in water leaving a treatment plant and at representative locations in the distribution system to be no higher than 4.0 mg/L Cl_2 (EPA, 2009). The recommended minimum chlorine concentration levels, leaving the treatment plant and at representative locations in the distribution system, are 0.2 mg/L Cl_2. EPA (2010) states:

> "For [public water systems] that use surface water or ground water under the influence of surface water (Subpart H systems) the residual disinfectant concentration in the water entering the distribution system cannot be less than 0.2 mg/L for more than 4 hours"

The other regulation concerning the amount of chlorine that is necessary in a water supply system dictates the Ct value (i.e., dosage) required in the system for pathogen removal rather than just the concentration of chlorine in the system. This is because the disinfecting efficiency of chlorine is a function of not only the concentration of chlorine in a system but also how long that concentration of chlorine is in contact with a pathogen (i.e., the contact time). The Ct values for pathogen removal are different for each pathogen.

2.2 Relationship of Ct to Specific Pathogens

Pathogens, or disease causing microorganisms, are commonly found in natural waters. The Ct values for removal of some common microorganisms are presented in Figure 4 and Table 6 provides required Ct values provided by the World Health Organization for 2 log (99%) removal of bacteria, viruses, and protozoa.



(Reproduced from EPA, 2013); Public Domain

Figure 4: Free Chlorine CT Requirements for Inactivation of Specific Microbes

Table 6: Required Ct Values to Inactivate Different Types of Microorganisms

Type of Microorganism	Required Ct (min-mg/L Cl_2)	Applicable Temperature Range (°C)	Applicable pH Range
Bacteria	0.04-0.08	0-10	7-9
Viruses	2-30	5	6-7
Protozoa	25-245	0-25	7-8

(Adapted from WHO, 2011)

2.2.1 Pathogens Present in Panamanian Rural Water Supplies

The only known study completed in Panama within the Comarca Ngöbe-Bugle that identified common pathogens in the region was the study entitled: *Parásitos intestinales en niños menores de 12 años en 8 comunidades de la Republica de Panamá* (translated as Intestinal Parasites in Children Under 12 Years in 8 Communities in the Republic of Panama). This study was conducted by the Gorgas Institute of Panama (Gorgas Institute of Panama, 2011). Table 7 presents their findings for waterborne parasites found in children under 12 in the entire country of Panama and for the city of San Felix which is partially located in the indigenous Comarca Ngöbe-Bugle.

Table 7: Number of Waterborne Parasites Found in Children Under 12 Years of Age in Panama and San Felix

Causal Agent	San Felix (n = 397)	Panama (n = 2,026)
Giardia lamblia	35 (9.2%)	314 (15.5%)
E. coli	44 (12%)	129 (6.4%)
Histolytica	14 (3.7%)	82 (4.0%)
I. buschii	29 (7.6%)	63 (3.1%)
C. mesnilii	3 (0.8%)	14 (0.7%)
Crypstoridium spp.	5 (1.3%)	87 (4.3%)
C. cayetanesis	5 (1.3%)	7 (0.3%)
C. belli	0 (0%)	1 (0.05%)
S. stercolaris	1 (0.4%)	13 (0.64%)

(Adapted from Gorgas Institute of Panama, 2011)

The majority of these causal agents were taken into account when investigated by Orner (2011) in his investigation into the efficacy of the MINSA in-line chlorinator. Table 8 provides the Ct requirement for inactivation of pathogens commonly found in Panama.

Table 8: Ct Requirement for Inactivation of Pathogens Commonly Found in Panama

Causal Agent	Ct Requirement (min-mg/L Cl_2)	Temperature (C^o)	pH
Salmonella typhi	1	20-25	7
Hepatitis A	0.41	25	8
Giardia lamblia	15	25	7
E. coli	0.25	23	7
E. Histolytica	20	27-30	7
Vibrio cholerae	0.5	20	7
Rotavirus	0.05	4	7

(Adapted from CDC, 2013)

Not included in Table 8 but identified in the Gorgas Institute of Panama's study (Table 7) and therefore of importance are the required Ct values for the inactivation of *I. buschii*, *C. mesnilii, Cryptosporidium*, *C. cayetanesis*, *C. belli* and *S. stercoralis*. *I. buschii* and *C. mesnilii* are not considered pathogenic and are therefore not included while *C. belli* is not found in the region. *Cryptosporidium* and *C. cayetanesis* are found as oocysts and are not susceptible to chlorine except at extremely high values, values that would be beyond limits safe for drinking water (WHO, 2013). Ct value for inactivation of *S. stercoralis* is reported to be 480 min-mg/L Cl_2 (Saqer, 2006). However, this value is often too high to reach in small scale water systems which do not have infrastructure to provide such a large hydraulic residence time to achieve this Ct value. *Histolytica* is found in Table 8 but a more recent review of literature suggests that *Histolytica* requires a Ct value of 35 min-mg/L Cl_2 for inactivation (WHO, 2013). Orner suggested that rural water system operations in Panama should aim to achieve a Ct value of 20 to inactivate the majority of local pathogens (Orner, 2011). However, a more appropriate Ct value after reviewing the literature presented in this section suggests that a value of at least 40 min-mg/L Cl_2 should be targeted to conservatively eliminate *Histolytica* (Ct value of 35 min-mg/L Cl_2) and all less resistant aforementioned pathogens.

2.2.2 Pathogen Inactivation

The simplest and most commonly used disinfection model is the Chick-Watson Model (Mihelcic and Zimmerman, 2010) where the "rate of inactivation of a microorganism is dependent upon the concentration of the disinfectant and contact time" (WHO, 2013). Equation 7 presents this model in its unintegrated form and Equation 8 in its integrated form:

$$r = -kC^nN$$

Equation 7

$$\ln\left(\frac{N}{N_o}\right) = -kC^nt$$

Equation 8

In Equation 7 and 8, r is the rate of microorganism inactivation (CFU/L-min), k is the Chick-Watson rate law constant (min^{-1}), n is the dilution factor (unit less), C is the concentration of the disinfectant (mg/L), N is the microorganism concentration at a future time and N_o is the starting microorganism concentration (CFU/L). When the dilution factor is equal to one Equation 8 simplifies to Ct (the product of the disinfection concentration and the contact time).

2.3 Previous Studies Investigating Chlorination of Gravity Fed Water Supply Systems in the Developing World

Three studies have investigated chlorination of gravity fed water supply systems in the developing world. The investigation that is most closely related to this thesis is by Orner (2011). Orner's thesis investigated four unique topics related to the Panama's Ministry of Health's (MINSA) in-line chlorinator. Of relevance to this thesis is his investigation of the efficacy of MINSA's in-line chlorinator in two communities in the Comarca Ngöbe-Bugle. Orner (2011) hypothesized that "the application of a chlorine tablet in the in-line chlorinator will result in free chlorine concentration necessary to achieve the Ct values required to disinfect specific pathogens that may be present in Panamanian gravity flow water supply distribution systems”. He investigated this claim by adding up to three chlorine tablets into MINSA’s in-line chlorinator at one time to try and achieve a free chlorine residual that would disinfect the pathogens he identified as present in Panamanian water supply systems. With three tablets the system reached an effective chlorine concentration level for only one day and then the concentration level dipped below the acceptable level necessary for pathogen inactivation. This showed the in-line chlorinator could reach effective levels of chlorination if properly configured and monitored.

Fitzpatrick (2008) investigated the efficacy of the Pulsar 1 unit in Ghana at chlorinating a gravity fed water system in Ghana. He found that the Pulsar 1 unit, a water powered chlorination unit, could reliably chlorinate a water system and provide an effective free chlorine concentration suitable for disinfection. The author also noted that the disinfection costs along with operation and maintenance costs were significantly lower than that of other technologies in the region. However Fitzpatrick noted that the drawbacks of the Pulsar 1 unit included increased system complexity and higher capital costs compared to other technologies.

Finally a study by Yamana and Nepf (2003) investigated the CTI-8 Chlorinator, a diffusion chlorinator used in over 30 communities in Nicaragua. Their study showed that the dissolution of tablets did not increase with increasing influent flowrate to the chlorinator. The authors mentioned that this may be a problem because when a large storm event occurs and flowrate increases by a significant degree the chlorinator may under-dose the systems water – as the same amount of chlorine would be used to chlorinate a much larger volume of water. However the authors did find the chlorinator effective at chlorinating water supply systems.

2.4 Interviewing to Assess Knowledge of Chlorination

Interviews allow researchers to obtain information from human subjects. The information sought by researchers dictate the medium of communication (face to face, over the phone, online, through mailings), the structure of the interview (informal, unstructured, semistructured or structured) and the type of questions asked during the interview. Considerations regarding respondents' background (language, literacy and culture) need to also be considered both before selection of an interview format and after an interview is concluded when assessment of the results are being interpreted. Important to this research, no formal studies were identified that assessed the knowledge of chlorination among peoples in the developing world. However, Section 2.4.4 describes several peripheral studies relating to chlorination preferences and social, cultural and behavioral factors that correlate to water treatment in the developing world.

2.4.1 Interview Structure

The structure of an interview forms a continuum defined by the amount of control the interviewer has over the interview. This continuum can be divided into four sections based on the amount of control the interviewer possesses. The four types of interview based on this structure are listed below in Table 9. Each interview structure has value and limitations. Structured interviews aim to "control the input that triggers people's responses so that their output can be reliably compared" (Bernard, 2006). However by doing this the interviewer limits the responses that an interviewee might be able to provide and therefore potentially loses important information that might be garnered from a less structured type of interview.

Table 9: The Four Types of Interviews Based on Structure

Interview Structure	Description
Informal	No structure or control, not scheduled, no information physically recorded during the interview
Unstructured	Some structure and control, can be scheduled or unscheduled, interviewee knows that they are being interviewed, information recorded while interview is occurring, interviewer has a predetermined direction of where they want the interview to lead but little to no control of how respondents will answer questions
Semistructured	The same as an unstructured interview but with the addition of the interviewer having an interview guide, which is “a written list of questions and topics that need to be covered in a particular order” (Bernard, 2006)
Structured	Total or near total control of interview, explicit instructions are given to interviewers on how to conduct interviews in a methodical, precise way, to create near identical interviews for multiple interviewees

(Adapted from Bernard, 2006)

2.4.2 Questionnaires

A questionnaire is a type of structured interview where a set of questions are presented to an interviewee (respondent) in a defined order and manner so the respondent will be willing and able to answer the questions. The interviewer will then be able to use the responses to evaluate a hypothesis. Questionnaires can be administered in a variety of ways; one of these ways is a face-to-face interview between the interviewer and the respondent. Table 10 reviews some advantages and disadvantages of face-to-face interviews that are applicable to the study in this thesis.

Table 10: Advantages and Disadvantages of Face-to-Face Interviews

Advantages	Disadvantages
Verbally conveyed questions do not require respondents to be literate	Interviewees' might want to give the interviewer the answer they believe the interview wants to personally hear
If a respondent does not understand a question the question can be rephrase by the interviewer	It is possible for the interviewer to unintentionally give away the correct response to a question based on tone of voice, meter of questioning or other non-verbal cues
There is control of the sequence the questions are asked in allowing assessment of one question first before the answer is potentially revealed in a later question	

(Adapted from Bernard, 2006)

Questionnaires can also be characterized by the type of questions that are asked within the questionnaire. Questionnaires have two categories of question types as described in Table 11.

Table 11: Type of Question in Questionnaire

Question Type	Description
Open-ended	Questions that allow the responder to formulate their own answer
Close-ended	Questions that ask the responder to choose an answer from a list of answers

(Adapted from Bernard, 2006)

2.4.3 Considerations when Executing a Questionnaire

Three specific considerations need to be thought-out before a questionnaire is executed, during execution and afterwards when assessing questionnaire data. These considerations are language type, literacy/educational level and the different culture of the respondents.

Presser (2004) summarizes why it is important to consider the difference in native language or even dialect of the surveyor and the respondent:

> "In the monocultural context, small changes in formulation of suboptimal design have been shown to affect respondents' understanding of the question asked or the accuracy of the measurement or count. Questionnaire designers go to considerable effort to try to ensure that the intended meaning of the question is also what respondents understand. In cross-cultural research, too, we can expect that small differences in formulation across languages can affect understanding and that inappropriate design or inappropriate translation can result in respondents not being asked what the researchers intended to ask."

In this quote, Presser (2004) states that it is imperative to have an appropriate design and translation of a given questionnaire to minimize the chance that respondents misunderstand the questions being asked of them. He references several studies that show how inaccuracies in translation lead to misunderstanding of questions. These misunderstandings can lead to recording of data that is not representative of the actual knowledge of respondents.

Consideration also needs to be taken when the pool of respondents has different levels of literacy and education. Surveyors need to adjust questionnaire design so that responders with different levels of literacy and education have an equal understanding of the questions so that hypotheses can be accurately assessed. Without adjusting for this consideration resultant data may be skewed toward literate and educated respondents even though the knowledge that the questions are attempting to assess may be the same across knowledge and education levels. Questions can be read to all respondents verbally to eliminate this potential problem

Finally cultural considerations need to be recognized. This is done by framing questions in a cultural context that is appropriate.

Bernard (2006) mentions that one way to modify a questionnaire to account for the three aforementioned considerations is to pre-screen a questionnaire. Pre-screening is the process of presenting a survey to a small group of individuals that are representative of the future respondent pool before the survey is formally executed. In this presentation to the small group the author vets each question with the group to ensure questions translate appropriately with respect to local language, wording, educational level and culture. Modifications of the questionnaire are then completed prior to interviewing other participants in the formal investigation.

2.4.4 Chlorination Preferences and Social, Cultural and Behavioral Factors that Correlate to Water Treatment in the Developing World

Nagata et al. (2011) investigated social determinants of drinking water beliefs and practices among the Tz'utujil Maya in Guatemala and found that education was significant in determining water practices of various groups. Nagata and colleagues (2011) state: "both those who had more years of schooling and those who were literate were more likely to self-treat their drinking water than those without those characteristics." This study also cited how beliefs that were influenced by political, historical and cultural factors were significant social determinants of healthy drinking water practices. This study also described results of a survey of 195 indigenous Tz'utujil Maya and 6 Ladino people. The survey found that 51.7% of respondents preferred tap water with chlorine. The most common reason given by respondents for preferring tap water with chlorine was its ability to kill bacteria. Of the 48.3% that preferred tap water without chlorine 48.5% disliked chlorinated tap water due to bad taste or smell. Another study investigated user preference to use chlorine as a point of use treatment over a type of filter treatment and a flocculent disinfectant treatment in rural Kenya (Albert et al, 2010). This study mentioned taste and smells as being deterrents of use along with difficulty of use and failure to remove turbidity from water as shortcomings of chlorinating water.

Figueroa et al. (2010) provide a detailed literature review of how social, cultural and behavioral traits correlate with household water treatment and storage. They review 27 studies from 1985 to 2005 “that had any aspect of behavior as part of the intervention or as part of the conclusions of the study.” The social, cultural and behavioral factors that impact household water treatment and storage were divided into individual-level factors, household factors, community factors, environmental and contextual factors and socio-demographic characteristics. A review of this scope is beyond the scope of this paper and readers interested in this topic should refer to this reference.

Chapter 3: Materials and Methods

3.1 Background Information

3.1.1 Location and Characteristics of Studied Community

The community studied in this thesis was Kuite, a small, indigenous community located within the Comarca Ngöbe-Bugle on the Caribbean side of the Cordillera mountain range in the ÑoKribo region. Figure 5 identifies the location of the field study and Table 12 provides characteristics of the gravity flow water system (referred to as an *aqueduct* in Panama).

(Reproduced from the CIA World Factbook, 2013); Public Domain, CIA Publication

Figure 5: Location of Field Study Site - Kuite

Table 12: Characteristics of Water Supply System Investigated in this Study

Community Name	**Kuite**
Houses in Community	28
Houses which the Aqueduct Serves	25
Population Benefiting from Aqueduct	183
Aqueduct Constructed by	Peace Corps
Aqueduct Constructed (Year)	2010

Kuite is comprised entirely of the indigenous Ngöbe tribe. Members of the community speak both the indigenous Ngöbe language Ngöbere and the national language Spanish. The adult population is largely illiterate with only four adults able to read and write.

3.1.2 Aqueduct Characteristics of Studied Community

Kuite's aqueduct was constructed over a period of 3 years from 2007-2010 and became usable in the year 2011 after some modifications were made to the system. The source is over 3 kilometers away from the storage tank. The storage tank rests on top of a small hill right outside the main community. Figure 6 shows a schematic of the aqueduct's distribution system in Kuite with connected houses labeled based on the head of each household. The "Key" included in the figure is the map key which allows readers to identify the names of each household connected to the aqueduct (labeled with uppercased letters) as well as identifies the free chlorine sampling locations and a distance scale for the distribution system. Table 13 then details the characteristics of the aqueduct in Kuite.

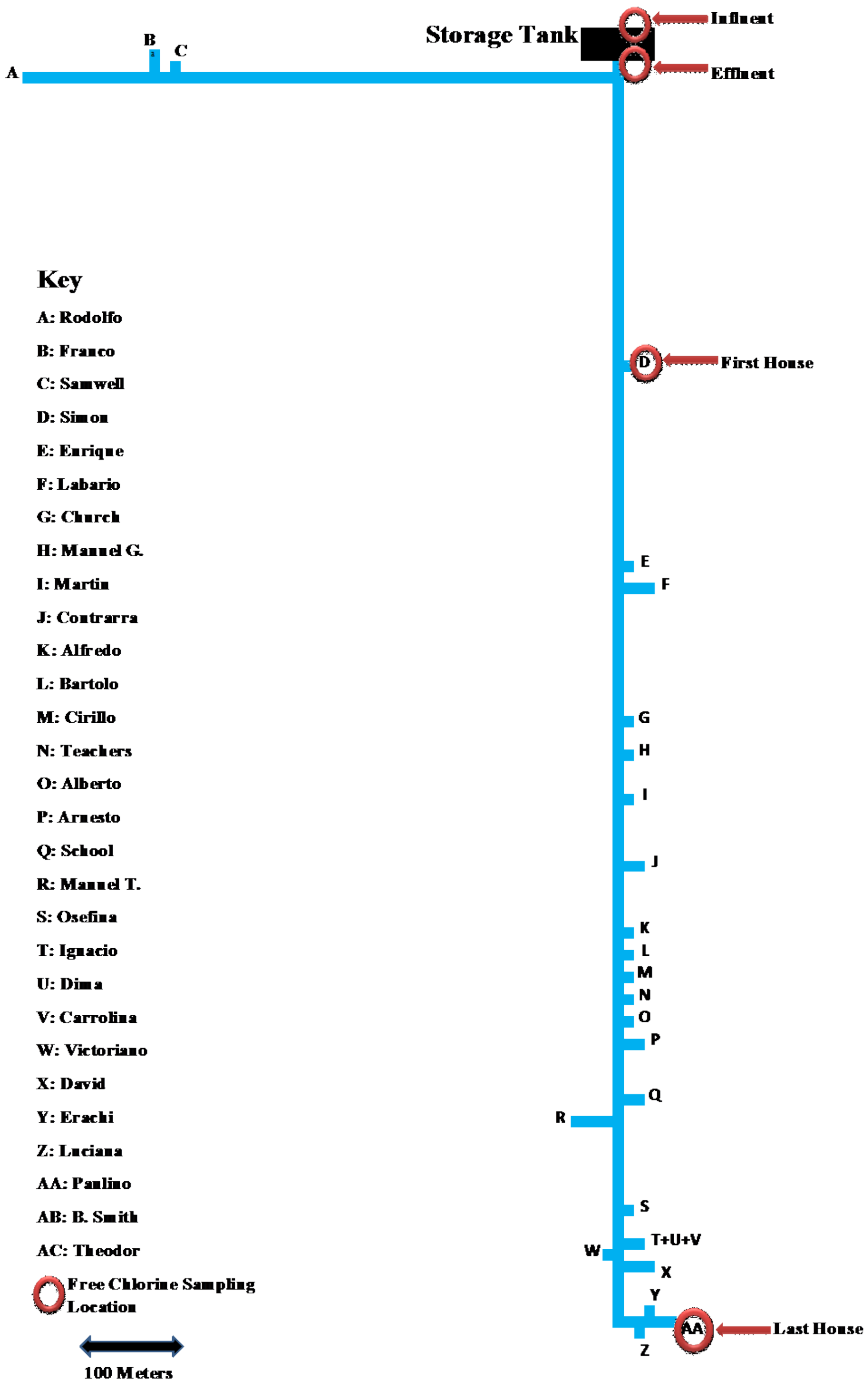


Figure 6: Schematic of Kuite Aqueduct Distribution System

Table 13: Characteristics of Kuite's Aqueduct

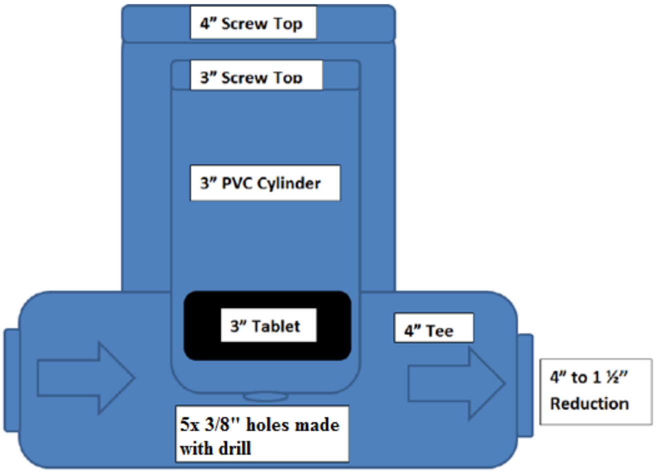
Type of Water Source	**Stream Catchment**
Size of Storage Tank (gallons) (264 gallons = 1 meter^3)	5,000
Location of Chlorinator	Before Tank
Distance from Catchment to Storage Tank (meters)	~3,000
Distance from Storage Tank to First House (meters)	281
Distance from Storage Tank to Last House (meters)	1,415

In addition, the flow into the storage tank in Kuite has always exceeded the demand of the users for the past two years. This results in the tank always being full and water overflowing from the storage tank at all times. This is because the storage tank was designed to be used for a community expected to double in size over the next 15-20 years.

3.1.3 MINSA's In-Line PVC Chlorinator

A Ministry of Health (MINSA) technician told the author that for about the last 5 years the Ministry of Health has been using their self-designed in-line chlorinators to chlorinate water systems in the Comarca Ngöbe-Bugle. Before this time the Ministry of Health had a number of large communities using drip chlorinators but due to lack of personnel to maintain these drip chlorinators nearly all were being incorrectly used or were not functional. The in-line chlorinator design was developed as a less expensive, durable, low maintenance way to chlorinate systems in the Comarca Ngöbe-Bugle. Currently the technician estimates that the Pacific side of the Comarca has over 100 aqueducts using this technology but only 9 aqueducts using this technology in the ÑoKribo region. This discrepancy in technology use may be due to the MINSA office being located on the Pacific side of the Comarca and therefore communities there receiving more support from the agency. Additionally the technician sited transportation of the chlorine tablets used in the in-line chlorinators as a barrier preventing wide use of the chlorinator in ÑoKribo. Several communities outside the Comarca Ngöbe-Bugle but in Panama are also using the chlorinator. The government however does not subsidize the price of the chlorine tablets in these communities outside of the Comarca Ngöbe-Bugle.

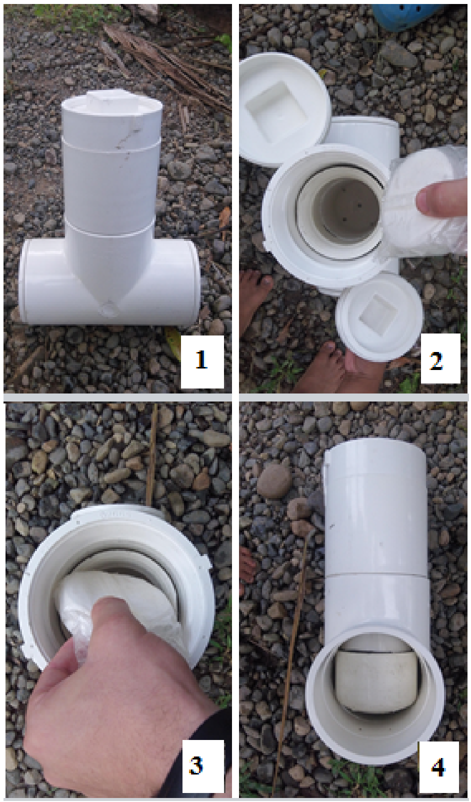
The in-line chlorinator, shown in Figure 7, is made entirely of polyvinyl chloride (PVC). The term "in-line" designates that the chlorinator is connected directly to the PVC pipe that is transporting water from the catchment source to the distribution tank. The chlorinator is attached 2-5 meters before the storage tank to the influent PVC pipe.



(Reproduced with permission from Orner, 2011; Authorization: Appendix E)

Figure 7: Diagram of the Ministry of Health's In-Line PVC Chlorinator

The chlorinator is made of a 4-inch Tee that has a small segment of 4-inch PVC on the upper Tee which is then closed off by a 4-inch screw top. A 3-inch cylinder (made from 3-inch PVC pipe) is inserted into the 4-inch Tee being accessed by the screw top. This cylinder consists of a 3-inch rounded top that faces down and a 3-inch screw top that faces up toward the 4-inch screw top. Five holes that are approximately 3/8 inch in diameter are drilled into the bottom 3-inch rounded top. This entire 3-inch cylinder is glued into place inside the 4-inch Tee. A chlorine tablet(s) is added by removing both screw tops and placing the chlorine tablet(s) into the 3-inch cylinder and then closing the screw tops. This chlorinator can be attached to different size pipes by reducing the two ends of the 4-inch Tee to the size of the influent pipe. For example in Figure 7 the influent and effluent PVC pipes are stated to be 1.5 inches. Figure 8 shows an unconnected in-line chlorinator and Table 14 provides details of the chlorine tablets used in MINSA's in-line chlorinator. For a more detailed list of chlorine tablet specifications see *Productos Quimicos IBIS Data Sheet* in Appendix A.



1) Front view
2) Top view showing where the chlorine tablets would be inserted (Note: holes in bottom)
3) Top view showing chlorine tablet being inserted into chlorinator
4) Side view showing the 3 inch cylinder sitting all the way down in the 4 inch Tee

Figure 8: Photo Description of MINSA's In-Line Chlorinator

MINSA is now selling the chlorinators pre-made with the aforementioned design to communities in the region for $25 (Panama uses U.S. dollars). The tablets are provided at no expense at each of MINSA's regional posts. Communities are permitted to collect 15 tablets during a single visit.

Table 14: Chlorine Tablet Product Specifications

Manufacturer	Productos Quimicos IBIS
Chemical Name	Calcium Hypochlorite
Weight of Tablet	200 grams
Shape of Tablet	Cylindrical "puck"
Diameter of Tablet	3 inches
Color of Tablet	white grayish
Chemical Formula	$Ca(OCl)_2$
Effective Chlorine	70% minimum

3.1.4 MINSA’s Current Implementation Method

MINSA technicians currently implement the chlorinators into systems by arriving at a community, giving a seminar on how to construct and use the chlorinator (approximately 30 minutes in duration), and then recommending a chlorination regimen for the community. The chlorination regimen is the recommendation by the technician of how many chlorine tablets the community should put in the chlorinator at a single time, for a stated duration (normally 1-2 weeks), to properly chlorinate. When asked about how a technician develops a chlorination regimen the author was told that the number of chlorine tablets used per 1-2 week cycle is determined solely on the influent flow into the storage tank. Also, when asked how long the chlorine tablets would last, three different technicians gave three different responses saying the chlorine tablets would last from 7-14 days. When a technician was asked by the author of this thesis if he thought this method of implementation was effective he said “Yo no se,” *I do not know*.

3.2 Method of Evaluation Summary

As mentioned in Chapter 1 the implementation of MINSA's regional in-line chlorinator was evaluated in this thesis. This consisted of evaluating four connected but unique investigations each having one associated hypothesis. Two investigations occurred after the MINSA seminar and two after the new seminar. Two of these investigations assessed the knowledge of chlorination and two assessed the effectiveness of chlorination. Table 15 summarizes these four investigations and their associated hypotheses.

Table 15: Summary of Investigations and Associated Hypotheses

	After MINSA Seminar	**After New Seminar**
Assessment of Knowledge of Chlorination	Hypothesis 1: Ineffective at Educating Community	Hypothesis 3: Effective at Educating Community.
Assessment of Effectiveness of Chlorination Regimen	Hypothesis 2: Ineffective Chlorination of Distribution System	Hypothesis 4: Effective Chlorination of Distribution System

Section 3.3 details the methods used to assess the knowledge of chlorination after each of the seminars as well as how the scored knowledge levels found were compared. Section 3.4 details the methods used to assess the effectiveness of a chlorination regimen after each seminar.

3.3 Methods Used to Assess Knowledge of Chlorination

The Institutional Review Board (IRB) at the University of South Florida was contacted prior to executing the surveys described in this section to determine if authorization by the review board was necessary. The IRB determined that this study was not collecting information about individuals; therefore, it did not meet the definition of human subjects research and would not require IRB approval (for documentation see Appendix B).

3.3.1 Testing Procedure – Execution of *User Knowledge of Chlorination Survey*

An assessment of the knowledge of chlorination was completed twice by the author in this investigation. First after a MINSA technician presented a chlorination seminar in Ngöbere, the Ngöbe's indigenous language, and second after the author of this thesis presented the newly developed seminar in Spanish. Both assessments, completed after each seminar, were done by administering the *User Knowledge of Chlorination Survey* (Appendix C).

The *User Knowledge of Chlorination Survey* is divided into two sections: general knowledge of chlorination and knowledge specifically about MINSA's in-line chlorinator. The general knowledge questions attempt to assess a participant's knowledge of chlorination that is independent of location or method of chlorination. The knowledge of MINSA's in-line chlorinator questions attempt to assess a participant's knowledge of the unique chlorinator used by MINSA with respect to operation and logistical considerations. The questions in the *User Knowledge of Chlorination Survey* were developed by the author of this thesis after reviewing literature and also using his past experiences of installing the in-line chlorinator in other communities to select questions that would assess respondent's knowledge of topics related to chlorination that were deemed important to sustainably maintaining the chlorinator's functionality and continual use. To verify appropriateness of the questions the author presented the survey to two MINSA technicians and asked them to review the questions. Both technicians thought the questions were appropriate.

The survey was given orally to community members in Spanish. The survey was administered immediately following each seminar. When executing the survey the participant and the author were separated from the rest of the community members in attendance for a one-on-one face-to-face interview. A structured face-to-face interview type was selected as it was thought to be most appropriate due to community members being accustomed to this as health practitioners in the region used this same type of interview. Also a structured interview type was chosen as survey questions had to be presented in a specific order as some questions found later in the survey might reveal answers to questions posed earlier in the survey. When the surveyor and a participant were separated from the rest of the seminar group the surveyor would read each question aloud for the participant and if asked could repeat the question as many times as the participant wanted. Questions were pre-screened by three community members before the seminars to ensure the questions were culturally appropriate and that the questions were worded in a clear manner. The three community members selected to pre-screen the survey were identified by the author of this thesis as community leaders and were thought to have had an average education and knowledge level when compared to the whole community. The MINSA seminar and new seminar were presented within two weeks of each other.

For the first seminar, which was presented by a MINSA technician, 12 participants were selected to participate in responding to the *User Knowledge of Chlorination Survey*. These participants were selected by asking community members in attendance (18 adults) for volunteers to complete the survey and selecting the first 12 volunteers. These 12 participants were told not to mention the questions of the survey to other community members.

For the second seminar, which was presented by the author of this thesis, 12 participants were again selected to participate in responding to the *User Knowledge of Chlorination Survey*. However this time the selection process was changed slightly as again community members were asked who would be willing to participate in the survey (35 adults were present at this seminar) and the first 12 volunteers were selected but with an added condition that the participant must have been absent from the first seminar.

Scoring of the survey was done while the survey was being executed by the surveyor (the author of this thesis). A binary scoring system was used scoring individual question responses as 1 or 0 indicating a correct or incorrect response (1 = correct, 0 = incorrect). Correct responses were determined by consulting an answer key that was created before surveying began.

3.3.2 Calculation – Statistical Analysis of Survey Data

Average question scores and average participant scores were determined for both surveyed groups independently. Equation 9 shows how an average question response score was calculated and Equation 10 shows how an average participant response score was calculated. Average survey scores were calculated for the entire *User Knowledge of Chlorination Survey* for each surveyed group using Equation 11.

$$\text{Question}_{\text{X-avg.}} = \frac{\text{Question}_{\text{X-Participant 1}} + \text{Question}_{\text{X-Participant 2}} + \dots}{\text{Number of Participants}} \times 100\%$$

Equation 9

$$\text{Participant Score}_{\text{avg.}} = \frac{\text{Score Question}_1 + \text{Score Question}_2 + \dots}{\text{Number of Questions}} \times 100\%$$

Equation 10

$$\text{Total Survey Score}_{\text{Average}} = \frac{\text{Participant}_{\text{1-Average Score}} + \text{Participant}_{\text{2-Average Score}} \cdots}{\text{Number of Participants}}$$

Equation 11

Additionally the method of calculation of average survey score in Equation 11 was used to calculate the average scores for the survey subsections for each surveyed group - general knowledge of chlorination and MINSA specific knowledge.

For clarity the seminar given by the MINSA technician will be referred to as the *MINSA Seminar* and the *User Knowledge of Chlorination Survey* completed after this seminar will be referred to as the *MINSA Survey*. Likewise the seminar given by the author based on the newly developed chlorination field guide (Appendix F) will be referred to as the *New Seminar* and the *User Knowledge of Chlorination Survey* completed after this seminar will be referred to as the *New Survey*. An investigation was performed comparing the knowledge level of participants attending the *MINSA Seminar* to that of participants attending the *New Seminar*. This was assessed by comparing percent of questions answered correctly by respondents to the *MINSA Survey* to percent of questions answered correctly by respondents to the *New Survey*. This comparison was performed for both individual questions, subsections (general knowledge of chlorination and MINSA specific knowledge), and for the complete survey. Equation 12 shows this calculation done for an individual question; the same method of calculation was performed for subsections and the total survey score.

$$\Delta\% \text{ Correct Response}_{\text{Question-X}} = \text{Question}_{\text{x-Average-New Survey}} - \text{Question}_{\text{x-Average-MINSA Survey}}$$

Equation 12

Evaluation of the significance of these percent changes were done by using an unpaired two tailed t-test. The samples were unpaired because the average value assigned to correct responses in Group A (*MINSA survey*) are independent of responses in Group B (*New Survey*). A t-test is appropriated because the data obtained is discrete, binary and ratio data. A two tailed test is used as the *New Seminar* may or may not increase the knowledge level of participants compared to the *MINSA Seminar*. The data is assumed to be normally distributed (Gaussian) allowing for a more statistically robust evaluation but an F-test will be performed before the data is analyzed to show equal variance in the two data sets. If the variances of the two data sets are found to be equal the t-statistic is calculated as described in Equation 13. However, if the variances are found to be unequal or if a comparison of the variances cannot be made (variances are assumed unequal) the t-statistic will be calculated using Equation 14.

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{1}{2}\left(s_1^2 + s_2^2\right)} \times \sqrt{\frac{2}{n}}}$$

Equation 13

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2 + s_2^2}{n}}}$$

Equation 14

Here $\overline{X}$ is the mean of one set of data, s^2 the standard deviation of one set of data and n the number of data points in the data set. A critical one tailed t-statistic value was obtained by using a t-distribution table and using $\alpha = 0.05$. This critical value was compared to the calculated t-statistic to determine significance. A significant value would indicate that the two sample means were unequal and that one sampled group answered a question, section or the whole survey better than then other.

3.4 Assessment of Effectiveness of Chlorination Regimen

Two separate chlorination regimens were evaluated. The first regimen was recommended by a MINSA technician to the studied community's water committee after he presented the MINSA seminar. The second regimen was developed for this thesis with the studied community's water committee and the regimen was derived from the newly developed field guide. A chlorine regimen provides two recommendations:

1) The number of chlorine tablet(s) to use
2) The time period over which these tablet(s) should be used before new tablet(s) are added

During both chlorination periods the following parameters were monitored:

1) Water flowrate
2) Free chlorine concentration
3) Chlorine tablet weight (wet or dry when applicable)

These parameters were monitored at the following times after new chlorine tablet(s) were inserted:

Table 16: Schedule of Monitoring Parameters During Field Tests

Time after Tablet(s) Insertion	Parameters Measured
0 hour (start)	Tablet Dry Weight and Tablet Wet Weight
2 hours	Flowrate, Free Chlorine and Tablet Wet Weight
24 hours (1 day)	Flowrate, Free Chlorine and Tablet Wet Weight
48 hours (2 days)	Flowrate, Free Chlorine and Tablet Wet Weight
72 hours (3 days)	Flowrate, Free Chlorine and Tablet Wet Weight
96 hours (4 days)	Flowrate, Free Chlorine and Tablet Wet Weight
120 hours (5 days)	Flowrate, Free Chlorine and Tablet Wet Weight
144 hours (6 days)	Flowrate, Free Chlorine and Tablet Wet Weight
168 hours (7 days)	Flowrate, Free Chlorine and Tablet Wet Weight

Prior to both regimens being tested the distribution system was “primed” by chlorinating the system for four weeks to ensure microbial buildup in the distribution system was removed. Directly before each regimen was executed chlorine was not used in the distribution system for three days. The two regimens where examined within two weeks of one another.

3.4.1 Testing Procedure and Calculation – Water Flowrate

Only the influent flowrate into the storage tank was measured. Influent flowrate was measured by placing a 5-gallon bucket under the PVC pipe that was carrying water from the source and entering the storage tank. The time required to fill the 5-gallon bucket was measured with a stopwatch. The influent flowrate was calculated as follows:

$$\text{Flowrate}_{\text{influent}} = \left(\frac{5\text{ gallons}}{\text{time elapsed (sec)}}\right) \times 60\left(\frac{\text{sec}}{\text{min}}\right)$$

Equation 15

This process was repeated once, the two calculated values were averaged, and this value was recorded.

3.4.2 Testing Procedure - Free Chlorine Concentration

Water samples to test for free chlorine were collected from:

1) The influent entering the storage tank
2) The effluent from the storage tank
3) The first house in the distribution system (water faucet closest to the tank)
4) The last house in the distribution system (water faucet farthest from the tank)

Effluent samples from the storage tank were taken from the cleanout valve connected to the tank after the valve was left open for five minutes. Waiting five minutes reduced the chance of debris contaminating the sample.

Free chlorine was measured using HACH Company’s (Loveland, Colorado) Pocket Colorimeter II (Product #5870000). This was done in accordance with HACH Method 8021 for low range free chlorine measurements (0.02-2.00 mg/L Cl_2). Additional details on this method can be obtained from the HACH Pocket Colorimeter II Instruction Manual (HACH, 2013).

In this method a 100-mL sample was taken from a given sampling location using a clean glass jar. Then immediately from this 100-mL sample two 10-mL HACH cells were filled. The colorimeter was then powered on and the place holder cap was removed. The first sample cell (the blank) was dried with a Kimwipe and then placed into the colorimeter. A HACH meter cap was then placed on top of the cell to cover the cell from light. The meter was then zeroed with this blank cell by pressing the blue "zero" key. A DPD Free Chlorine Pillow Packet for low range free chlorine testing manufactured by HACH (Cat. 21055-69) was then added to the second cell. This cell was then shaken for 20 seconds, dried with a Kimwipe and then placed in the colorimeter's holder. A HACH meter cap was then placed on top of the cell and within one minute the green "read/enter" key was pressed to read the free chlorine concentration. This process was repeated one more time with the same 100-mL sample. After each reading the sample cell was flushed with water three times. The two free chlorine concentration readings (mg/L Cl_2) were recorded and later averaged.

3.4.3 Testing Procedure – Chlorine Tablet Weight

Chlorine tablet(s) weight was determined using a small electronic scale normally used locally to measure the weight of small food items. The scale was able to determine the weight of an object down to one gram. The scale was first turned on and zeroed by pressing the "zero" key. If the tablet(s) was wet the tablet(s) was first shaken gently for 10 seconds to remove excess water. If multiple tablets were used all the tablets were shaken individually to remove excess water but weighed together. The tablet(s) was then placed on the scale and the measurement was recorded.

Due to a design flaw of the in-line chlorinator constructed by MINSA technicians an incorrect reduction from the 3" screw top to the 3" pipe that holds the tablets was used. This reduction was too narrow and therefore tablets need to be cut in half so that they would be able to fit into the chlorinator. Tablets were cut in half with a hacksaw and a small amount of chlorine was lost in the process. In this thesis one tablet will represent two halves of the same tablet which are inserted into the chlorinator. This flaw was presented to the MINSA technicians and a new thinner reduction within the chlorinator is now being used allowing chlorine tablets no longer needing to be cut in half.

3.4.4 Calculation - Chlorine Contact Time

Chlorine contact time refers to the amount of time chlorine is in contact with water in the storage tank and piped distribution system. This time starts when water passes through the in-line chlorinator and ends when water leaves the first faucet in the distribution system (the faucet closest to the storage tank). This time period is calculated in two separate parts and then the time values for each are added together to get the total contact time. The first time period calculated was the chlorine contact time of water in the storage tank. The second contact time calculated was the time water remained in the piped distribution system.

3.4.4.1 Contact Time in a Storage Tank

Contact time in a storage tank is a function of the daily minimum volume of water the storage tank holds, the daily maximum influent or effluent flow (whichever is larger) and a baffling factor. The qualifying terms with respect to the storage tank volume and flow (daily minimum, daily maximum) are used because this will give shortest chlorine contact time during daily operation. In the site studied the minimum volume of water in the storage tank during the day was equal to the full storage capacity of the tank. This is due to the influent flow entering the tank always being greater than the effluent flow leaving the tank hence the tank always remaining full and overflowing. The tank is known to be always full and overflowing by visual historical data given by the community and confirmed by the author of this thesis during his two years living in the community. This also allows for the measured influent flow value to be used for the maximum effluent flow value used in calculations as the influent flow will always be greater than the effluent flow and provide a more conservative calculated Ct value. The volume of a storage tank was calculated by entering the inside of the tank when the tank was empty (during cleaning or maintenance) and measuring the length, width and height of the tank with a tape measure. The height of the tank was measured from the bottom of the tank to the bottom of the overflow pipe. The volume of the storage tank was calculated in Equation 16 and the chlorine contact time in the storage tank was calculated in Equation 17.

$$\text{Tank Volume (gal)} = \text{Length (ft)} \times \text{Width (ft)} \times \text{Height (ft)} \times 7.48 \left(\frac{\text{gal}}{\text{ft}^3}\right)$$

Equation 16

$$\text{Contact time in storage tank (min)} = \frac{\text{Tank Volume (gal)}}{\text{Max Flowrate } \left(\frac{\text{gal}}{\text{min}}\right)} \times 0.3$$

Equation 17

The value 0.3 in Equation 17 is a tank's "baffling factor" that accounts for the chlorinated water entering the tank not mixing completely with all the water already in the tank before leaving the tank. As a result of this imperfect mixing the chlorinated water stays in the tank for only an estimated 30% of the calculated time hence the value 0.3. This value is a conservative value for a baffling factor for a cubical, un-baffled tank with a bifurcated influent pipe and effluent pipe on the opposite wall of the tank (Washington Department of Health, 2011 and EPA, 2003).

3.4.4.2 Contact Time in the Piped Distribution System

The contact time in the piped distribution system was calculated by first determining the total volume of water stored in the pipes starting from the storage tank and ending at the first house in the distribution system. Then this value was divided by the maximum flow rate. In the following equation pipe length was measured with a tape measure and the inside pipe diameter was determined from labeling on the pipe. The total volume of water in a pipe was determined as:

$$\text{Volume in Pipe (gal)} = \text{Length of Pipe (ft)} \times \pi \times \left(\frac{\text{Inside Dia. (in)}}{2}\right)^2 \times \left(\frac{7.48\left(\frac{\text{gallons}}{\text{ft}^3}\right)}{144\left(\frac{\text{in}^2}{\text{ft}^2}\right)}\right)$$

Equation 18

Equation 18 was used to calculate the volume of water in each unique pipe diameter between the storage tank and the first faucet in the distribution system. The total volume in the piped system was then calculated as:

$$\text{Total Volume in Piped System (gal)} = \sum_{r=1}^{n} \text{Volume in Pipe of Diameter}_r$$

Equation 19

The contact time in the piped system was then calculated by dividing the value obtained from Equation 19 (Total Volume in Piped System) by the value obtained from Equation 15 (Influent Flowrate) as shown in the following equation:

$$\text{Contact time in Pipes (min)} = \frac{\text{Total Volume in Piped System (gal)}}{\text{Influent Flowrate }\left(\frac{\text{gal}}{\text{min}}\right)}$$

Equation 20

This is a conservative estimate for the contact time in the piped system which assumes a very high usage rate in the distribution system. In actual day to day use the contact time would be larger than this calculated value. The total contact time is the sum of Equation 16 (Contact time in Storage Tank) and Equation 20 (Contact time in Pipes) as shown in Equation 21:

$$\text{Total Contact Time (min)} = \text{Contact time in Tank (min)} + \text{Contact time in Pipes (min)}$$

Equation 21

3.4.5 Calculation – Ct Value

The Ct value for a particular sample was calculated by multiplying the measured free chlorine concentration value by the calculated total contact time.

$$\text{Ct}\left(\text{min}\,\frac{\text{mg}}{\text{L}}\,\text{Cl}_2\right) = \text{Free Chlorine Concentration}\left(\frac{\text{mg}}{\text{L}}\,\text{Cl}_2\right) \times \text{Total Contact Time (min)}$$

Equation 22

Chapter 4: Results and Discussion

This chapter is divided into three sections. The first section, Section 4.1, presents and discusses the results of correct responses associated with the *User Knowledge of Chlorination Survey* that was administered after a seminar given by a Ministry of Health (MINSA) technician as well as after the author presented a newly developed seminar. Section 4.2 - presents and discusses the field data that were collected to assess the efficacy of two chlorination implementation methods. These two implementation methods were: the method currently being used by MINSA technicians; and a new method based on a newly developed field guide (Appendix F). Section 4.3 - compares findings of this thesis to those found in a related investigation by Orner (2011).

4.1 Results of the *User Knowledge of Chlorination Survey*

The *User Knowledge of Chlorination Survey* (Appendix C) was administered to residents living in the community of Kuite on two separate occasions. The first occasion was after a MINSA technician gave a seminar introducing a community to chlorination principles and the MINSA in-line chlorinator. The survey was administered a second time after the author presented a new seminar based on a newly developed chlorination field guide. The *User Knowledge of Chlorination Survey* has two distinct sections: “General Knowledge” and “MINSA Specific”. The “General Knowledge” section has questions that assess a participant’s knowledge of chlorination that is independent of location or method of chlorination. The “MINSA Specific” section has questions that assess a participant’s knowledge of the unique in-line chlorinator used by MINSA with respect to operational and logistical considerations.

4.1.1 Comparison of Individual Question Results

After the *User Knowledge of Chlorination Survey* was administered, following both seminars, an average individual question score (percent of respondents answering a question correctly) was calculated for each surveyed group. Table 17 presents the percent of correct responses of each surveyed group for each question asked and compares their values. Comparing the column titled "change in correct response," Table 17 shows that respondents who attended the new revised seminar on average answered 20 of the 22 questions in the *User Knowledge of Chlorination Survey* more correctly than respondents attending the MINSA seminar. In the "General Knowledge" section respondents attending the new seminar on average answered 13 of 14 questions more correctly than respondents attending the MINSA seminar. Similarly in the "MINSA Specific" section respondents attending the new seminar on average answered 7 of 8 questions more correctly than respondents attending the MINSA seminar.

Table 17 also lists if the data sets compared – the 12 respondents answering a particular question that attended the MINSA seminar and the 12 respondents answering the same question that attended the new seminar – have equal or unequal variance. This assessment was done using an F-test and was necessary so that the appropriate student's t-test could be run on the data sets for comparison. As stated in Chapter 3 both surveyed groups were assumed to be normally distributed. The normal distribution was assumed given the small overall size of the adult population (42 adults) in reference to the sample size for each seminar in the study (12 adults), which was 29% of the adult population. This assumption would give a more robust statistical analysis to the data sets. The column on the far right in Table 17 shows that in 12 of the 22 questions (questions with $P < 0.05$ and highlighted blue) there is a significant difference in the percent of correct responses between the two sampled groups. Questions of particular interest included in Table 17 are questions 2, 6a, 6d and 7 of the “General Knowledge” section; and questions 2, 3, 6 and 8 of the “MINSA Specific” section.

Table 17: Individual Question Results - Percent of Respondents in Each Surveyed Group Answering Individual Questions in the *User Knowledge of Chlorination Survey* Correctly (In the “Change in Correct Response” Column Green Highlighting Represents a Positive Change and Red Highlighting Represents a Negative Change; In the “P Value” Column Blue Highlighting Represents a Statistically Significant P Value)

	Survey Administered After:		Change in Correct Response (%)	Equal Variance	P Value
	MINSA Seminar (n = 12)	New Seminar (n =12)			
	% Respondents Answering Correctly				
General Knowledge					
Question 1	67%	75%	8%	Yes	0.670
Question 2	83%	100%	17%	No	0.166
Question 3	8%	50%	42%	No	0.027
Question 4	33%	67%	33%	Yes	0.111
Question 5	8%	58%	50%	No	0.009
Question 6a	58%	42%	-17%	Yes	0.436
Question 6b	42%	67%	25%	Yes	0.237
Question 6c	8%	50%	42%	Yes	0.024
Question 6d	75%	100%	25%	No	0.082
Question 7	0%	33%	33%	No	0.039
Question 8	25%	83%	58%	Yes	0.003
Question 9	8%	67%	58%	No	0.002
Question 10	42%	75%	33%	Yes	0.106
Question 11	25%	67%	42%	Yes	0.042
MINSA Specific					
Question 1	50%	58%	8%	Yes	0.698
Question 2	0%	67%	67%	No	0.001
Question 3	0%	92%	92%	No	0.000
Question 4	25%	67%	42%	Yes	0.042
Question 5	58%	83%	25%	Yes	0.193
Question 6	100%	92%	-8%	No	0.339
Question 7	8%	58%	50%	No	0.009
Question 8	0%	67%	67%	No	0.001

Question 2 of the “General Knowledge” section asked respondents: “Why do some communities chlorinate water?” The question was noteworthy because after the new seminar 100% of respondents answered the question correctly. This suggests that everyone who attended the new seminar knew beforehand or learned during the seminar why chlorinating water was important. This is significant as knowing why chlorination is used is important in motivating communities to chlorinate their water.

Question 6a of the “General Knowledge” section asked respondents: “Can chlorine kill or remove [dirt in water]?” Here fewer respondents attending the new seminar answered the question correctly. This may be due to respondents in the new seminar believing that chlorine can remove and kill anything in water. This might be because during the new seminar the presenter mentioned how chlorine can help protect community members from a number of different things found in water and only briefly mentioned that chlorine could not remove dirt. Community members might have thought chlorine can remove every “bad” thing from water, dirt included. It is noteworthy to mention that the difference in correct response percentage for this question between the two groups was found to not be significant.

Question 6d of the “General Knowledge” section asked respondents: “Can chlorine kill or remove [Microbes/Bacteria in water]?” The question was noteworthy to this study because after the new seminar 100% of respondents answered the question correctly. This suggests that everyone who attended the new seminar knew beforehand or learned during the seminar that chlorine can kill or remove microbes/bacteria. Instructing participants of the new seminar that chlorine could kill microbes (the common word used in the region by health practitioners) was a key goal of the new seminar. The result showing 100% of respondents answered this question correctly strongly suggests that this goal was met.

Question 7 of the “General Knowledge” section asked respondents: “What two factors determine if chlorine will be able to kill microbes?” This question was noteworthy to this study because no respondents of the MINSA seminar answered the question correctly. The question was screened before the seminars thereby ensuring respondents would understand the question. Therefore the result that no respondents could answer the question correctly after the MINSA seminar suggests that the MINSA seminar did not effectively educate anyone in attendance at the seminar of what two factors are necessary to know or collect to be able to determine if chlorine will kill microbes present in a sample of water. This question highlights a key shortcoming of the MINSA seminar. The new seminar while doing a statistically significant better job at educating respondents only had 33 percent of respondents answer this question correctly. This suggests that either the concept may be too difficult to explain in the region (possibly due to knowledge level of the people) or that a new presentation method is necessary to educate communities on the factors that are necessary to determine if chlorine can kill microbes.

Question 2 of the “MINSA Specific” section asked respondents: “How many chlorine tablets are you going to use at one time in the chlorinator?” This question was noteworthy to this study because no respondents who attended the MINSA seminar answered the question correctly. This suggests that attendees of the MINSA seminar did not learn how to determine how many chlorine tablets should be used in the chlorinator. Without this knowledge it is unlikely that the community can effectively chlorinate their water distribution system. The 67% improvement in correct responses after the new seminar highlights a significant success of the new seminar over the MINSA seminar.

Question 3 of the “MINSA Specific” section asked respondents: “How many days or weeks will [the] tablets last?” This question was noteworthy to this study because no respondents who attended the MINSA seminar answered the question correctly and also because the improvement in correct responses was the greatest for this question at 92%, a greater improvement than any other question included in the survey. The reason for this large change is that during the MINSA seminar the technician was unsure of how long the tablets should be left in the chlorinator saying that in some systems tablets would last for a longer period of time than others. In contrast during the new seminar the presenter stated that tablets should be left in the chlorinator for one week and then replaced. The time period of a week was chosen as chlorine tablets were found to decay within 7-9 days of insertion according to MINSA technicians and previous field studies. Logistically having communities replace chlorine tablets every 9 days was too difficult and therefore a stated time period of 7 days was used to instruct community members in the new seminar. The 92% correct response rate suggests that the time period presented in the new seminar was easy for community members to remember.

Question 6 of the “MINSA Specific” section asked respondents: “If you need assistance with your chlorinator who can you ask for help?” This question was noteworthy to this study because fewer respondents attending the new seminar answered the question correctly compared to the MINSA seminar. This is because the correct answer to this question was “a MINSA technician” and a MINSA technician presented the MINSA seminar and mentioned multiple times that he could help the community if they had problems with their chlorinator. The difference in correct response percentage between the two groups for this question was found to not be statistically significant and therefore not of great concern.

Question 8 of the “MINSA Specific” section asked respondents: “How can you clean/maintain the chlorinator?” This question was noteworthy to this study because no respondents who attended the MINSA seminar answered the question correctly. This was due to the MINSA technician never covering this in the MINSA seminar. Sixty-seven percent of the respondents of the new seminar correctly answered the question, a statistically significant difference, highlighting a significant improvement in educating community members in the new seminar.

4.1.2 Comparison of Averaged Participant Results

Correct responses by individual participants (respondents) taking the *User Knowledge of Chlorination Survey* were compared after the survey was administered following both seminars. Table 18 and Table 19 present the raw scores of participants who completed the survey after the MINSA seminar and after the new seminar respectively. The two tables break down the percent of questions answered correctly by each participant by section ("General Knowledge" and "MINSA Specific") as well as for the total survey. Table 20 then presents the average of these individual participant responses for each surveyed group, the values found in the last rows of Tables 18 and 19, and compares their values.

Table 18: Individual Participant Results for Attendees of the MINSA Seminar – Percent of Questions Each Surveyed Participant Answered Correctly in Each Section of the *User Knowledge of Chlorination Survey* and for the Total Survey (General Knowledge and MINSA Specific Combined)

	General Knowledge (n = 14)	MINSA Specific (n = 8)	Total (n = 22)
	% Questions Answered Correctly		
Participant 1	21%	25%	23%
Participant 2	64%	38%	55%
Participant 3	29%	38%	32%
Participant 4	7%	25%	14%
Participant 5	29%	13%	23%
Participant 6	29%	38%	32%
Participant 7	71%	50%	64%
Participant 8	36%	13%	27%
Participant 9	64%	50%	59%

Table 18 (Continued)

Participant 10	14%	13%	14%
Participant 11	43%	25%	36%
Participant 12	7%	38%	18%
AVERAGE:	35%	30%	33%

Table 19: Individual Participant Results for Attendees of the New Seminar – Percent of Questions Each Surveyed Participant Answered Correctly in Each Section of the *User Knowledge of Chlorination Survey* and for the Total Survey (General Knowledge and MINSA Specific Combined)

	General Knowledge (n = 14)	MINSA Specific (n = 8)	Total (n = 22)
	% Questions Answered Correctly		
Participant 1	100%	100%	100%
Participant 2	79%	75%	77%
Participant 3	71%	88%	77%
Participant 4	86%	38%	68%
Participant 5	36%	63%	45%
Participant 6	36%	75%	50%
Participant 7	86%	100%	91%
Participant 8	86%	100%	91%
Participant 9	36%	50%	41%
Participant 10	14%	25%	18%
Participant 11	79%	75%	77%
Participant 12	93%	88%	91%
AVERAGE:	67%	73%	69%

Table 20: Comparison of the Average Percent of Respondents Answering Questions Correctly – Post-MINSA Seminar Versus Post-New Seminar (In the "Change in Average %" Column Green Highlighting Represents a Positive Change and Red Highlighting Represents a Negative Change; In the "P Value" Column Blue Highlighting Represents a Statistically Significant P Value)

	Survey Administered After:		Change in Average %	Equal Variance	P Value
	MINSA Seminar	New Seminar			
	Average % of Respondents Answering Correctly				
General Knowledge	35%	67%	32%	Yes	0.005
MINSA Specific	30%	73%	43%	No	0.000
TOTAL	33%	69%	36%	Yes	0.000

Table 20 shows that based on the average correct response of participants, participants in the new seminar answered more questions correctly compared to participants in the MINSA seminar in both sections of the *User Knowledge of Chlorination Survey* and over the total survey as well. This higher score by new seminar respondents suggests that the new seminar is better at educating community members on both general knowledge of chlorination and knowledge specific to MINSA's in-line chlorinator. Table 20 also shows that this difference was statistically significant in all three cases indicating that if the same two seminars were to be given again the new seminar attendees would likely answer questions more correctly than MINSA seminar attendees in both knowledge sections.

4.1.3 The Effect of Presenting Each Seminar in a Different Language

In Section 3.3.1 it was mentioned that the MINSA seminar was presented by a MINSA technician in Ngöbere, the Ngöbe's indigenous language, and the new seminar was presented by the author of this thesis in Spanish. The effect that this had on the responses to survey questions was not studied but may not be significant. This is because the Ngöbere language does not have words to describe many of the technical terms mentioned in the seminar. For example the following words do not exist in Ngöbere, or at least do not exist or are not used in the dialect of Ngöbere spoken in the studied site: chlorine, chlorinator, microbe, virus, algae, contact time and several others. Some of these words simply do not exist in Ngöbere (e.g., chlorine, chlorinator). Other words in Ngöbere like microbe or virus don’t have a specific word in Ngöbere but instead respondents would use an all-encompassing word for example “sickness” to describe both words. Other words in Ngöbere like “contact time” could be described but it would be difficult to understand when described in Ngöbere, in this instance because Ngöbere only uses very general words for describing time (e.g., morning, noon, night, et cetera). The result of all of these difficulties in translating these technical terms and concepts to Ngöbere was that when the MINSA technician presented his seminar a large portion of the seminar ended up being a mix of Ngöbere and Spanish. The technician spoke Ngöbere when describing some aspects but Spanish when technical themes were introduced. This is not to say that presenting the MINSA seminar in Ngöbere had no advantages, community members may have felt more relaxed or may have been better able to understand the portions of the seminar that were presented in Ngöbere.

4.1.4 Qualitative Comparison of the MINSA Seminar to the New Seminar

The MINSA seminar was presented by a MINSA technician and lasted for approximately 30 minutes. The new Seminar was presented by the author of this thesis and lasted approximately 120 minutes. The difference in length of the seminars was due to both the amount of material covered and the style of presentation of each seminar. The MINSA seminar covered how to install and use the chlorinator and then asked if community members had questions. The seminar did not describe why a chlorinator was used, it did not describe any basic knowledge of chlorination, it did not instruct community members on how they could determine if the chlorinator was functioning properly and it did not provide instruction on how to maintain or clean the chlorinator. The new seminar differed in that it covered all of these aforementioned topics and the style of the seminar was more conversational as opposed to the MINSA seminar which was presented in a lecture format. The new seminar posed questions to the community and then discussed their answers. For example when attempting to teach the importance of chlorination the presenter of the new seminar would ask the community: “Why would chlorinating your water system be important?” After several community members responded the presenter would lead the community toward the correct answer rather than simply telling them the correct answer. This presentation style is used in many Peace Corps training materials geared toward uneducated, illiterate groups where community members need a presentation style that is of a slower pace and more engaging so that community members have time to process and fully understand the information.

Additionally a significant difference in correct responses between the two surveyed groups could be due to the MINSA seminar never covering material about certain questions posed in the *User Knowledge of Chlorination Survey*. For example the MINSA seminar never covered why a community might want to chlorinate their water system (the first question in the *User Knowledge of Chlorination Survey*). Therefore respondents answering this question after the MINSA seminar answered the question based on their own personal knowledge that they had prior to the MINSA seminar and the seminar had no impact on their response. As a result the change between the two surveyed groups for this question more closely assesses if this information was effectively taught to some community members in the new seminar rather than assessing if one seminar taught this material better than another seminar. This assumes both groups were comprised of members who knew the same amount of information as the other group prior to each seminar. Ideally you would sample several participants of a given seminar before the seminar and then several more after the seminar so that an assessment could be made on how much participants learned during a given seminar. This however was not possible as there were only 42 adults living in the community and the author did not want to reduce the sample size of any respondent group. There was a decision made not to survey each participant that responded to a survey both before and after the seminar they attended because the author of this thesis did not want to prime participants with questions that they would then specifically listen for during the seminar.

The survey results are still seen as valuable as they clearly suggest that participants attending the new seminar have more knowledge of chlorination and know more about the in-line chlorinator than participants of the MINSA seminar. However this increase in knowledge could be due to either the style of presentation or the fact that one seminar covered the material posed by a given question and the other did not. The importance of each of these factors cannot be fully determined in this study.

4.2 Results Assessing the Efficacy of Two Chlorination Implementation Methods

An investigation assessing the efficacy of two chlorination implementation methods was completed. An implementation method includes how a recommended chlorination regimen is developed, assessed and modified if necessary. A chlorination regimen dictates the amount of chlorine that is added to the chlorinator (e.g., the number of chlorine tablets) and the length of time these tablets are to remain in the chlorinator before they are replaced with new tablets. The efficacy of each method is assessed on the ability of the method to chlorinate effectively, after iterations if necessary. Effective chlorination is defined in this paper as the Ct value of the system at all times being greater than or equal to 40 min-mg/L Cl_2.

The first implementation method investigated was developed by a MINSA technician after he presented the MINSA seminar. This method will be called the “MINSA method.” The technician stated that to effectively chlorinate the studied community’s gravity fed water system the community needed to insert two chlorine tablets into the chlorinator. The technician provided no definitive time period for how long the chlorine tablets would last and did not say when to insert new tablets. The technician did not mention how to assess if the system was being chlorinated effectively or how to modify the regimen if the system was found not to be chlorinating effectively. The technician communicated that the recommendation of two tablets was based on the system having a “medium” amount of influent flow into the storage tank.

The second implementation method investigated in this research was developed by the author with the studied community based on a newly developed field guide. This method will be called the “new method.” The new field guide presented the Ct method to the studied community’s water committee, showed them how to calculate the chlorine residence time for their system and detailed how the community could calculate the necessary free chlorine concentration to achieve the desired 40 min-mg/L Cl_2 level. The author noted that community members understood the need to calculate residence time but thought that community members would be unable to recalculate this value without the help of a technician in the future. Therefore the author recommended that the community contact a MINSA technician if they changed any of the variables associated with calculating the chlorine residence time (tank size, location of first house, pipe sizes in distribution system, et cetera). Based on free chlorine concentrations collected during the “MINSA method’s” chlorination regimen the water committee decided to chlorinate their system with three chlorine tablets for one week and then decide if more or less chlorine was necessary.

Three field studies were completed assessing the efficacy of the two implementation methods. Field study one used the recommended regimen of a MINSA technician to assess the "MINSA method." Field study two used the chlorination regimen of the community developed from the new field guide to assess the "new method." A large storm event occurred on day two of field study two and as a result the chlorine residual samples that were taken were believed to not be representative of normal conditions (see Section 4.2.5). Therefore a third field study was needed to assess the "new method" of implementation.

4.2.1 Influent Flowrate for Field Studies 1, 2 and 3

The influent flowrates for field studies 1, 2 and 3 are presented in Table 21. The value measured in the field was the time necessary (in seconds) to fill a five gallon bucket and then the flowrate (in gallons per minute) was calculated.

Table 21: Measured Times to Fill a 5-Gallon Bucket and the Associated Calculated Flowrates for Field Studies 1, 2 and 3 Over Each Study's One Week Testing Period

Time Sample was Collected	*Field Study 1*		*Field Study 2*		*Field Study 3*	
	Measured Time (s)	**Calculated Flowrate (gal/min)**	**Measured Time (s)**	**Calculated Flowrate (gal/min)**	**Measured Time (s)**	**Calculated Flowrate (gal/min)**
Hour 2	24	12.5	23	13.04	24	12.5
Day 1	25	12.0	23	13.04	25	12
Day 2	24	12.5	24	12.5	24	12.5
Day 3	23	13.0	23	13.04	25	12
Day 4	24	12.5	24	12.5	24	12.5
Day 5	25	12.0	24	12.5	23	13.04
Day 6	23	13.04	25	12.0	25	12
Day 7	24	12.5	24	12.5	24	12.5

The flowrate ranged from 12 to 13.04 gal/min over the three field tests. This variation is most likely due to the measurement technique and/or small flow fluctuations due to air pockets in the pipes before the water reaches the storage tank. The average value for the flowrate across the three field tests was 12.5 gal/min with a 95% confidence interval of 12.35 – 12.67 gal/min. The average value was used for the calculation of chlorine residence time.

4.2.2 Chlorine Tablet Weight for Field Studies: 1, 2 and 3

The summed weight (in grams) of all chlorine tablets used in each field study was measured. Dry weight was measured before insertion into the chlorinator and then the wet weight was measured until completion of each study. Table 22 presents the weights of the tablets for field studies 1, 2 and 3.

Table 22: The Summed Dry and Wet Weight of All Chlorine Tablets Inserted into the Chlorinator at a Given Time for Field Studies 1, 2 and 3 Over Each Study's One Week Testing Period

Time Measurement was Collected	Dry or Wet Weight (g)	Field Study 1 (2 Tablets)	Field Study 2 (3 Tablets)	Field Study 3 (3 Tablets)
Hour 0	Dry	388	570	565
	Wet	404	605	597
Hour 2	Wet	394	575	570
Day 1	Wet	327	484	485
Day 2	Wet	269	396	392
Day 3	Wet	211	314	313
Day 4	Wet	156	244	240
Day 5	Wet	105	187	182
Day 6	Wet	68	132	128
Day 7	Wet	28	83	77

Table 22 shows that each tablet weighed slightly less than the 200 gram weight that the manufacturer lists. This is because each tablet had to be broken in half to fit into the chlorinator (a tablet listed in Table 22 implies two halves). When each tablet is broken some of the solid chlorine is lost. On day seven only 28 grams of chlorine remained of the tablets in field study one, 83 grams remained in field study two, and 77 grams remained in field study three. Figure 4 shows the decrease in tablets weight over time in all three field studies.

Linear treadlines for the three field studies are also depicted in Figure 9. The slope of the fitted lines represent the decrease in weight of the tablets over time. The slope of the fitted lines for field studies 2 and 3 are similar with a summed tablet decay of 3.08 and 3.09 grams per minute respectively. The slope of the treadline for field study 1 was 2.26 grams per minute. The smaller decay rate for the summed weight in field study 1 compared to field study 2 and 3 makes intuitive sense. With three tablets inserted into the chlorinator there is more total surface area of chlorine tablet in contact with water (during operation all tablets are completely immersed in water), this larger contact area allows for a faster decay rate. Interestingly, if the summed decay rate is divided by the number of tablets in each field study the individual tablet decay rate for field studies one, two and three was determined to be 1.129, 1.027 and 1.029 grams per minute respectively. This shows the decay rate of an individual tablet is slightly greater in field study one where there are only two tablets in the chlorinator compared to field studies two and three where there are three tablets in each chlorinator. This may suggest that the dominating mode of mass transfer of the chlorine into the water is convection - as suggested by the greater slope in

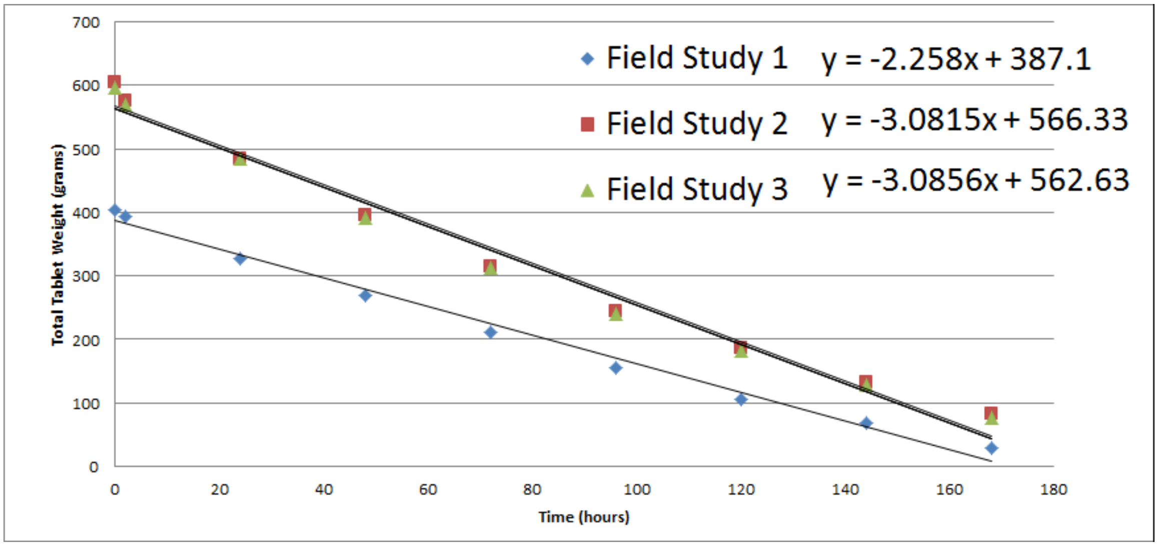


Figure 9: Decrease in the Weight of Tablets for Field Studies 1, 2 and 3 Over Each Study's One Week Testing Period

treadlines for field studies two and three - where mass transfer by diffusion plays a smaller but noticeable role - as suggested by the individual tablet decay rate being larger.

4.2.3 Measured Free Chlorine Concentrations for Field Studies 1 and 3

Free chlorine was measured at four locations in all three field studies – at the influent pipe into the storage tank, at the cleanout valve for the storage tank (to measure effluent chlorine leaving the storage tank), at the first house in the distribution system and at the last house in the distribution system. The measured free chlorine concentrations at these locations are presented in Table 23 for field study one and Table 24 for field study three. This data is also represented graphically in Figures 10 for field study one and Figure 11 for field study three.

Table 23: Field Study 1 – Two Tablets Inserted into Chlorinator Over One Week – Measured Free Chlorine Concentrations at: Influent and Effluent Pipes of the Storage Tank; First and Last House in the Water Distribution System

Time Sample was Collected	Free Chlorine Concentration (mg/L Cl_2) at Locations:			
	Influent Pipe	Effluent Pipe	First House	Last House
Hour 2	0.30	0.20	0.14	0.01
Day 1	0.15	0.03	0.09	0.02
Day 2	0.15	0.09	0.02	0.15
Day 3	0.34	0.06	0.05	0.03
Day 4	0.30	0.11	0.06	0.08
Day 5	0.17	0.09	0.08	0.10
Day 6	0.10	0.04	0.06	0.01
Day 7	0.06	0.02	0.00	0.00

Table 24: Field Study 3 – Three Tablets Inserted into Chlorinator Over One Week – Measured Free Chlorine Concentrations at: Influent and Effluent Pipes of the Storage Tank; First and Last House in the Water Distribution System

Time Sample was Collected	Free Chlorine Concentration (mg/L Cl_2)			
	Influent	Effluent	First House	Last House
Hour 2	1.42	0.33	0.37	0.29
Day 1	1.10	0.50	0.52	0.35
Day 2	0.94	0.44	0.21	0.19
Day 3	1.16	0.63	0.61	0.52
Day 4	0.88	0.48	0.72	0.57
Day 5	0.90	0.63	0.63	0.52
Day 6	0.91	0.54	0.24	0.22
Day 7	0.34	0.27	0.26	0.20

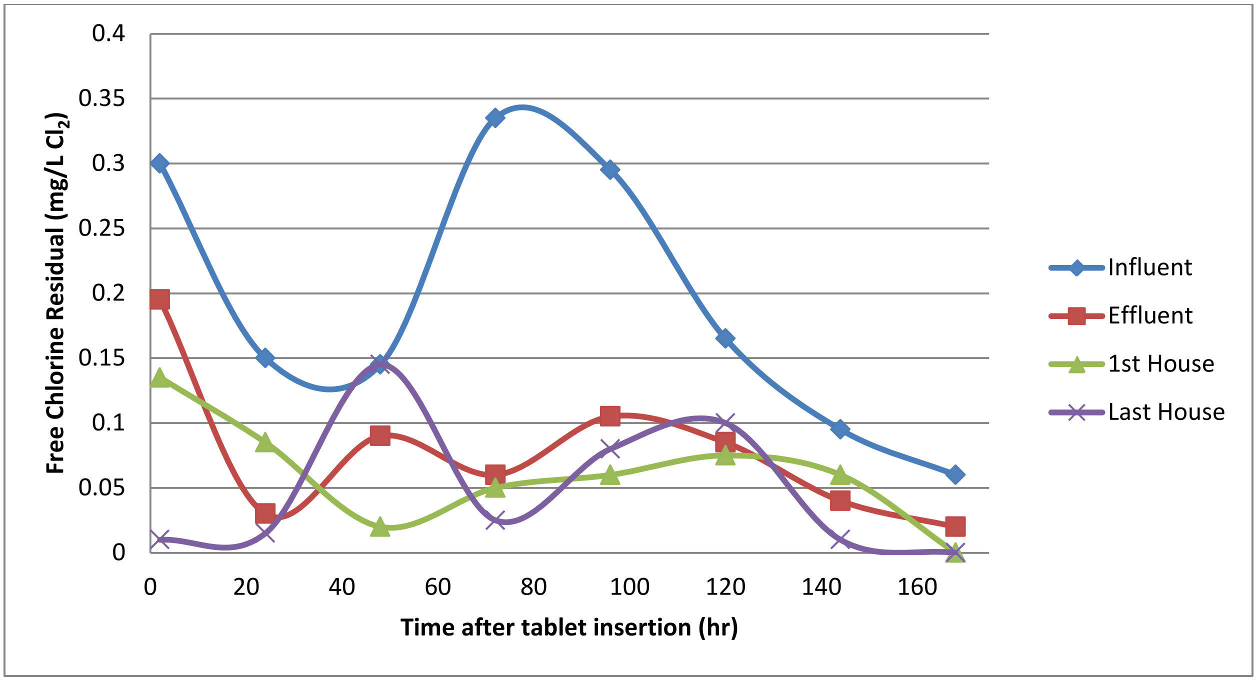


Figure 10: Field Study 1 – Two Tablets Inserted into Chlorinator Over One Week – Fluctuating Free Chlorine Concentrations at: Influent and Effluent Pipes of the Storage Tank; First and Last House in the Water Distribution System

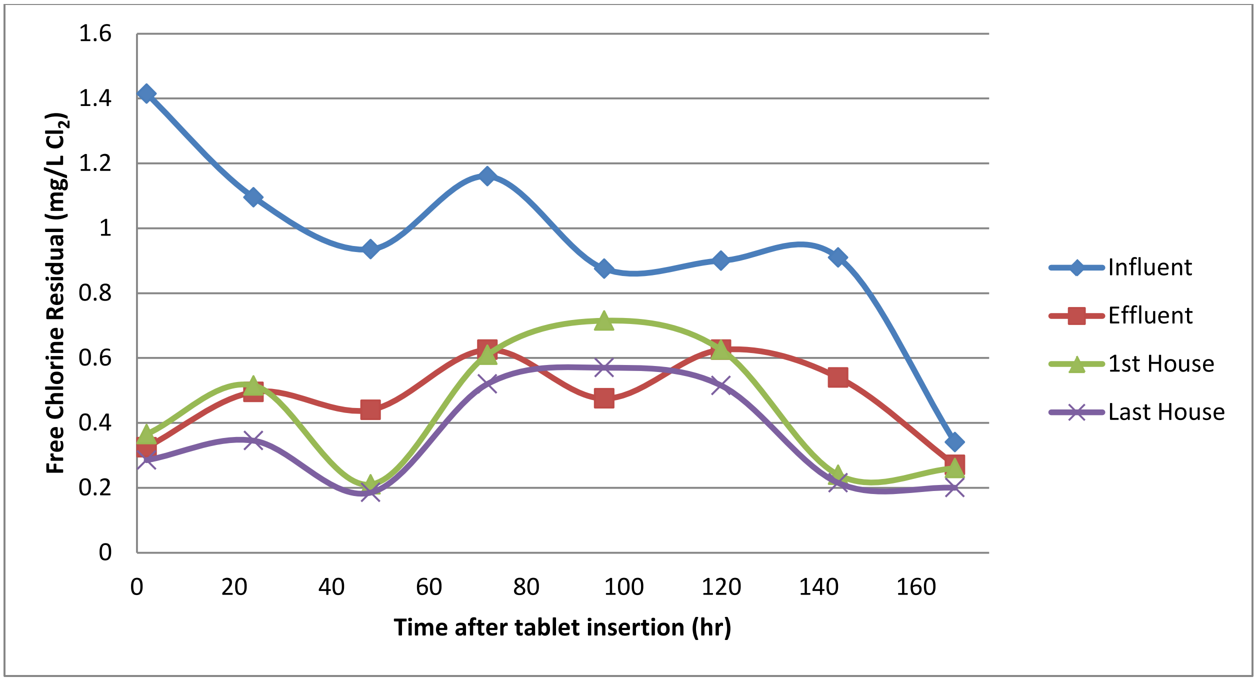


Figure 11: Field Study 3 – Three Tablets Inserted into Chlorinator Over One Week – Fluctuating Free Chlorine Concentrations at: Influent and Effluent Pipes of the Storage Tank; First and Last House in the Water Distribution System

In both field studies one and three there is a trend of decreasing measured free chlorine concentration for the first two days and then an increase in chlorine concentration on the third day. It was not understood why this occurred. This may be due to the tablet needing three days to become saturated with water and then shedding a large amount of tablet weight and chlorine on the third day or simply due to measuring a slug of water that was slightly more chlorinated than at other times during the day during both field studies.

Three chlorination parameters were mentioned in the literature review chapter as important to consider when assessing chlorination. The first parameter was to ensure that the total chlorine residual never exceeded 4.0 mg/L as ingesting water with a residual level over this limit for long periods of time could have negative health effects. This chlorination parameter was not assessed in this study. The free chlorine concentration in field study one never rose above

0.34 mg/L Cl_2 and the free concentration in field study three never rose above 1.42 mg/L Cl_2. This suggests the total chlorine concentration would likely be below 4.0 mg/L for field study one but may be close to the 4.0 mg/L Cl_2 limit in field study two.

The second chlorination parameter was to ensure that there was a free chlorine residual of 0.2 mg/L Cl_2 or higher at locations throughout the distribution system. It is advantageous to have a free chlorine residual of 0.2 mg/L Cl_2 or higher at locations throughout the distribution system to act as a secondary disinfectant in case a contaminant enters the water in the distribution system, for example through a broken pipe. A free chlorine residual of 0.2 mg/L Cl_2 is maintained in field study three but not in field study one. In field study one the free chlorine concentration is below 0.2 mg/L Cl_2 at all times at the first and last house in the distribution system and often not met at the influent and effluent sampling locations. In comparison in field study three the free residual is above 0.2 mg/L Cl_2 at all times and all locations except for at one data point (day two at the last house) where the residual was measured to be 0.19 mg/L Cl_2.

Taste and odor issues associated with chlorination of water were not assessed in this investigation; however, a short discussion is noteworthy. A common misconception identified in the developed world is that taste and odors associated with water are solely a result of chlorination (White, 1999). On the contrary noticeable taste or odor in water is most likely from algae, organic compounds (from decaying vegetative matter), or presence of hydrogen sulfide or other sulfurous compounds (White, 1999). White (1999) states that:

> "Tastes and odors from the application of chlorine are not likely to occur from the chlorine compounds themselves up to the limits listed: free chlorine (HOCl) - 20.0 mg/L; monochloramine - 5.0 mg/L; dichloramine - 0.8 mg/L; and nitrogen trichloride: 0.02 mg/L"

The large threshold difference between free chlorine and combined chlorines is another reason passing the chlorination breakpoint is desirable - there will be very little combined chlorine and as long as the free residual is less than 20 mg/L it is unlikely water will have a taste or odor issues due to chlorine. Also at these high levels chlorine can remove other odor causing agents.

In addition, the pH of water in the studied community's distribution system was not measured in this investigation. This was a major shortcoming of this investigation. As mentioned in Section 3.1.3 free chlorine is measured as a combination of hypochlorous acid (HOCl) and as its constituent base, the hypochlorite ion (OCl^-). Hypochlorous acid is a weak acid (pKa = 7.53) and undergoes partial hydrogen disassociation producing the base hypochlorite ion. Knowing the pH of the water in a distribution system is important as the germicidal effectiveness of hypochlorous acid is far greater than that of the hypochlorite ion (White, 1999). The Ct values used in this investigation assumed that the water had a pH between 7-8, if this is not true different Ct values need to be used as benchmarks for each microorganism and for a global benchmark. Ct values would be higher if the water had a more basic pH. In conventional water treatment this is not a problem as the pH of water is reduced when chlorinating and then raised after a set contact time to be softened or passed into the distribution system.

The third marker is to ensure the Ct value for a distribution system is ≥ 40 min-mg/L Cl_2. This marker is assessed in Section 4.2.4 but first a comparison of the free chlorine concentrations of the effluent leaving the storage tanks is presented. These concentrations are noteworthy as they are used when calculating a Ct value for the system at a given time. Figure 12 graphically shows the difference in the concentrations of free chlorine for field studies one and three over one week. The associated raw data used to create these graphs can be found in Appendix D.

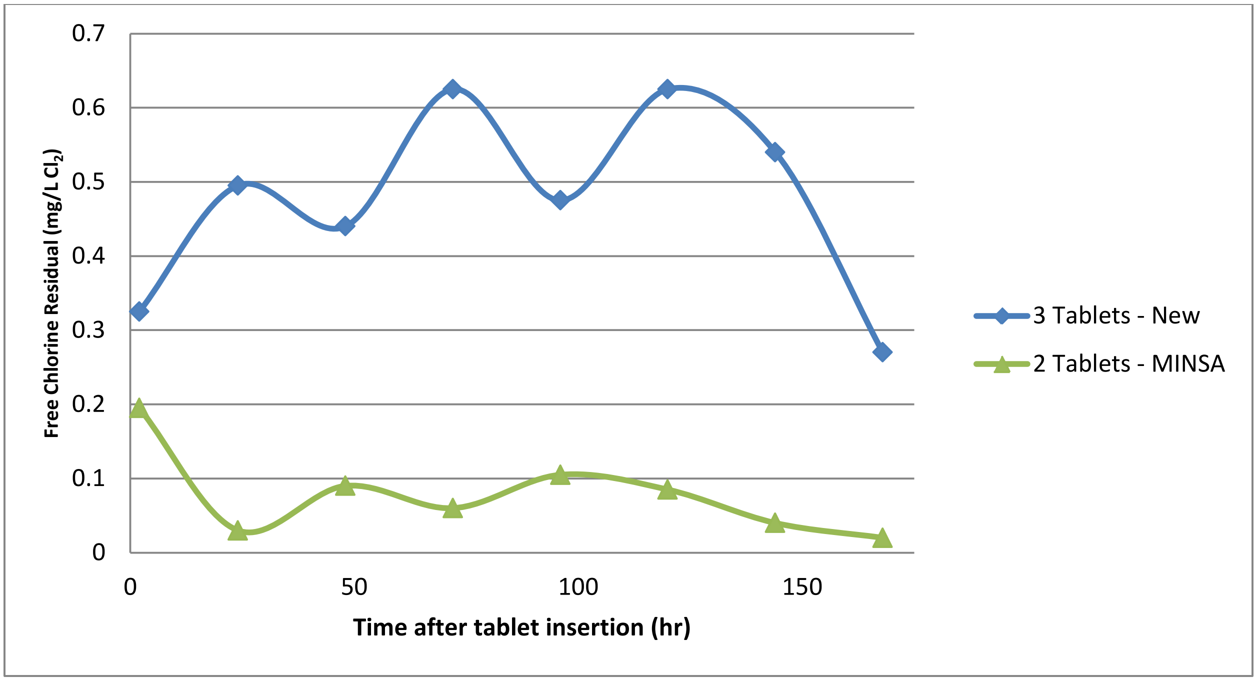


Figure 12: Comparison of Free Chlorine Concentration Over One Week for Field Studies 1 and 3 – Free Chlorine Samples Were Taken from the Effluent Pipe of the Storage Tank; Two Chlorine Tablets Were Used in Field Study 1 and Three Tablets Were Used in Field Study 3

The free chlorine concentration in field study three is higher compared to the free chlorine concentration of field study one. This is true for any data point in comparison when looking at a given sample location and a corresponding time. Field study one has on average a 9 fold increase in free chlorine residual. This suggests that with the two chlorine tablets in field study one, water is chlorinated to near the chlorine breakpoint – as there is a small amount (< 0.2 mg/L Cl_2) of free chlorine residual – but when one additional chlorine tablet is added, as in field study three, the additional chlorine is almost completely present in the form of free chlorine suggesting that the water is chlorinated past the chlorine breakpoint.

4.2.4 Comparison of Ct Values for Field Studies 1 and 3

The contact time for Kuite's distribution system was first calculated so the Ct value for the system could then be calculated. The 5,000 gallon storage tank was determined to have a contact time of 120 minutes (for a flowrate of 12.5 gal/min) and the 283 feet of piping from the tank to the first house a contact time of 12.9 minutes. This resulted in a total contact time of 133 minutes for the storage tank and distribution system. This contact time was used to calculate the Ct values for all three field studies. Figure 13 presents a comparison of the Ct values determined for field studies one and three over the one week testing period.

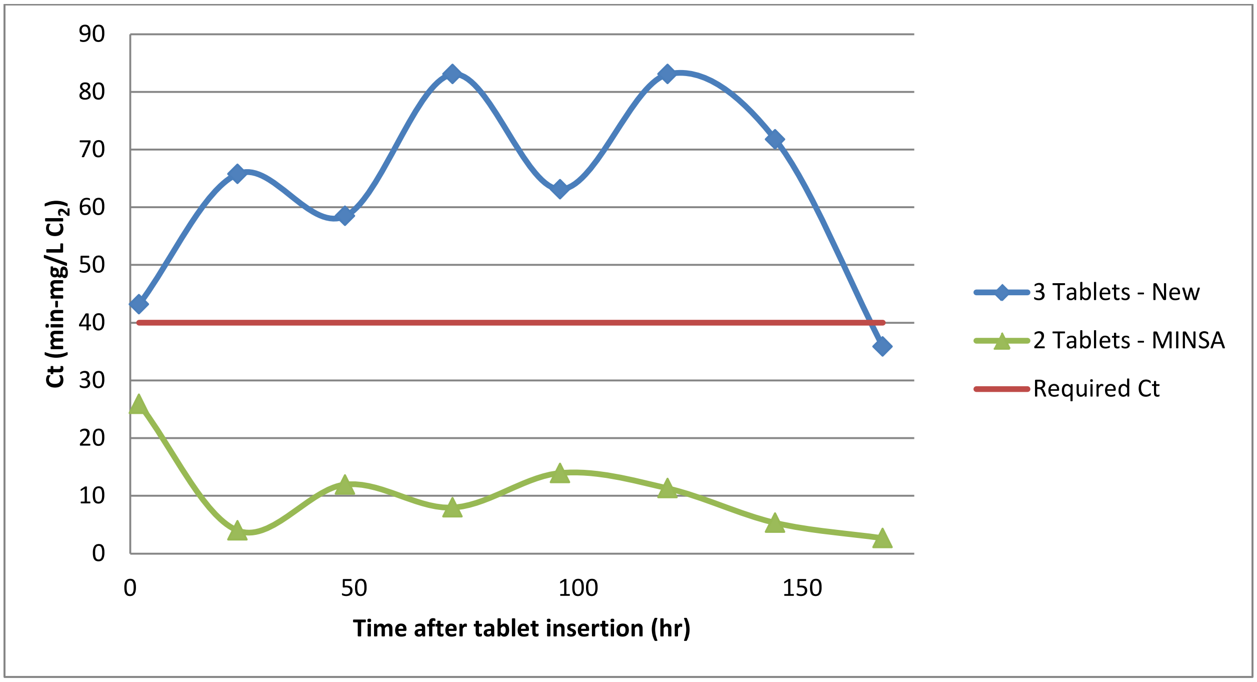


Figure 13: Comparison of Ct Values Over a One Week Testing Period for Field Study 1 Where Two Chlorine Tablets Were Used to Chlorinate With MINSA's In-Line Chlorinator and Field Study 3 Where Three Tablets Were Used to Chlorinate. The Required Ct Value for Pathogen Inactivation is Also Presented.

Figure 13 shows that in field study one (2 tablets assessing the MINSA implementation method) the required Ct level of 40.0 min-mg/L Cl_2 was never met. This is significant as this limit was set to kill common waterborne pathogens found in the region. This limit not being met suggests that some waterborne pathogens would survive, including *Giardia lamblia* and *E. histolytica* which have Ct values of 15 and 35 min-mg/L Cl_2 respectively. Field study one only had a sufficiently high Ct value to inactivate *Giardia lamblia* for the first day and never reached a high enough Ct value to safely inactivate *E. histolytica*. In comparison field study three (3 tablets assessing the new implementation method) met the required Ct level at all points except when tested on the last day where the Ct value was found to be 35.9 min-mg/L Cl_2. This lower value on the final day of the tablets being used would be sufficient to inactivate all target pathogen including *E. histolytica* but would not meet the required Ct value of 40.0 min-mg/L Cl_2.

In the literature review (Chapter 2) sources were provided that listed two different Ct values needed to achieve inactivation of *E. histolytica*, 20 and 35 min-mg/L Cl_2. Orner (2011) used the smaller of these two values and therefore set his recommended required Ct value to evaluate the efficacy of the chlorinator in his study to be 20 min-mg/L Cl_2. This study based the recommended required Ct value on the larger Ct value found in literature to inactivate *E. histolytica* and then added another 5.0 min-mg/L Cl_2 onto this literature Ct value. This additional 5.0 min-mg/L Cl_2 was added as a safety factor to conservatively assure users that *E. histolytica* is being inactivated. While a Ct value $\geq$ 40 min-mg/L Cl_2 would be optimal, a fluctuation of Ct values between 20 and 40 min-mg/L Cl_2 would still provide an effective Ct value to inactivate all targeted pathogens except for possibly *E. histolytica*.

4.2.5 Field Study 2 – Large Storm Events and Their Impact on Measured Free Chlorine Concentration

The data collected for field study two were not used for evaluation of the new implementation method as a large storm event occurred on the second day of data collection. The stream catchment box that captures water for the system was flooded with debris and as a result the water that entered the system became highly turbid. This greatly reduced the measured free chlorine concentrations not only for that day but for the rest of the weeklong testing period. This is shown in Figure 14 which presents the measured free chlorine residual leaving the storage tank for field study two and field study three both of which used 3 chlorine tablets. The free chlorine residual in field study two decreased to less than 0.1 mg/L Cl_2 immediately after excess debris entered the water system and slowly recovered during the week to a similar residual level measured in field study three on day seven. It was not determined if this measured residual was significantly lower due to debris in the water causing a larger chlorine demand or due to machine error in reading samples with a large amount of turbidity. A larger chlorine demand would be caused by a larger amount of total organic carbon in the water which is often associated with increased turbidity (LeChevallier et al, 1981). This larger demand would then decrease the amount of free chlorine in the water.

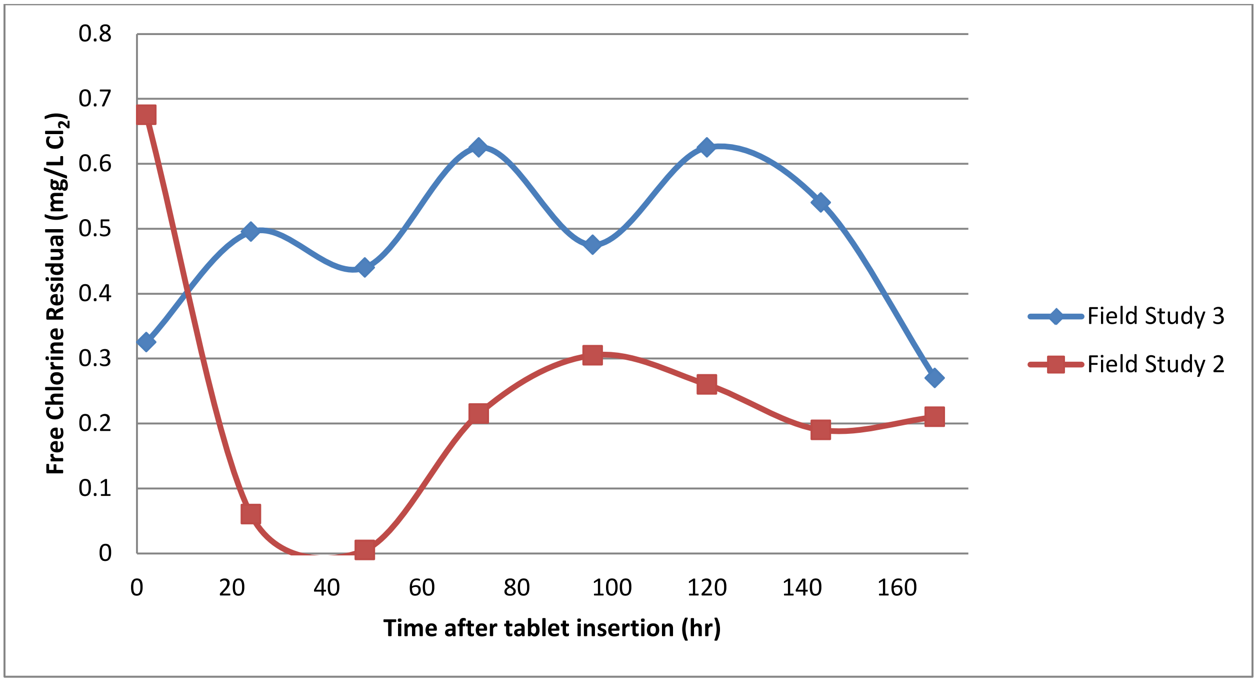


Figure 14: Comparison of Free Chlorine Concentration Over One Week for Field Studies 2 and 3 – Free Chlorine Samples Were Taken from the Effluent Pipe of the Storage Tank; Three Chlorine Tablets Were Used both Field Studies. Field Study 3 Represents the Free Residual Found During Normal Conditions and Field Study 2 Represents a Free Residual Obtained During a Large Storm Event (Occurring on Day One of Field Study 2, Shortly After the Insertion of Tablets).

The colorimeter can improperly measure the chlorine concentration when there is a high amount of turbidity. HACH (Loveland, CO) recommends filtering samples that have a large amount of turbidity to ameliorate this problem. Filtering of turbid samples was not possible as the equipment necessary to perform the filtrations was not available.

4.3 Comparison to Orner's (2011) Study of the Efficacy of MINSA's Chlorinator

Several notable comparisons can be made between this study and Orner's (2011). The most important is the difference in free chlorine concentrations obtained and the related longevity of chlorine tablets. Orner used tablets manufactured by *Provichlor* (Morelia, Mexico) where the tablets in this study were manufactured by *Productos Quimicos IBIS* (David, Panama). In Orner's study tablets inserted into the chlorinator that were not sealed in plastic wrapping lasted less than 24 hours and often less than 3 hours. In comparison tablets in this study were never sealed in plastic wrap prior to use but lasted a full week. This fast decay of the tablet weight when tablets were not wrapped in plastic in Orner's study led to measured free residuals of over 20 mg/L Cl_2. This value is 10 times greater than any value obtained in this study.

In addition, when Orner inserted three tablets wrapped in plastic (so that the tablets would decay slower) into the chlorinator they decayed at a similar rate to the tablets in field study three as can be seen in Figure 15. However the free residual Orner obtained with this tablet decay was much different than the free residual obtained in this study. This can be seen in Figure 16 where Orner's field study seven free residual is compared to the free residual found in field study three of this thesis.

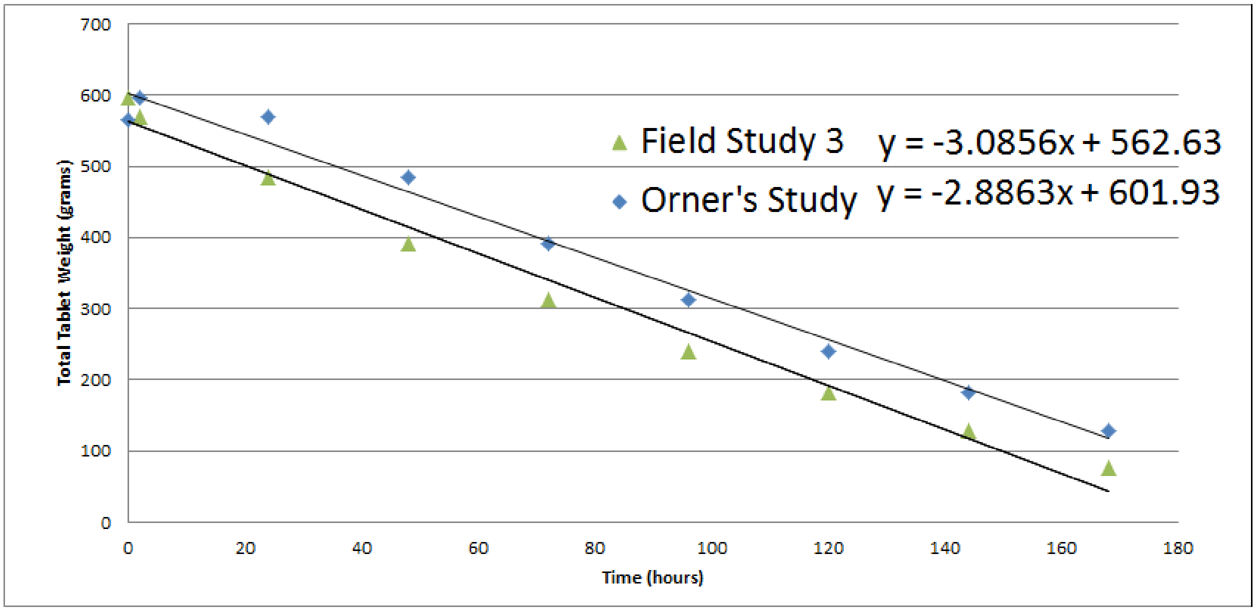


Figure 15: Comparison of the Decrease of Chlorine Tablet Weight Over One Week - Orner's (2011) Field Study 7 to this Study's Field Study 3. Included are the Linear Treadlines and Associated Linear Equations of the Plotted Data for both Studies.

The free residual in field study three is at all times greater than the free residual measured by Orner in his field study seven. On average the free residual measured in field study three is three times greater than the free residual measured in Orner's field study seven. This difference may be due to Orner's field study seven having a greater flowrate than this studies field study three (15.90 and 12.5 gallons per minute respectively), the difference in tablet composition – manufacture processes of the chlorine tablets, or a difference in water quality characteristics causing a greater chlorine demand. The difference in flowrate is the most likely the largest factor in the decreased free chlorine residual however the difference in tablet composition and water quality may be important factors. The water quality is expected to be different as the water is taken from two distinctly different regions separated by a mountain range (see discussion in Section 1.1).

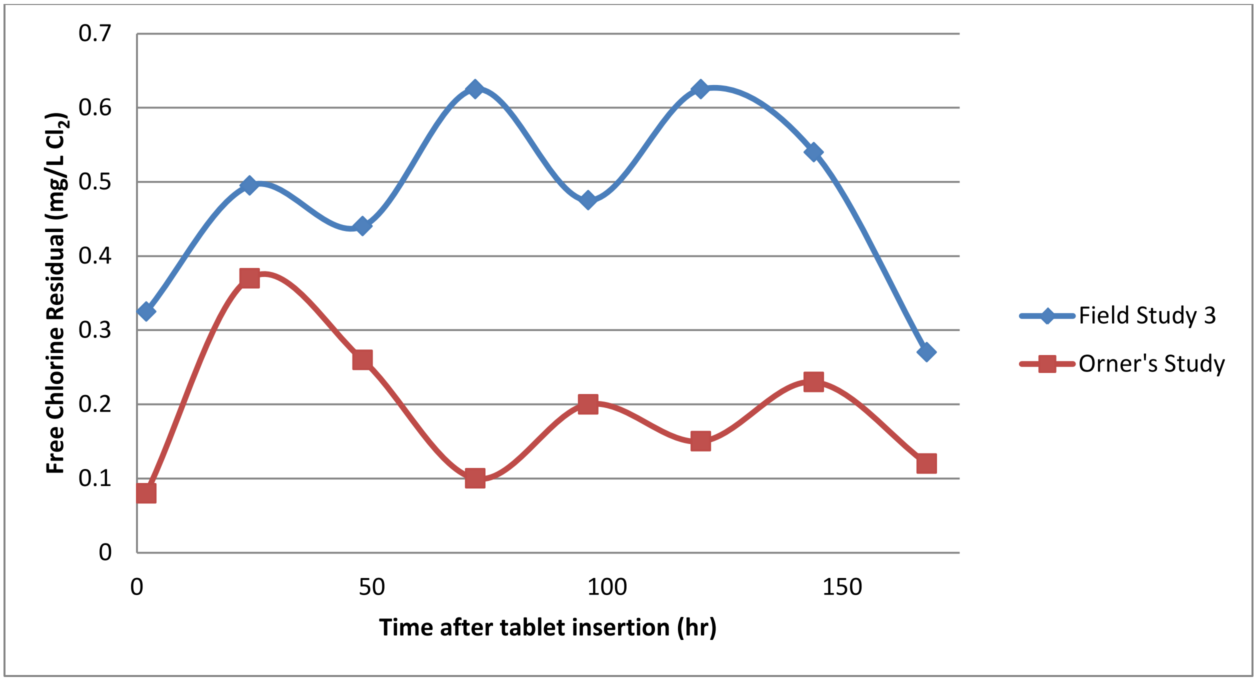


Figure 16: Comparison of Free Chlorine Residual Over a One Week Period - Orner's (2011) Field Study 7 to this Study's Field Study 3. Both Studies Used Three Chlorine Tablets Inserted into a MINSA Designed in-line Chlorinator.

The differences found in this study and Orner's are notable for two reasons. The first is to highlight the difference in free residual obtained by using tablets manufactured by two different companies. This is important as the chlorination regimens communities were using with the old tablets (number of tablets used and for what length of time) may need to be changed to effectively chlorinate their systems with the new chlorine tablets. The second reason is to show the necessity of a chlorination method that promotes monitoring of chlorine residual, evaluation of associated Ct results and then modification of the chlorination regimen if necessary. Orner's field study seven has a similar flowrate to field study three of this thesis – the MINSA implementation method would likely recommend the same chlorination method for both systems as flowrate was their only criteria for recommendation of a regimen. If a MINSA technician simply used the same regimen found to effectively chlorinate Kuite's water system in Calabazal (the site of Orner's field study seven) the regimen would not work. This is because other system characteristics - storage tank size, pipe size and length to the first house, water quality characteristics et cetera - lead to large differences in calculated Ct values. This is shown in Figure 17 which presents the calculated Ct values for Orner's field study seven and the calculated Ct values for field study three in this study.

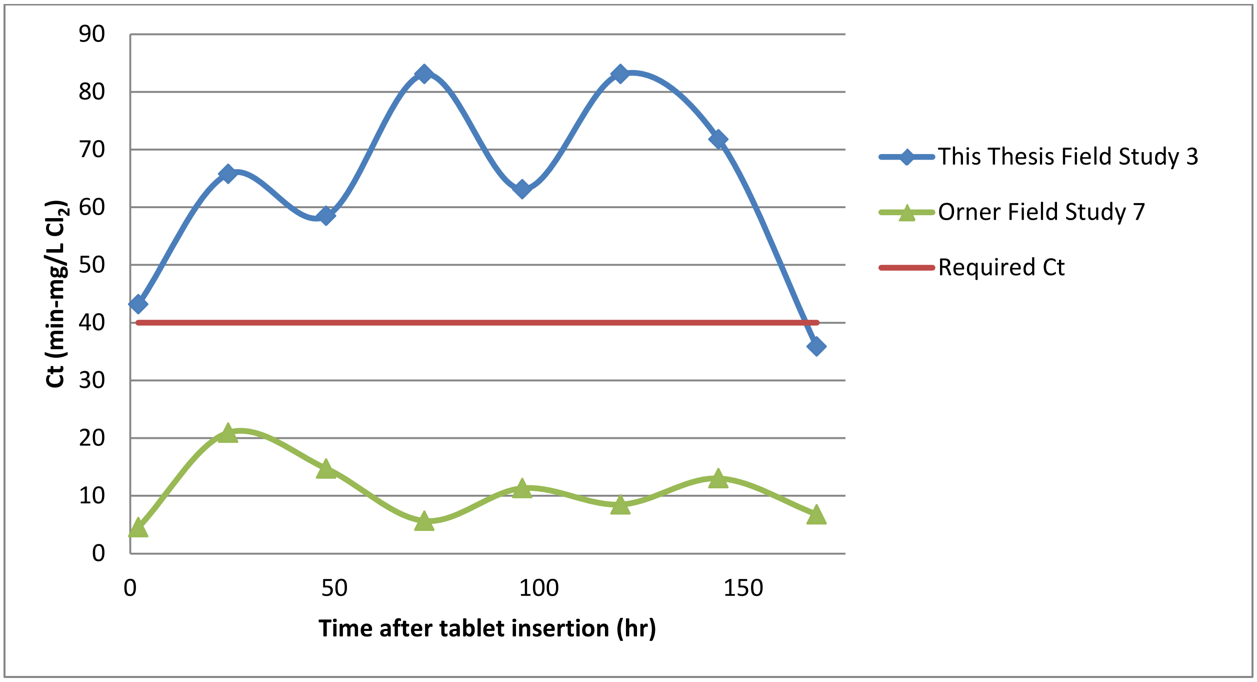


Figure 17: Comparison of the Calculated Ct Values Over One Week for Field Study 3 of This Thesis to Field Study 7 from Orner (2011). Also Displayed is the Required Ct Level to Eliminate Regional Waterborne Pathogens. Both Studies Used Three Chlorine Tablets Inserted into a MINSA Designed in-line Chlorinator and Both had Similar Measured Influent Flowrates – Orner's Flowrate was 15.9 gallons per minute and the Flowrate of Field Study 3 was 12.5 gallons per minute.

The new implementation method would note that the Ct values calculated for Orner's field study seven with his chlorination regimen were low and recommend another regimen where more chlorine tablets are added. This process of iteration would eventually lead to an effective chlorination regimen. Conversely the MINSA implementation method would continue with the first recommend regimen and therefore continue to ineffectively chlorinate.

Chapter 5: Conclusions and Recommendations

Access to safe drinking water has a direct effect on improving the health and quality of life of consumers. One country still struggling with providing access to safe drinking water to all of its residents is Panama. Panama’s largest indigenous group, the Ngöbe people, is disproportionately affected by lack of safe drinking water. One way Panama’s Ministry of Health (MINSA) is attempting to increase access to safe drinking water to the Ngöbe people is by disinfecting the water already captured by rural gravity fed water systems constructed within in the reservation inhabited by the Ngöbe people. To disinfect this water MINSA is using an in-line chlorinator specifically designed to accommodate locally manufactured calcium hypochlorite tablets as a source of chlorine.

The objectives of this study were to assess the current implementation method MINSA uses when adding an in-line chlorinator into a community’s gravity fed water distribution system and compare this implementation method to a new proposed implementation method that is derived from a newly developed field guide (Appendix F). These objectives were evaluated by investigating four connected hypotheses. Two hypotheses investigated the effectiveness of two different seminars at educating a community on chlorination. These seminars were presented to community members before a chlorinator was installed in their community and their effectiveness was evaluated using the *User Knowledge of Chlorination Survey*. The other two hypotheses investigated the efficacy of a MINSA chlorination method and a new chlorination method which were evaluated through field testing to determine if each method met chlorination requirements using the Ct method.

Section 5.1 presents the conclusions associated with the two hypotheses relating to the *User Knowledge of Chlorination Survey*. Section 5.2 presents the conclusions associated with the two hypotheses relating to achieving required Ct values for each chlorination implementation method. Section 5.3 presents recommendations for future field applications and Section 5.4 presents recommendations for future research.

5.1 Evaluation of Hypothesis 1 and 3 – Assessment of *User Knowledge of Chlorination Survey* for Attendees of the MINSA Seminar and the Newly Developed Seminar

Prior to installing MINSA's in-line chlorinator a seminar was presented to the studied community. Two different seminars were presented, the first by a MINSA technician and the second by the author of this thesis. Each seminar was evaluated on its ability to effectively educate a community on general knowledge of chlorination and specific knowledge of MINSA's in-line chlorinator. The assessment tool used to evaluate these seminars was the *User Knowledge of Chlorination Survey* which was administered to 12 attendees of each seminar. Effective education was assessed on a per question basis and qualified when 2/3's ≥ of respondents answer a given question correctly.

Hypothesis one investigated if the current chlorination seminar given by MINSA technicians was effective at educating communities on general knowledge of chlorination and specific knowledge of MINSA's in-line chlorinator. It was hypothesized that the seminar would be ineffective in this regard as the author of this thesis had seen the seminar previously presented to another community. Results showed that of the 14 questions in the "General Knowledge" section of the *User Knowledge of Chlorination Survey*, only 3 questions had ≥ 2/3's of respondents answer the question correctly. In the "MINSA Specific" section only 1 of the 8 questions had ≥ 2/3's of the respondents answer the question correctly. The average section scores for respondents answering questions correctly after the MINSA seminar were 35% for the "General Knowledge" section and 30% for the "MINSA Specific" section. The average total survey score for all respondents after the MINSA seminar was 33%. Therefore hypothesis one was accepted – the MINSA seminar was ineffective at educating communities on general knowledge of chlorination and specific knowledge of MINSA's in-line chlorinator.

Hypothesis three investigated if the new chlorination seminar developed and delivered by the author of this thesis and derived from a newly developed field guide was effective at educating communities on general knowledge of chlorination and specific knowledge of MINSA's in-line chlorinator. It was hypothesized that the seminar would be effective in this regard. Results showed that of the 14 questions in the "General Knowledge" section of the *User Knowledge of Chlorination Survey,* 9 questions had ≥ 2/3's of respondents answer the question correctly. In the "MINSA Specific" section 6 of the 8 questions had ≥ 2/3's of the respondents answer the question correctly. The average section scores for respondents answering questions correctly after the new seminar were 67% for the "General Knowledge" section and 73% for the "MINSA Specific" section. The average total survey score for all respondents after the new seminar was 69%. Therefore hypothesis three was accepted – the new seminar was effective at educating communities on general knowledge of chlorination and specific knowledge of MINSA's in-line chlorinator.

A comparison of the two surveys was also completed. Table 20 in Section 4.1.2 shows that respondents answered questions more correctly after the new seminar in both sections of the *User Knowledge of Chlorination Survey* and over the total survey in comparison to respondents who attended the MINSA seminar. This difference in correctly answering survey questions in each section and over the total survey was found to be statistically significant.

5.2 Evaluation of Hypothesis 2 and 4 – Assessment of the Efficacy of Two Different Chlorination Methods – the MINSA Method as Recommended by a MINSA Technician and the New Method as Developed in a New Field Guide

An investigation assessing the efficacy of two chlorination implementation methods was completed. An implementation method includes how a recommended chlorination regimen is developed, assessed and modified if necessary. A chlorination regimen dictates the amount of chlorine that is added to the chlorinator (e.g., the number of chlorine tablets) and the length of time these tablets are to remain in the chlorinator before they are replaced with new tablets. The efficacy of each method was assessed on the ability of the method to chlorinate effectively, after iterations if necessary. Effective chlorination was defined in this paper as the calculated Ct value of the effluent water leaving the storage tank to the distribution system at all times being ≥ 40 min-mg/L Cl_2.

Hypothesis two investigated if the chlorinator implementation method recommended by a MINSA technician would effectively chlorinate the studied community's gravity fed water distribution system. It was hypothesized that the current chlorinator implementation method as detailed in the MINSA chlorination seminar by a MINSA technician would ineffectively chlorinate the studied community's distribution system. Field study one evaluated this hypothesis and found that with the recommended two chlorine tablets inserted into the studied community's chlorinator the effluent flow from the storage tank to the distribution system had a free chlorine residual that varied from 0.020 - 0.195 mg/L Cl_2. This resulted in a range of calculated Ct values of 2.7 - 25.9 min-mg/L Cl_2. The Ct values never reached the required 40 min-mg/L Cl_2 level that would ensure disinfection of all targeted pathogens relevant to this area. Therefore hypothesis two was accepted – the chlorinator implementation method as detailed in the MINSA chlorination seminar by a MINSA technician ineffectively chlorinated the studied community's distribution system.

Hypothesis four investigated if the chlorinator implementation method developed in the new field guide allowed communities to effectively chlorinate their gravity fed water distribution systems. It was hypothesized that the chlorinator implementation method developed in the new field guide would allow the studied community to effectively chlorinate their distribution system. Field study three evaluated this hypothesis and concluded that with the recommended three chlorine tablets inserted into the studied community's chlorinator the effluent flow from the storage tank to the distribution system had a free chlorine residual that varied from 0.270 - 0.625 mg/L Cl_2. This resulted in a range of calculated Ct values from 35.9 - 83.0 min-mg/L Cl_2. The Ct values reached the required 40 min-mg/L Cl_2 level at all times except for on the last day where the calculated Ct value dipped below the required 40.0 min-mg/L Cl_2 level. However, this one day drop was not seen as significant as a Ct values below 40 min-mg/L Cl_2 but above 35 min-mg/L Cl_2 would provide an effective Ct value for all targeted pathogens but would not meet the 40 min-mg/L Cl_2 level that includes a safety factor of 5 min-mg/L Cl_2 (see discussion in Section 2.2.1). Therefore hypothesis four was accepted – the chlorinator implementation method developed in the new field guide allowed the studied community to effectively chlorinate their distribution system.

By comparison the new implementation method developed in the new field guide was more effective at chlorinating the studied systems gravity fed water distribution system. Also noteworthy is a discussion presented in Section 4.3 of data collected by Orner (2011) and its relevance to this thesis. Orner presented free chlorine residual data for a system with a similar flowrate to that of the field study's in this thesis. However when he used three chlorine tablets the calculated Ct values for the system over one week remained below the required level. In Section 4.3 it was explained that an advantage of the new implementation method was that it described how users could calculated running Ct values for their system throughout the week which would then allow them to compare these values to a Ct benchmark value (40.0 min-mg/L Cl_2) and determine if they need to adjust their chlorination regimen. The new method would have noted that the Ct values calculated for Orner's field study were low and therefore users would have adjusted their regimen to add more chlorine tablets. This process of iteration developed in the new implementation method would eventually lead to an effective chlorination regimen. Conversely the MINSA implementation method would continue with the first recommend regimen (as there is no built in iteration steps in this method) and therefore continue to ineffectively chlorinate. This comparison highlights a key shortcoming of the MINSA implementation method that the new implementation method improves on. The new method is dynamic compared to a MINSA method that is static and unable to adjust for varying conditions.

5.3 Recommendations for Future Field Applications

The author recommends the use of the newly developed field guide by both MINSA technicians and communities where it is applicable (in locations where community members have an adequate education level to use the field guide). This thesis serves as a first assessment of the developed field guide and concluded that it improves on the previous MINSA seminar by better educating communities not only on general knowledge relating to chlorination but also on knowledge specific to MINSA's in-line chlorinator. The author also recommends the use of the new field guide to develop a chlorination regimen, monitor the regimen and adjust the regimen if necessary. The iterative process of testing a regimen, monitoring the free residual of the regimen, and then adjusting the chlorination regimen if necessary is a key to successful chlorination when different communities have varying system characteristic (i.e., tank size, pipe diameters and length to the first house in the distribution system, flowrate, et cetera) and also differing water quality characteristics. The process of recommending the first starting regimen, monitoring, and then adjusting this regimen may be beyond the scope of many communities in the region. Therefore it is important for technicians to lead this process and stay in contact with communities that are chlorinating their systems. This would require all current MINSA technicians in the region to be trained on how to present the new seminar and then also trained on how to calculate Ct values. This training could be done in conjunction with the US Peace Corps who currently has volunteers within the region who are knowledgeable of how to present the current new seminar and how to properly calculate Ct values from measured free chlorine samples.

The author recommends that the field guide is expanded as new better methods are developed to teach community members about chlorination and how to best chlorinate their water systems. Specifically visual aids should be added to the field guide that could be used to educate illiterate community members. These aids could be in the form of pictures or videos describing a specific process such as how to add a chlorine tablet to the chlorinator or how to measure the free chlorine residual at a sample location.

It is recommended that MINSA technicians install the chlorinator with the water committee of each community that plans on using the chlorinator. This is to insure the chlorinator is positioned at an appropriate location (before the storage tank) and any adjustments to the chlorinator can be made if necessary. This also allows the technician the ability to discuss with the water committee if a different chlorinator installation configuration is needed. Many systems that are capturing water from surface water sources need to install the chlorinator with a bypass line so that if the chlorinator becomes clogged with debris the bypass line can be used while the chlorinator is cleaned. This is explained in the new field guide but the installation is somewhat complicated and may be beyond the scope of many communities. The recommendation of having a MINSA technician install the chlorinator with the community and actively show them how to add a chlorine tablet and maintain the chlorinator through activities and not just in a seminar is based on the idea of how experiential learning is important in many communities where the majority of residents are illiterate. As these activities are developed and refined they should be added into the field guide and be an integral part of future implementations of the chlorinator.

It is recommended that communities located on the Pacific side of the Cordillera mountain range where there is a distinct dry season manage the effluent flow leaving their storage tank during the dry season to maximize the chlorine contact time. Currently there are two common practices to manage water for a community water system during the dry season when community water demand exceeds the amount of water available. The first is to leave the exit valve of the storage tank open allowing users to use all of the water available when there is any water available. This results in the storage tank continually remaining empty and a very low flow of water to the community. The second common practice is to shut off the exit valve of the storage tank for 22-23 hours, allow the tank to fill for an entire day and night and then open the exit valve once every day for 1-2 hours. This allows the tank to fill and provides a large flow to all houses in the community but only for a short period of time. It is recommended that the second management approach be implemented when using MINSA’s in-line chlorinator. The first approach allows for only a very short chlorine contact time where the second approach allows for a much longer contact time. The result would mean a larger calculated Ct value for the second water management approach compared to the first. This second approach should therefore allow for better disinfection of water.

It is recommended that MINSA technicians install chlorinators in clusters of 3-4 communities close to each other at one time. MINSA technicians are normally only allotted 2-3 days to present a chlorination seminar and monitor a single system. This is an insufficient time to see if a recommended regimen is effective as the final days in a regimen's week are often critical in determining if the free residual in the system will hit a low value. By clustering installation of chlorinators to several communities close to each other a technician could allot an entire week to several communities and monitor the residual at all communities for an entire week.

Finally, it is recommended that MINSA technicians start to compile records of past successful chlorination regimens in different communities. Technicians should record varying system characteristic, varying water quality characteristics, the regimen they recommended, and then record the resultant free residual they found. If a detailed record is made of past implementations technicians can start to have better first guesses on their first recommended regimen to a community. This will reduce the number of iterations necessary to come to an effective chlorination regimen and save time and money on continual monitoring.

5.4 Recommendations for Future Research

Future research investigating how the MINSA chlorinator functions under variable system and water quality conditions would be useful to technicians. Specifically research investigating how the MINSA chlorinator functions during storm events when surface waters are inundated with particulate matter and other debris would be useful. This may lead to a future recommendation that all systems require some type of filtration prior to chlorination. Filtering water is currently a common practice in the developed world when water is turbid as increased turbidity causes an increase in chlorine demand and therefore a decrease in chlorine residual (see Section 4.2.5).

When the author was installing the MINSA in-line chlorinator in another community not studied in this thesis the chlorinator was found to be unusable in systems with a much larger flowrate than studied in this thesis (> 20 gallons per minute). This flowrate produced a significant amount of increased pressure on the chlorinator. This resulted in a reduced flow through the chlorinator that was significant enough to be easily visible to members of the water committee of this community. This resulted in the community not wanting the chlorinator to be used in their system. Research could be done looking at another type of chlorinator that uses the same chlorine tablets as the MINSA in-line chlorinator for these types of systems (e.g., pot / floating chlorinators).

Finally dynamic modeling of the MINSA in-line chlorinator in distribution systems could be investigated to better understand how systems using this technology function. Modeling of chlorine in water distribution systems has been investigated in past studies (e.g., Rodriguez et al., 2004; Liu et al., 2010; Brown et al., 2011); however, modeling of free chlorine residual in rural gravity fed systems in the developing world does not currently exist in literature.

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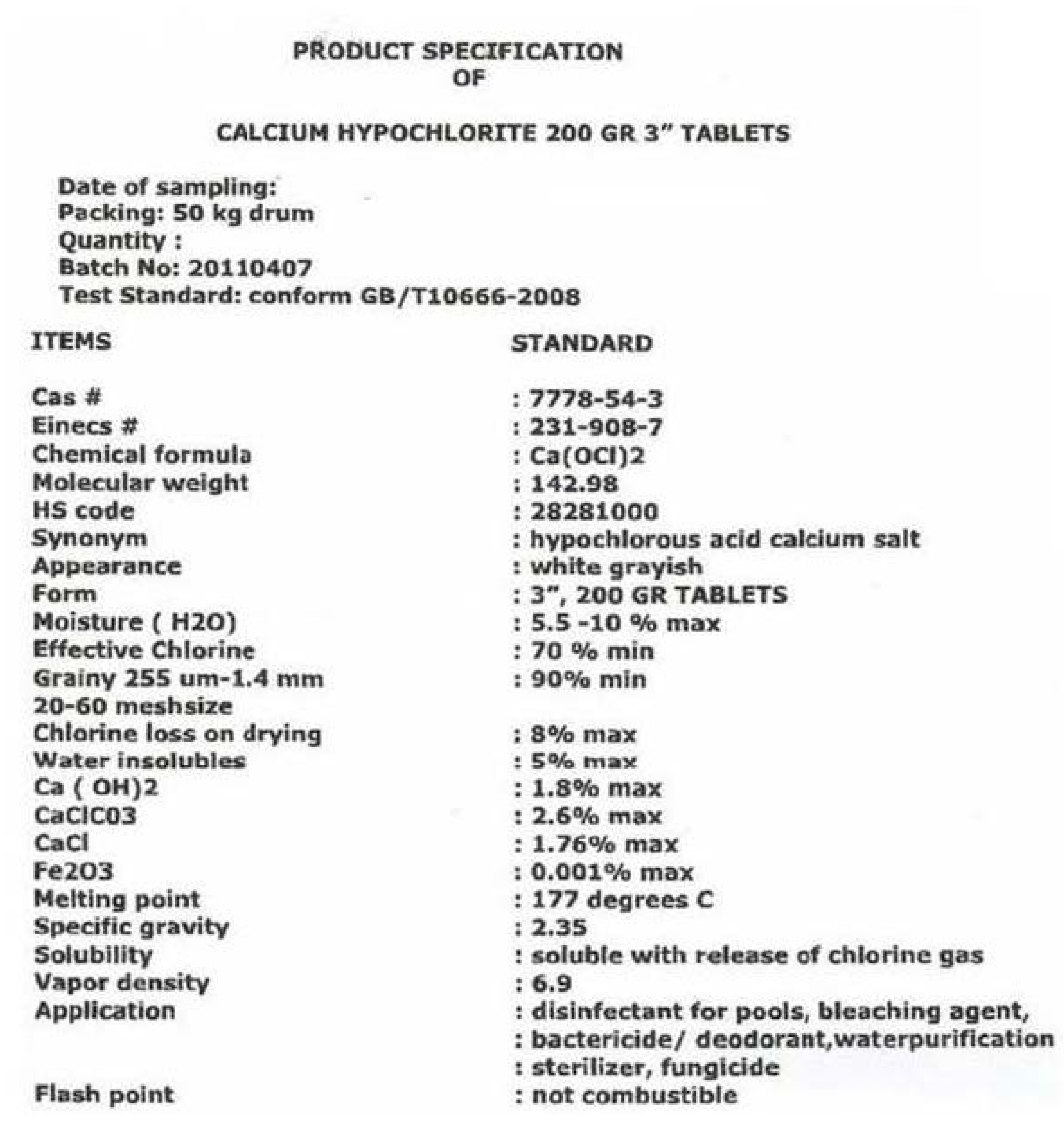
Appendices

Appendix A: Productos Químicos IBIS Data Sheet



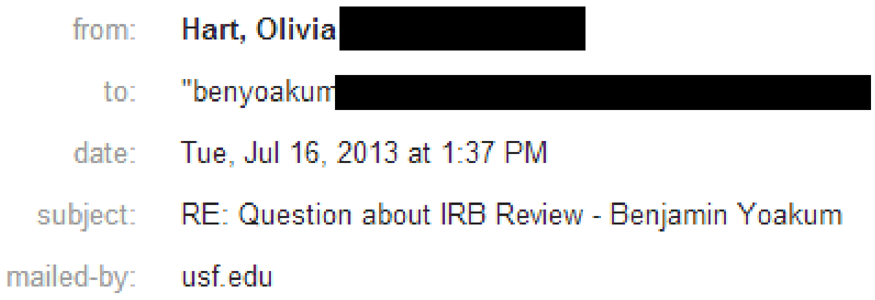
PRODUCT SPECIFICATION
OF

CALCIUM HYPOCHLORITE 200 GR 3" TABLETS

Date of sampling:
Packing: 50 kg drum
Quantity :
Batch No: 20110407
Test Standard: conform GB/T10666-2008

ITEMS	STANDARD
Cas #	: 7778-54-3
Einecs #	: 231-908-7
Chemical formula	: Ca(OCl)2
Molecular weight	: 142.98
HS code	: 28281000
Synonym	: hypochlorous acid calcium salt
Appearance	: white grayish
Form	: 3", 200 GR TABLETS
Moisture (H2O)	: 5.5 -10 % max
Effective Chlorine	: 70 % min
Grainy 255 um-1.4 mm	: 90% min
20-60 meshsize	
Chlorine loss on drying	: 8% max
Water insolubles	: 5% max
Ca (OH)2	: 1.8% max
CaClC03	: 2.6% max
CaCl	: 1.76% max
Fe2O3	: 0.001% max
Melting point	: 177 degrees C
Specific gravity	: 2.35
Solubility	: soluble with release of chlorine gas
Vapor density	: 6.9
Application	: disinfectant for pools, bleaching agent, : bactericide/ deodorant,waterpurification : sterilizer, fungicide
Flash point	: not combustible

Appendix B: Email Correspondence - IRB Approval



from: **Hart, Olivia** [redacted]

to: "benyoakum [redacted]

date: Tue, Jul 16, 2013 at 1:37 PM

subject: RE: Question about IRB Review - Benjamin Yoakum

mailed-by: usf.edu

Dear Mr. Yoakum,
[redacted] forwarded your email to me for a response. Your assessment is correct so I would provide you the same response that [redacted] probably received. As defined by the federal regulations, a human subject is a living individual about whom an investigator conducting research obtains data through intervention or interaction with the individual or identifiable private information. Research is defined as a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge. For a project to include human subjects research which is under the purview of the USF IRB, both of the definitions outlined above must be met.

As your study is not collecting information about individuals, I do not feel that this meets the definition of human subjects research thereby requiring IRB approval. Should the scope of your project expand, you should contact the IRB to see if the expansion crosses into the definition of human subjects research requiring IRB review and approval. If you have any questions or concerns, please feel free to contact me.

Thank you,

Olivia Hart, MPA, CIP
IRB Education Coordinator
Research Integrity & Compliance
Phone: [redacted]
FAX: [redacted]
USF IRB website: http://www3.research.usf.edu/dric/hrpp/

Appendix C: *User Knowledge of Chlorination Survey* (English Translation)

General Knowledge of Chlorination Questions:

1) What does water have in it that sometimes makes people sick?
2) Why do some communities chlorinate water?
3) If you can smell chlorine in the water you receive from your tap is/can the water be safe to consume?
4) If you can taste chlorine in the water you receive from your tap is/can the water be safe to consume?
5) How can you tell if there is too much chlorine in the water and it is unsafe to drink?
6) Can chlorine kill or remove the following things found in water; if you do not know one of the items listed please say so:
    a) Dirt?
    b) Algae?
    c) Viruses?
    d) Microbes / Bacteria?
7) What two factors determine whether chlorine will be able to kill microbes in your aqueduct's distribution system?
8) What does chlorine concentration refer to?
9) What does chlorine contact time refer to?
10) What can prevent water from being properly chlorinated?
11) If you want to store water in your household how should you store it?

MINSA Specific Questions:

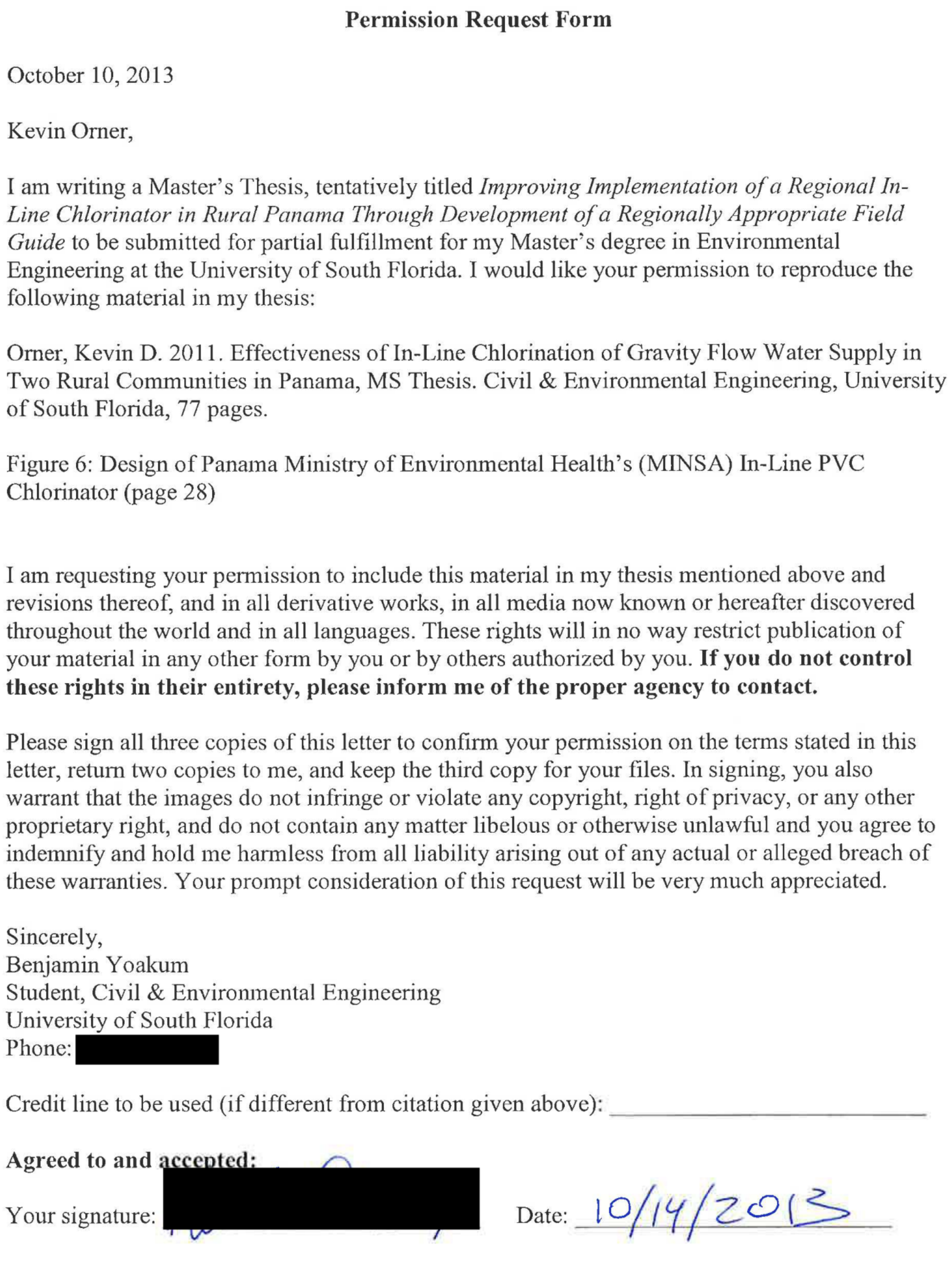
1) Where should you install the in-line chlorinator?
2) How many chlorine tablets are you going to use at one time in the chlorinator?
3) How many days or weeks will these tablet(s) last?
4) Where can you buy a new chlorinator if your current chlorinator breaks?
5) Where can you get new chlorine tablets?
6) If you need assistance with your chlorinator who can you call for help?
7) How often do you need to clean/maintenance the chlorinator?
8) How can you clean/maintenance the chlorinator?

Appendix D: Free Chlorine Residuals Not Provided In Results Chapter

Table D1: Field Study 2 – Three Tablets Inserted into Chlorinator Over One Week – Measured Free Chlorine Concentrations at: Influent and Effluent Pipes of the Storage Tank; First and Last House in the Water Distribution System

Time Sample was Collected	Free Chlorine Concentration (mg/L Cl_2)			
	Influent	Effluent	First House	Last House
Hour 2	0.95	0.68	0.77	0.30
Day 1	0.21	0.06	0.05	0.00
Day 2	0.00	0.01	0.05	0.00
Day 3	0.27	0.22	0.19	0.03
Day 4	0.47	0.31	0.35	0.14
Day 5	0.32	0.26	0.27	0.16
Day 6	0.23	0.19	0.19	0.21
Day 7	0.29	0.21	0.22	0.25

Appendix E: Permission to Reproduce Figure from Orner 2011



Permission Request Form

October 10, 2013

Kevin Orner,

I am writing a Master's Thesis, tentatively titled *Improving Implementation of a Regional In-Line Chlorinator in Rural Panama Through Development of a Regionally Appropriate Field Guide* to be submitted for partial fulfillment for my Master's degree in Environmental Engineering at the University of South Florida. I would like your permission to reproduce the following material in my thesis:

Orner, Kevin D. 2011. Effectiveness of In-Line Chlorination of Gravity Flow Water Supply in Two Rural Communities in Panama, MS Thesis. Civil & Environmental Engineering, University of South Florida, 77 pages.

Figure 6: Design of Panama Ministry of Environmental Health's (MINSA) In-Line PVC Chlorinator (page 28)

I am requesting your permission to include this material in my thesis mentioned above and revisions thereof, and in all derivative works, in all media now known or hereafter discovered throughout the world and in all languages. These rights will in no way restrict publication of your material in any other form by you or by others authorized by you. **If you do not control these rights in their entirety, please inform me of the proper agency to contact.**

Please sign all three copies of this letter to confirm your permission on the terms stated in this letter, return two copies to me, and keep the third copy for your files. In signing, you also warrant that the images do not infringe or violate any copyright, right of privacy, or any other proprietary right, and do not contain any matter libelous or otherwise unlawful and you agree to indemnify and hold me harmless from all liability arising out of any actual or alleged breach of these warranties. Your prompt consideration of this request will be very much appreciated.

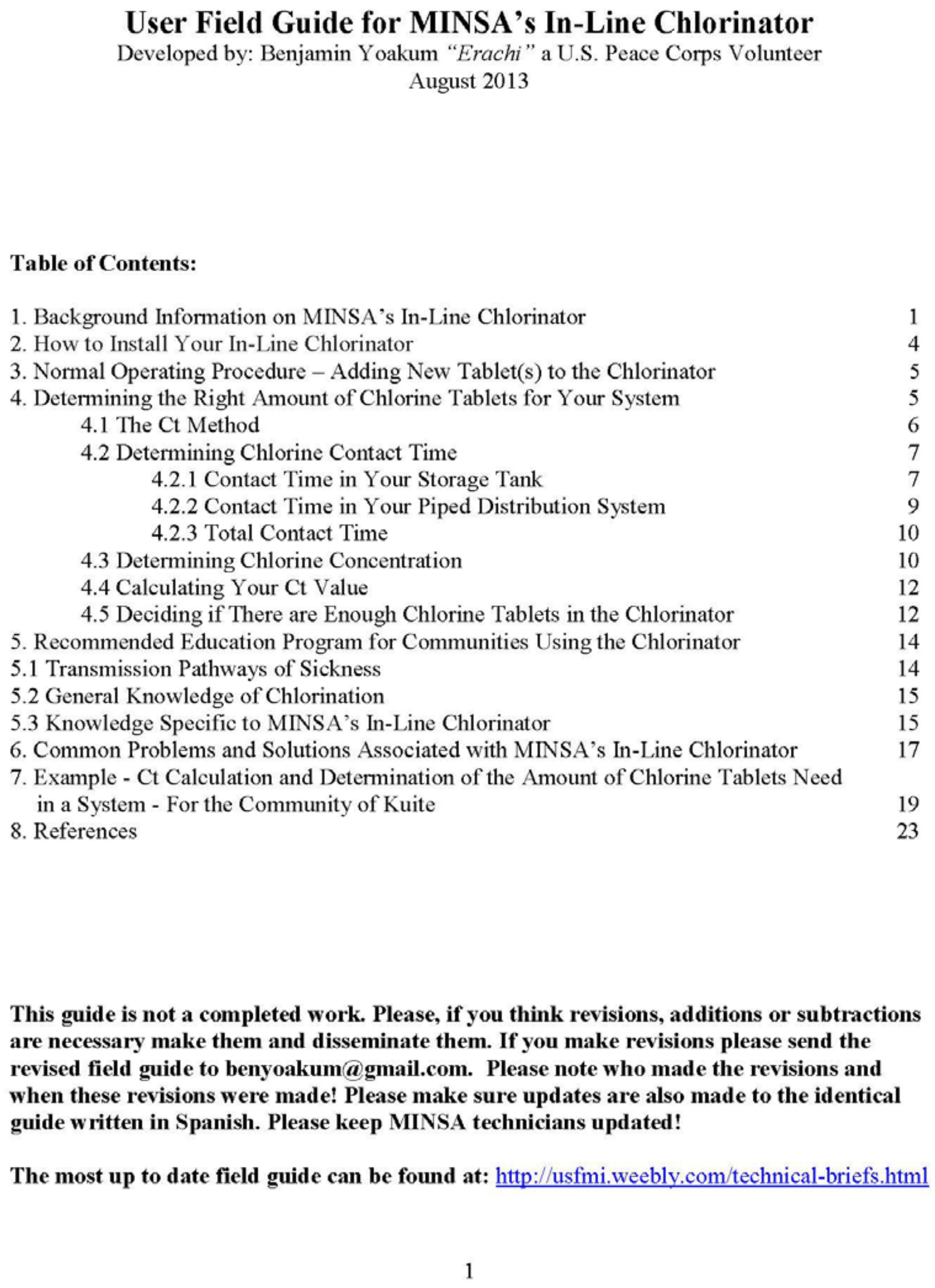
Sincerely,
Benjamin Yoakum
Student, Civil & Environmental Engineering
University of South Florida
Phone: [redacted]

Credit line to be used (if different from citation given above): ____________________

Agreed to and accepted:

Your signature: [redacted] Date: 10/14/2013

Appendix F: Developed User Field Guide for MINSA's In-Line Chlorinator



User Field Guide for MINSA's In-Line Chlorinator

Developed by: Benjamin Yoakum *"Erachi"* a U.S. Peace Corps Volunteer
August 2013

Table of Contents:

This guide is not a completed work. Please, if you think revisions, additions or subtractions are necessary make them and disseminate them. If you make revisions please send the revised field guide to benyoakum@gmail.com. Please note who made the revisions and when these revisions were made! Please make sure updates are also made to the identical guide written in Spanish. Please keep MINSA technicians updated!

The most up to date field guide can be found at: http://usfmi.weebly.com/technical-briefs.html

Appendix F (Continued)

1. Background Information on MINSA's In-Line Chlorinator:

MINSA's in-line chlorinator is an instrument that adds chlorine to rural gravity fed water supply systems. The term "in-line" designates that the chlorinator is connected directly to the polyvinyl chloride (PVC) pipe that is transporting water from the catchment source to the storage/distribution tank. The chlorinator is attached 2-5 meters before the storage tank to the influent PVC pipe. The in-line chlorinator, shown in Figure 1, is made entirely of PVC.

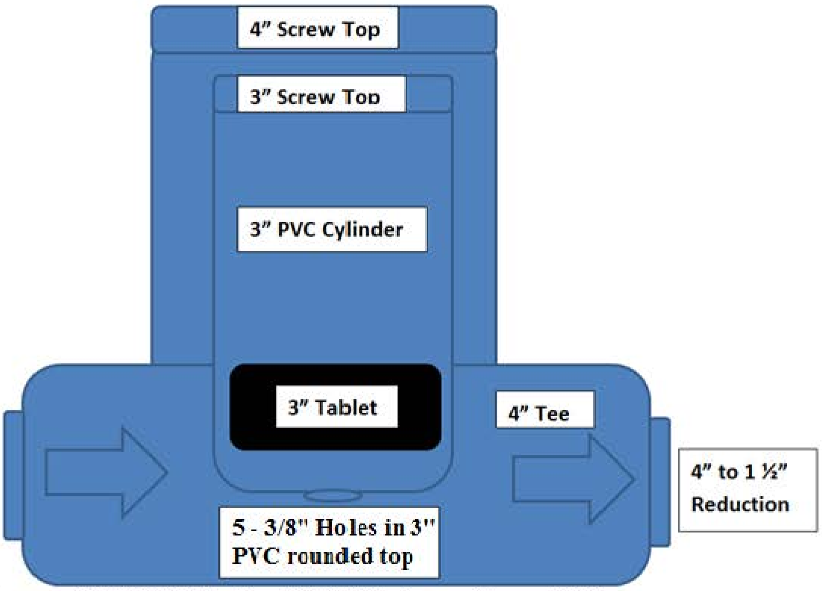
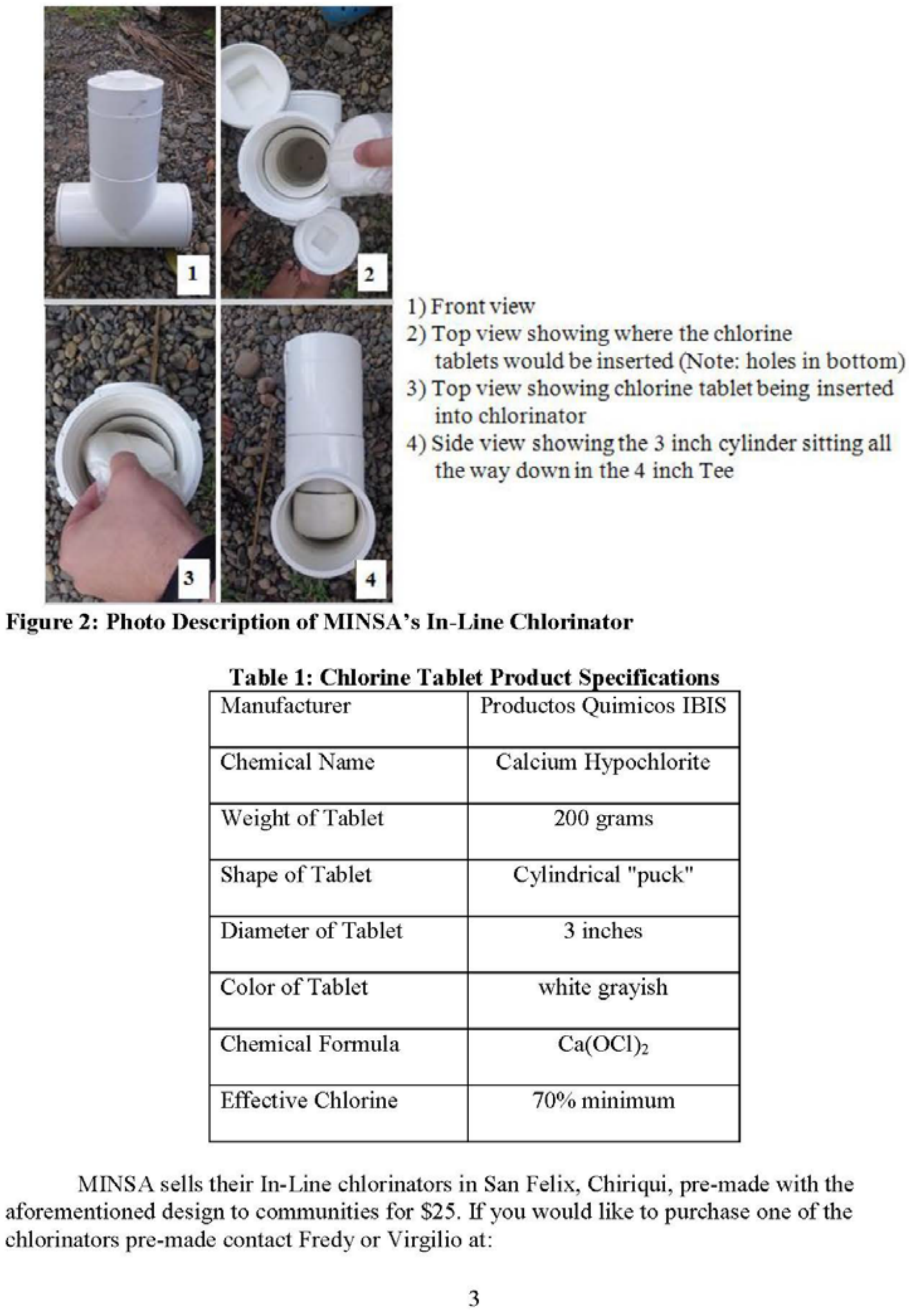


Figure 1: Diagram of MINSA's In-Line PVC Chlorinator (Orner, 2011)

The chlorinator is made of a 4-inch Tee that has a small segment of 4-inch PVC on the upper Tee which is then closed off by a 4-inch screw top. A 3-inch cylinder (made from 3-inch PVC pipe) is inserted into the 4-inch Tee being accessed by the screw top. This cylinder consists of a 3-inch rounded top that faces down and a 3-inch screw top that faces up toward the 4-inch screw top. Five holes that are approximately 3/8 inch in diameter are drilled into the bottom 3-inch rounded top. This entire 3-inch cylinder is glued into place inside the 4-inch Tee. A chlorine tablet(s) is added by removing both screw tops and placing the chlorine tablet(s) into the 3-inch cylinder and then closing the screw tops. This chlorinator can be attached to different size pipes by reducing the two ends of the 4-inch Tee to the size of the influent pipe. For example in Figure 1 the influent and effluent PVC pipes are stated to be 1.5 inches. Figure 2 shows an unconnected in-line chlorinator and Table 1 provides details of the chlorine tablets used in MINSA's in-line chlorinator.

Appendix F (Continued)



1) Front view
2) Top view showing where the chlorine tablets would be inserted (Note: holes in bottom)
3) Top view showing chlorine tablet being inserted into chlorinator
4) Side view showing the 3 inch cylinder sitting all the way down in the 4 inch Tee

Figure 2: Photo Description of MINSA's In-Line Chlorinator

Table 1: Chlorine Tablet Product Specifications

Manufacturer	Productos Quimicos IBIS
Chemical Name	Calcium Hypochlorite
Weight of Tablet	200 grams
Shape of Tablet	Cylindrical "puck"
Diameter of Tablet	3 inches
Color of Tablet	white grayish
Chemical Formula	$Ca(OCl)_2$
Effective Chlorine	70% minimum

MINSA sells their In-Line chlorinators in San Felix, Chiriqui, pre-made with the aforementioned design to communities for $25. If you would like to purchase one of the chlorinators pre-made contact Fredy or Virgilio at:

3

Appendix F (Continued)

Fredy: [redacted]
Virgilio: [redacted]

It is strongly recommended that you purchase your chlorinator directly from MINSA as they have more experience constructing them and will most likely be cheaper for your community as 3" and 4" pipes are expensive to purchase.

2. How to Install Your In-Line Chlorinator:
There are a few items you will need before attempting to install your in-line chlorinator:

1) Hacksaw – for cutting pipe
2) PVC Glue – a small bottle should be adequate
3) PVC shutoff valve – this needs to be the same size of the pipe where you are putting in the chlorinator
4) 2 reductions from 2" to the size of pipe where you are putting in the chlorinator
5) Teflon tape or a rubber 3" gasket (to seal the screw tops)
6) A MINSA In-Line Chlorinator

When installing the chlorinator you want select a location that is close to the storage tank but also on level ground. You can put the chlorinator further up the line (closer to your source and farther from the storage tank) but you need to consider the future additional work added to the operator to walk farther from the tank every week when adding a new chlorine tablet(s).

Once you have decided on a location for the chlorinator you need to turn off the water upstream of where you are planning to install the chlorinator. When the water is off cut the pipe and glue in the new shutoff valve first and then the chlorinator second (closer to the tank). There should be a few feet separating the shutoff valve from the chlorinator. This allows the user to easily replace the valve or the chlorinator without needing to replace both if only one breaks. See figure 3 for a visual description of this installation.

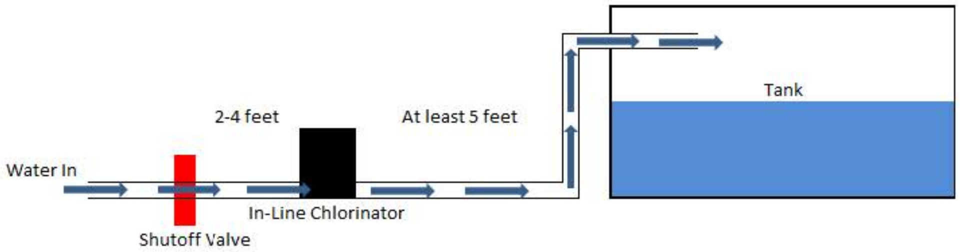


Figure 3: Location of Shutoff Valve, Chlorinator and Tank

The chlorinator if purchased from MINSA in San Felix comes with 2 reductions from 4" to 2" but users may need another 2 reductions from 2" to the size of the pipe that is located at the installation site. For example if the pipe where you are installing the chlorinator is 1½" then you will need to buy and glue in the two 2" to 1½" reductions to the pre-made chlorinator. The user also needs to apply Teflon tape or rubber gaskets to each of the screw tops. Without applying this water will leak out of the top of the chlorinator through the screw tops. The gaskets are a better option if your water committee has the money and can find them in a hardware store. If you cannot afford or cannot find the gaskets Teflon tape will work fine but you will need to reapply the tape once every 3-6 months as the tape will naturally start coming off after repeated use. Also it may be necessary to physically support the chlorinator so that it does not fall over or tilt from side to side. This can be done by using sticks, rocks or even partially burying the chlorinator so only the top Tee portion is visible.

The installation method listed above will work for most systems however if you are capturing water from a stream source and a significant amount of debris is entering your storage tank your chlorinator may clog often. If this is the case you should set up your system differently to account for the possibility of your chlorinator clogging. Please see the discussion of this topic in Section 5.3.

3. Normal Operating Procedure – Adding New Tablet(s) to the Chlorinator

Now that your chlorinator is installed you are ready to start chlorinating. To chlorinate effectively you need to add new chlorine tablet(s) to the chlorinator once a week. Therefore, the aqueduct operator or committee managing the aqueduct needs to schedule a set day and time to add the new chlorine tablet(s). It is important that the tablet(s) are added on the same day and time every week. For example you may choose 6am every Monday to add a new tablet(s). When the operator is at the chlorinator he needs to follow the following procedure to add new tablet(s):

1) Shut off the water coming to the chlorinator using the shutoff valve next to the chlorinator
2) Remove both screw tops
3) Remove any excess chlorine tablets that may be left in the chlorinator
4) Insert the new chlorine tablet(s)
5) Close both screw tops (add additional Teflon tape if necessary)
6) Reopen the shutoff valve

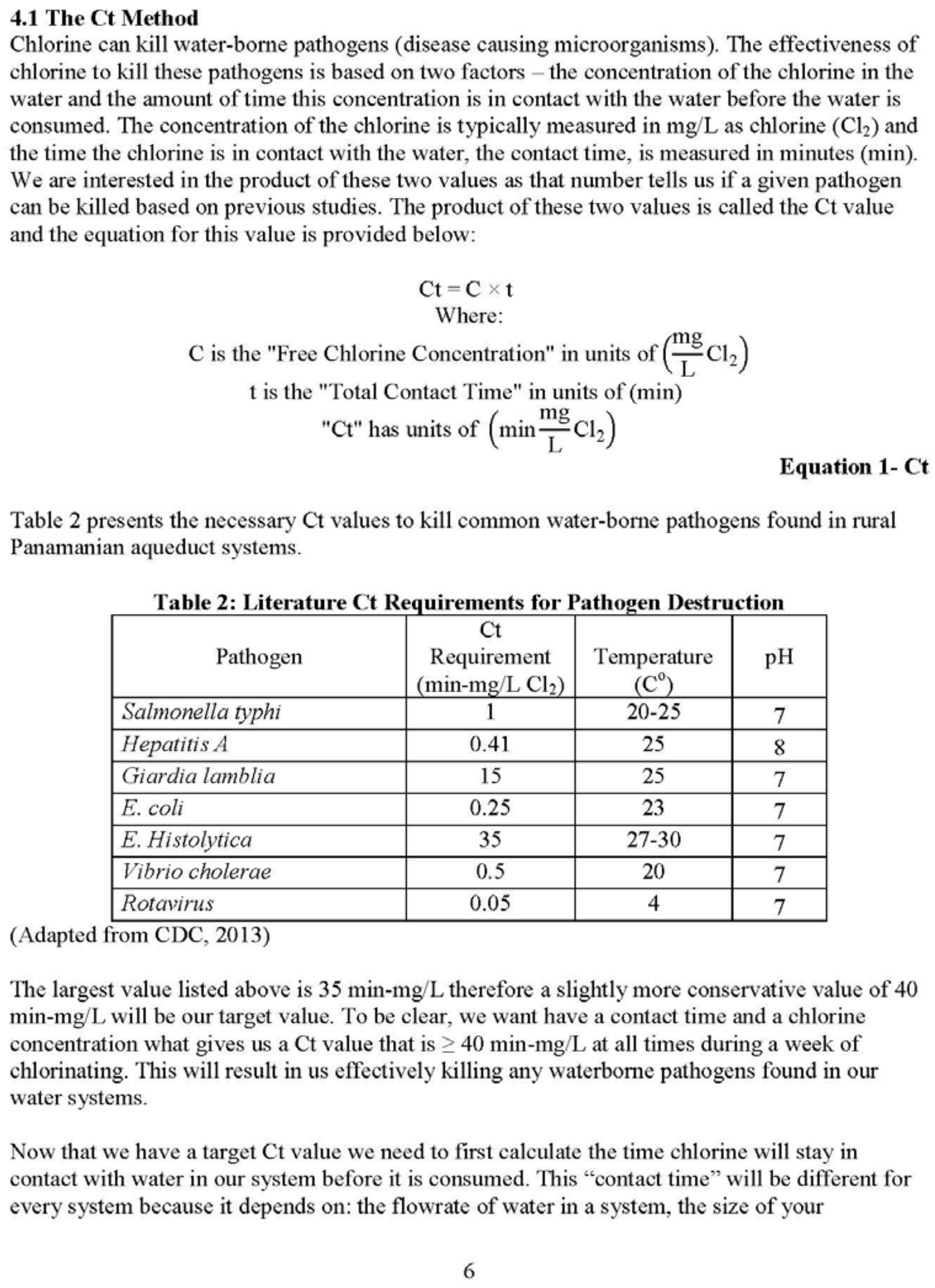
Chlorine Tablets:

Chlorine tablets can be obtained from your local MINSA technician. Currently the tablets are free of charge in the Comarca Ngöbe-Bugle and in other Provinces they are being sold for $2 per tablet. The tablets should be handled with care so they do not break. It is also recommended to use a piece of plastic or paper when handling the tablets. This is because the chlorine tablet if in direct contact to skin can cause a mild itchy/burning sensation and will leave an odor on your hands.

4. Determining the Right Amount of Chlorine Tablets for Your System

Determining the correct amount of chlorine tablets to use for your system is important. Using too little chlorine allows for poor disinfection and the possibility for the water in your aqueduct to remain contaminated. Using too much chlorine can leave an unwanted taste and odor in your water and in extreme cases can have negative health effects. The process of determining the right amount of chlorine tablets is somewhat complicated and should be done with your local MINSA technician. The process of determining how many chlorine tablets you should use in your system is described in this field guide. If you are interested in how this process was derived or are interested in the chemistry of this process refer to the references listed at the end of this guide.

Appendix F (Continued)



4.1 The Ct Method

Chlorine can kill water-borne pathogens (disease causing microorganisms). The effectiveness of chlorine to kill these pathogens is based on two factors – the concentration of the chlorine in the water and the amount of time this concentration is in contact with the water before the water is consumed. The concentration of the chlorine is typically measured in mg/L as chlorine (Cl_2) and the time the chlorine is in contact with the water, the contact time, is measured in minutes (min). We are interested in the product of these two values as that number tells us if a given pathogen can be killed based on previous studies. The product of these two values is called the Ct value and the equation for this value is provided below:

$$
\begin{gathered}
\mathrm{Ct} = \mathrm{C} \times \mathrm{t} \\
\text{Where:} \\
\text{C is the "Free Chlorine Concentration" in units of } \left(\frac{\mathrm{mg}}{\mathrm{L}}\mathrm{Cl_2}\right) \\
\text{t is the "Total Contact Time" in units of (min)} \\
\text{"Ct" has units of } \left(\mathrm{min}\frac{\mathrm{mg}}{\mathrm{L}}\mathrm{Cl_2}\right)
\end{gathered}
$$

Equation 1- Ct

Table 2 presents the necessary Ct values to kill common water-borne pathogens found in rural Panamanian aqueduct systems.

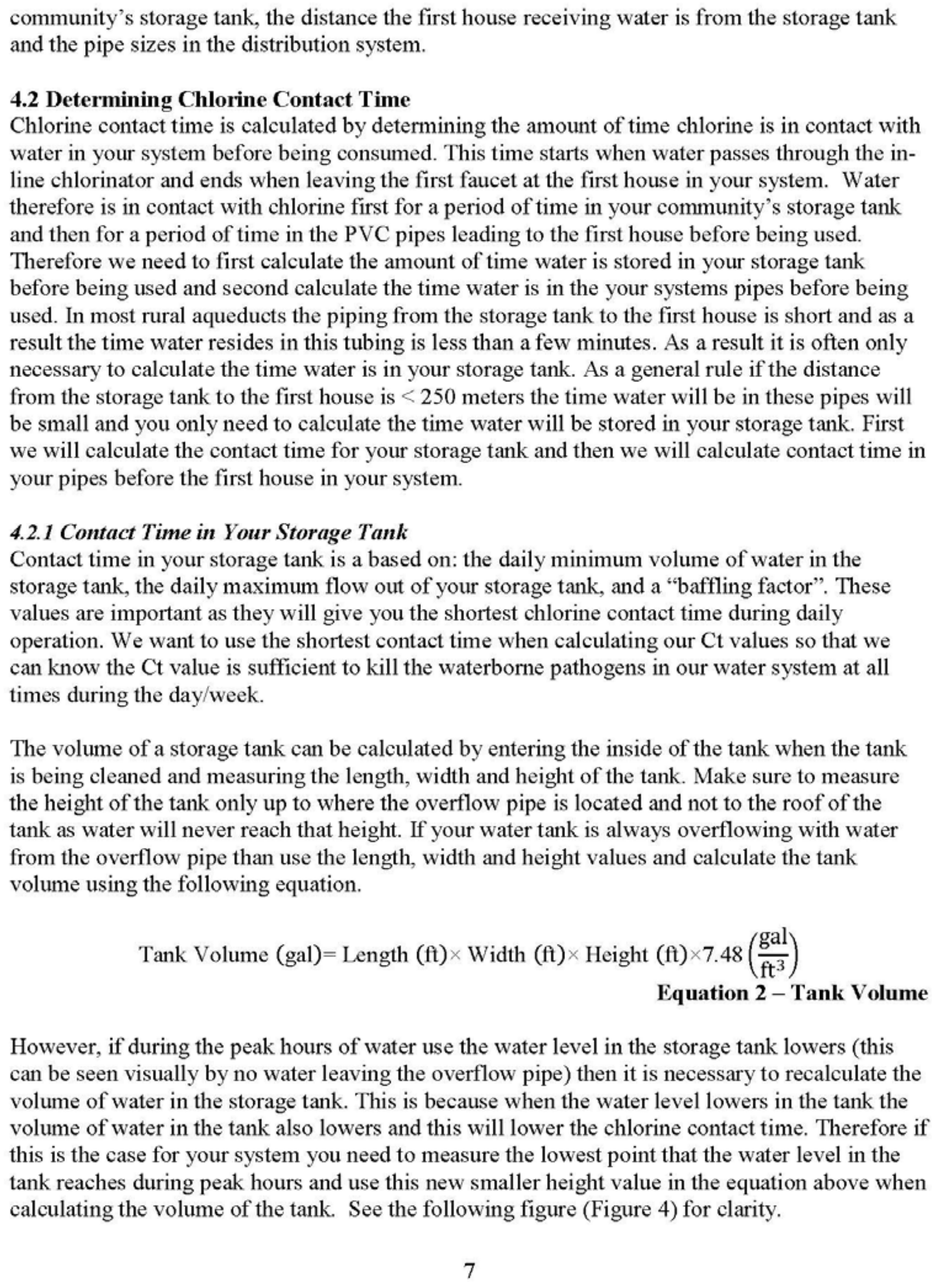
Table 2: Literature Ct Requirements for Pathogen Destruction

Pathogen	Ct Requirement (min-mg/L Cl_2)	Temperature (C^o)	pH
Salmonella typhi	1	20-25	7
Hepatitis A	0.41	25	8
Giardia lamblia	15	25	7
E. coli	0.25	23	7
E. Histolytica	35	27-30	7
Vibrio cholerae	0.5	20	7
Rotavirus	0.05	4	7

(Adapted from CDC, 2013)

The largest value listed above is 35 min-mg/L therefore a slightly more conservative value of 40 min-mg/L will be our target value. To be clear, we want have a contact time and a chlorine concentration what gives us a Ct value that is ≥ 40 min-mg/L at all times during a week of chlorinating. This will result in us effectively killing any waterborne pathogens found in our water systems.

Now that we have a target Ct value we need to first calculate the time chlorine will stay in contact with water in our system before it is consumed. This "contact time" will be different for every system because it depends on: the flowrate of water in a system, the size of your



community's storage tank, the distance the first house receiving water is from the storage tank and the pipe sizes in the distribution system.

4.2 Determining Chlorine Contact Time

Chlorine contact time is calculated by determining the amount of time chlorine is in contact with water in your system before being consumed. This time starts when water passes through the in-line chlorinator and ends when leaving the first faucet at the first house in your system. Water therefore is in contact with chlorine first for a period of time in your community's storage tank and then for a period of time in the PVC pipes leading to the first house before being used. Therefore we need to first calculate the amount of time water is stored in your storage tank before being used and second calculate the time water is in the your systems pipes before being used. In most rural aqueducts the piping from the storage tank to the first house is short and as a result the time water resides in this tubing is less than a few minutes. As a result it is often only necessary to calculate the time water is in your storage tank. As a general rule if the distance from the storage tank to the first house is < 250 meters the time water will be in these pipes will be small and you only need to calculate the time water will be stored in your storage tank. First we will calculate the contact time for your storage tank and then we will calculate contact time in your pipes before the first house in your system.

4.2.1 Contact Time in Your Storage Tank

Contact time in your storage tank is a based on: the daily minimum volume of water in the storage tank, the daily maximum flow out of your storage tank, and a "baffling factor". These values are important as they will give you the shortest chlorine contact time during daily operation. We want to use the shortest contact time when calculating our Ct values so that we can know the Ct value is sufficient to kill the waterborne pathogens in our water system at all times during the day/week.

The volume of a storage tank can be calculated by entering the inside of the tank when the tank is being cleaned and measuring the length, width and height of the tank. Make sure to measure the height of the tank only up to where the overflow pipe is located and not to the roof of the tank as water will never reach that height. If your water tank is always overflowing with water from the overflow pipe than use the length, width and height values and calculate the tank volume using the following equation.

$$\text{Tank Volume (gal)} = \text{Length (ft)} \times \text{Width (ft)} \times \text{Height (ft)} \times 7.48 \left(\frac{\text{gal}}{\text{ft}^3}\right)$$

Equation 2 – Tank Volume

However, if during the peak hours of water use the water level in the storage tank lowers (this can be seen visually by no water leaving the overflow pipe) then it is necessary to recalculate the volume of water in the storage tank. This is because when the water level lowers in the tank the volume of water in the tank also lowers and this will lower the chlorine contact time. Therefore if this is the case for your system you need to measure the lowest point that the water level in the tank reaches during peak hours and use this new smaller height value in the equation above when calculating the volume of the tank. See the following figure (Figure 4) for clarity.

Appendix F (Continued)

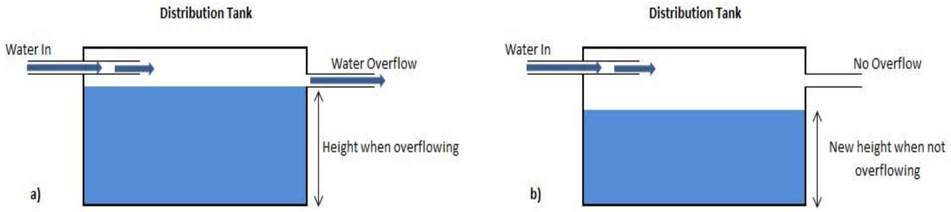


Figure 4: Height of Water When: a) Water is overflowing b) Water is not overflowing

Next we need to calculate the maximum flow rate of water out of the tank on a normal day of use. This maximum flow rate will normally coincide with the minimum water level in the distribution tank. To calculate the maximum flow rate measure the water level in the tank every 30 minutes during the time period you expect users to use the most water. Typically this is in the morning when everyone is cooking breakfast, bathing and getting ready for the day or in the mid to late afternoon. After you have measured the water level a couple of times, identify the value that has the largest change in the level of water over a given 30 minute time interval. A representation of this change in water level can be seen in Figure 5:

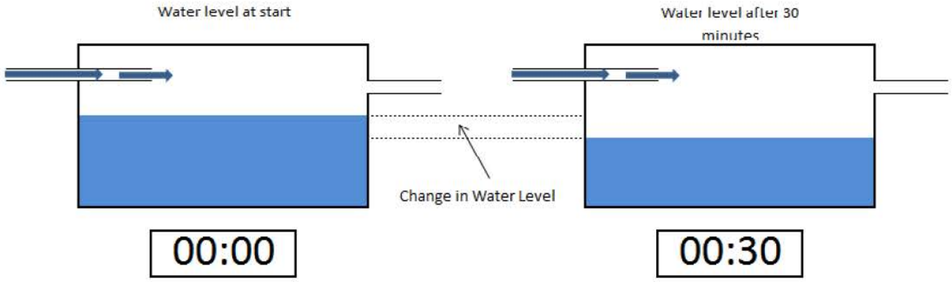


Figure 5: Change in water level over a given 30 minute interval

For example in Figure 5 at time 00:00 the water height might be 5 feet and 30 minutes later at time 00:30 the height of water in the tank might be 4.5 feet. The change in the height of water would therefore be: 5 feet - 4.5 feet = 0.5 feet. This value will be referred to as the “change in water level” in Equation 3.

Use the length and width values you previously calculated for the total tank volume along with the “change in water level” value to calculate the maximum flow rate by using the following formula:

$$\text{Max Flow Rate}\left(\frac{\text{gal}}{\text{min}}\right) =$$

$$\frac{\text{Length(ft)} \times \text{Width(ft)} \times \text{Change in water level(ft)} \times 7.48\ \text{gal/ft}^3}{30\ \text{minutes}} + \text{Flow into storage tank}\left(\frac{\text{gal}}{\text{min}}\right)$$

Equation 3 – Max Flow Rate

In the above formula the "flow into the storage tank" is the flow of the water from the source entering the tank through the influent pipe (the pipe that is bringing water to your storage tank). This can easily be calculated with a 5 gallon bucket and a stop watch. Simply measure the time it takes to fill the 5 gallon bucket with your stop watch and use that time value in the following formula to calculate the flow into the your tank:

$$\text{Flow into storage tank } \left(\frac{\text{gal}}{\text{min}}\right) = \left(\frac{5 \text{ gallons}}{\text{time elapsed (sec)}}\right) \times 60 \left(\frac{\text{sec}}{\text{min}}\right)$$

Equation 4 – Flow into Storage Tank

However, if your distribution tank is always overflowing (this can be visually seen as there is always water flowing out of the overflow pipe) simply use the "Flow into storage tank" value for you max flowrate.

Now it is time to calculate the chlorine contact time in your storage tank. To calculate this value use the "max flowrate" and "tank volume" values you have already calculated in the following formula:

$$\text{Contact time in storage tank (min)} = \frac{\text{Tank Volume (gal)}}{\text{Max Flowrate } \left(\frac{gal}{\text{min}}\right)} \times 0.3$$

Equation 5 – Contact Time in Storage Tank

The value 0.3 in Equation 5 is the tank's "baffling factor." This value accounts for the chlorinated water entering the tank not mixing completely with all the water already in the tank before leaving the tank. As a result of this imperfect mixing the chlorinated water stays in the tank for only an estimated 30% of the calculated time hence the value 0.3. This value is a conservative value for a baffling factor for a standard cubical tank.

Now that we have calculated the chlorine contact time for your storage tank it is time to calculate the chlorine contact time for your piped distribution system.

4.2.2 Contact Time in Your Piped Distribution System

The contact time in the piped distribution system is the time water is in contact with chlorine starting from when the water leaves the storage tank until it reaches the faucet of the first house in the distribution system. This is calculated by first determining the total volume of water stored in the pipes starting from the storage tank and ending at the first house. Then this value this value is divided by the maximum flow rate.

In the following equation pipe length was measured with a tape measure and the inside pipe diameter was determined from labeling on the pipe. The total volume of water in a pipe was determined as:

$$\text{Volume in Pipe (gal)} = \text{Length of Pipe (ft)} \times \pi \times \left(\frac{\text{Pipe Diameter (in)}}{2}\right)^2 \times \left(\frac{7.48\left(\frac{gallons}{ft^3}\right)}{144\left(\frac{in^2}{ft^2}\right)}\right)$$

Equation 6 – Volume of Water in a Pipe

You may need to use this equation several times if you have several different diameter pipes between the storage tank and the first house. Once you have the volume of water in each different pipe calculated you need to add all of these volumes together to get the total volume in the piped system (Equation 7).

$$\text{Total Volume in Piped System (gal)} = \text{Volume in Pipe of Diameter}_1 + \text{Volume in Pipe of Diameter}_2 + \text{Volume in Pipe of Diameter}_3 \ldots$$

Equation 7 – Total Volume in Piped System

The contact time in the piped system is then calculated by dividing the value obtained from Equation 7 (Total Volume in Piped System) by the value obtained from Equation 3 (Max Flowrate) as shown in the following equation:

$$\text{Contact time in Pipes (min)} = \frac{\text{Total Volume in Piped System (gal)}}{\text{Influent Flowrate } \left(\frac{\text{gal}}{\text{min}}\right)}$$

Equation 8 – Contact Time in Pipes

4.2.3 Total Contact Time

Now we can calculate the total chlorine contact time of your system. This is done by adding the value you obtained from Equation 5 (Contact time in Storage Tank) and Equation 8 (Contact Time in Pipes) as shown in Equation 9:

$$\text{Total Contact Time (min)} = \text{Contact time in Tank (min)} + \text{Contact time in Pipes (min)}$$

Equation 9 – Total Contact Time

Remember if the distance between your storage tank and the first house in your distribution system is short then the "Contact Time in Pipes" value you calculate will be very small. Therefore if this distance is small (< 250 meters) you do not need to calculate the "Contact Time in Pipes" value.

4.3 Determining Chlorine Concentration

We now need to know the chlorine concentration in the water. Specifically we need to know the free chlorine concentration in water. The flowchart in figure 6 presented below will help explain what the term free chlorine represents:

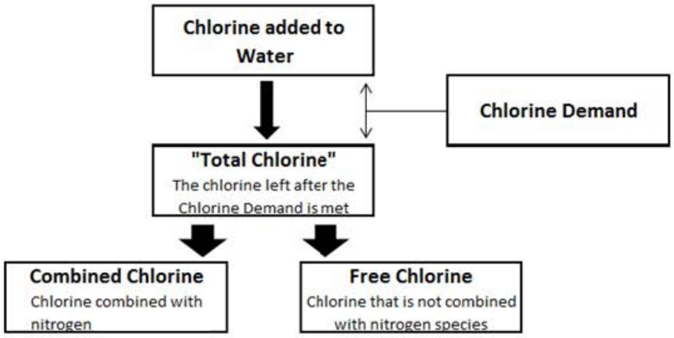


Figure 6: Chlorine Residuals Created when Chlorine is Added to Water

When chlorine is added to water some of the chlorine is used up killing off bacteria and other organisms in the water. The amount of chlorine needed in this process is called the chlorine demand. The concentration of chlorine left in the water after this process is finished is called the "Total Chlorine" concentration. "Total Chlorine" is the sum of two different species of chlorine: "Combined Chlorine" and "Free Chlorine". "Combined Chlorine" is the chlorine that is *combined* with nitrogen (a type of chemical) compounds in the water. This type of chlorine is not as good and disinfecting water as the other type of chlorine, "Free Chlorine." The other type of chlorine in water is "Free Chlorine" is the chlorine in your water that is not combined with nitrogen compounds. This "Free Chlorine" has a great ability to disinfect water and therefore the presence of this type of chlorine determines if water is sufficiently chlorinated. When we measure chlorine we are interested only in the concentration of "Free Chlorine" that is in water.

Currently MINSA in the Comarca Ngöbe-Bugle using a color wheels made by HACH Company to determine the free chlorine concentration in rural aqueducts in the region. The HACH testing manual for this color wheel can be found on the last page of this document. This manual explains how to take a sample and measure the free chlorine concentration of a sample of water.

Side note on using other instruments to measure "free chlorine" concentration: The use of digital colorimeters is also an effective way of measuring chlorine concentrations but the use of this instrument will not be discussed here as the instrument is expensive and is currently not used in the region. Kits specifically manufactured to measured chlorine in pools (this is often stated on the kits box) should be avoided as they often only measure "total chlorine" concentrations and are often not accurate.

Three values are important to remember when taking free chlorine measurements:

1) *Maximum Total Chlorine Concentration at any Location*: The World Health Organization (WHO) states that the maximum residual disinfectant level (MRDL) or the maximum level the concentration of "Total Chlorine" should reach is 5 mg/L Cl_2. This is because people regularly drinking water with chlorine residual values higher than 5 mg/L Cl_2 may develop health problems. However in this guide we are only sampling "Free Chlorine" concentrations. Therefore a good rule of thumb is to limit the level of free chlorine to a

maximum of 3 mg/L Cl_2. By doing this you can be fairly sure the total chlorine residual will be less than 5 mg/L Cl_2. Samples to determine if you are exceeding the *Maximum Total Chlorine Concentration at any Location* should be taken from the influent pipe into the distribution tank. This water will have this highest chlorine concentration in the entire system.

2) *Minimum Free Chlorine Concentration*: The minimum free chlorine concentration recommended is 0.2 mg/L Cl_2 at the last house receiving water in your distribution system. The last house is chosen to test for this value as it has the greatest chance of having the lowest free chlorine concentration value due to the chlorine being used up while sitting in the system. It is important to have some chlorine in all locations in your system so that if for example from a broken pipe is broken there will be some chlorine available to disinfect the water at that location. Again samples to determine the *Minimum Free Chlorine Residual* should be taken from the faucet of the last house in the system.

3) *Free Chlorine Concentration to Meet the Required Ct Value*: Finally you need a free chlorine concentration value that is large enough to give you a Ct value that is sufficient to disinfect the water in your system. Samples to determine the *Free Chlorine Concentration to Meet the Required Ct Value* should be taken from the cleanout valve of the distribution tank. By sampling water from the clean out valve you have the best estimate of the concentration of "Free Chlorine" leaving your storage tank. However, it is advised that you leave the exit valve open for 5 minutes before taking a sample so that dirt does not enter your sample. This calculation is presented in the next section (4.4).

4.4 Calculating Your Ct Value

We can now determine the Ct value for your system at a given time. You should already have the following two values: Total Contact Time (value from Equation 9) and "Free Chlorine" Concentration (measured as described in Section 4.3). To calculate the Ct value for your system multiply these two values together to get the final Ct value:

$$\text{Ct Value} = \text{Total Contact Time} \times \text{Free Chlorine Concentration}$$

which is

$$\text{Ct}\left(\frac{\text{mg-min}}{\text{L}}\text{Cl}_2\right) = \text{C}\left(\frac{\text{mg}}{\text{L}}\text{Cl}_2\right) \times \text{t (min)}$$

Equation 1 - Ct

4.5 Deciding if there are Enough Chlorine Tablets in the Chlorinator

As mentioned before we want our Ct value to be at or above 40 mg-min/L at all times during the week. If your calculated value is greater than or equal to 40 mg-min/L congratulations you are effectively chlorinating your water system (Note: This is assuming your *Maximum Total Chlorine Concentration at any Location* is an acceptable level). If your Ct value is below 40 mg-min/L you need to increase the amount of tablets you are using each week. This should increase your chlorine concentration which will then increase your calculated Ct value. It is recommended that you increase the amount of chlorine added by ½ a tablet per trial until you reach your target 40 mg-min/L Cl_2 Ct value. Therefore if you were using 2 tablets and found your Ct value was less than 40 min-mg/L in the next trial/week you would use 2 and ½ tablets. If again with 2 and

Appendix F (Continued)

½ tablets your Ct value was below 40 mg-min/L you would again increase the amount of chlorine by ½ tablet and use 3 tablets for the next trial/week.

In another example if you used 2 chlorine tablets in your chlorinator and found that your Ct value was > 40.0 min-mg/L but your *Maximum Total Chlorine Concentration at any Location* was thought to be above 5 mg/L (due to you finding a "Free Chlorine" concentration of > 3 mg/L) you would need to reduce the amount of chlorine in your chlorinator by ½ of a tablet to 1 and ½ chlorine tablets and retest your system. This process is presented visually in Figure 7:

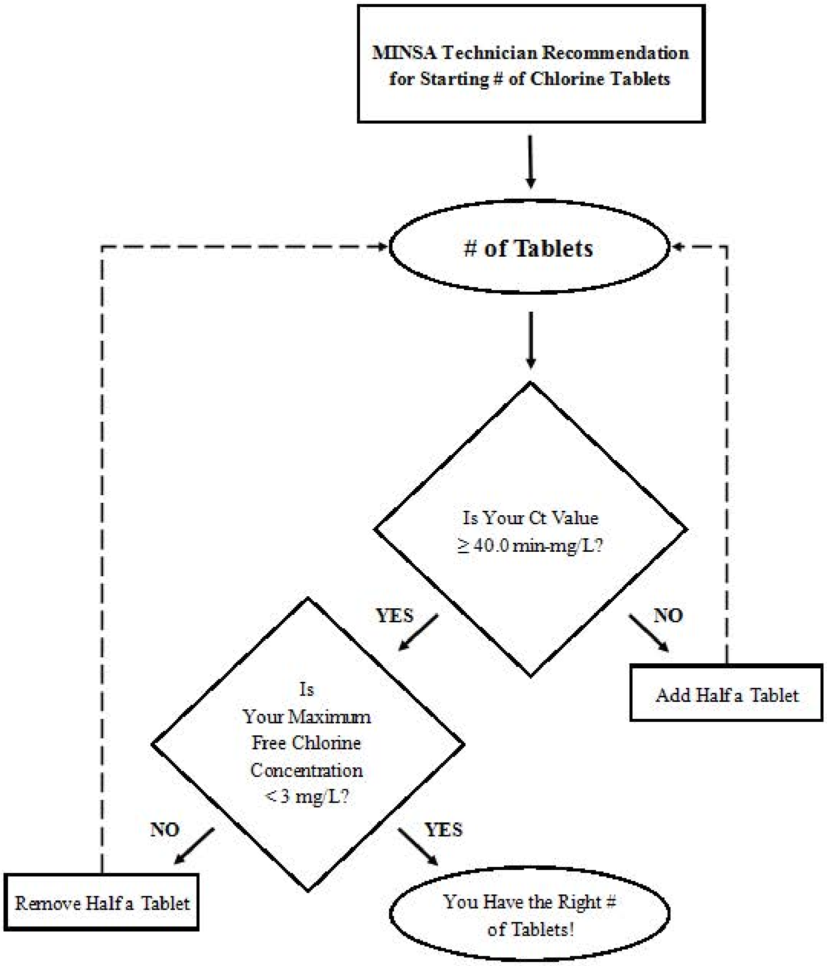
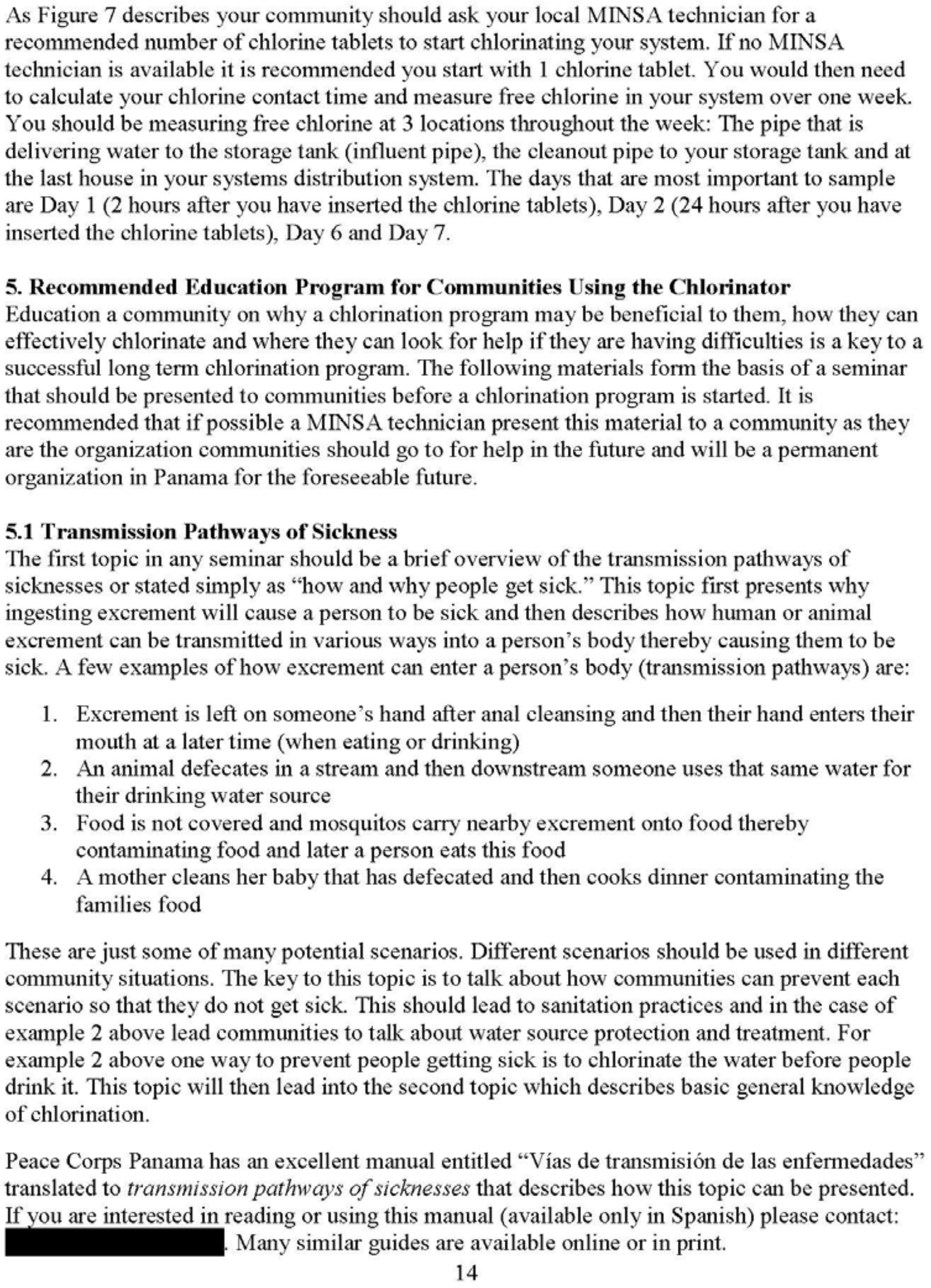


Figure 7: Flowchart - How to Determine a Correct # of Tablets for Your Chlorinator



As Figure 7 describes your community should ask your local MINSA technician for a recommended number of chlorine tablets to start chlorinating your system. If no MINSA technician is available it is recommended you start with 1 chlorine tablet. You would then need to calculate your chlorine contact time and measure free chlorine in your system over one week. You should be measuring free chlorine at 3 locations throughout the week: The pipe that is delivering water to the storage tank (influent pipe), the cleanout pipe to your storage tank and at the last house in your systems distribution system. The days that are most important to sample are Day 1 (2 hours after you have inserted the chlorine tablets), Day 2 (24 hours after you have inserted the chlorine tablets), Day 6 and Day 7.

5. Recommended Education Program for Communities Using the Chlorinator

Education a community on why a chlorination program may be beneficial to them, how they can effectively chlorinate and where they can look for help if they are having difficulties is a key to a successful long term chlorination program. The following materials form the basis of a seminar that should be presented to communities before a chlorination program is started. It is recommended that if possible a MINSA technician present this material to a community as they are the organization communities should go to for help in the future and will be a permanent organization in Panama for the foreseeable future.

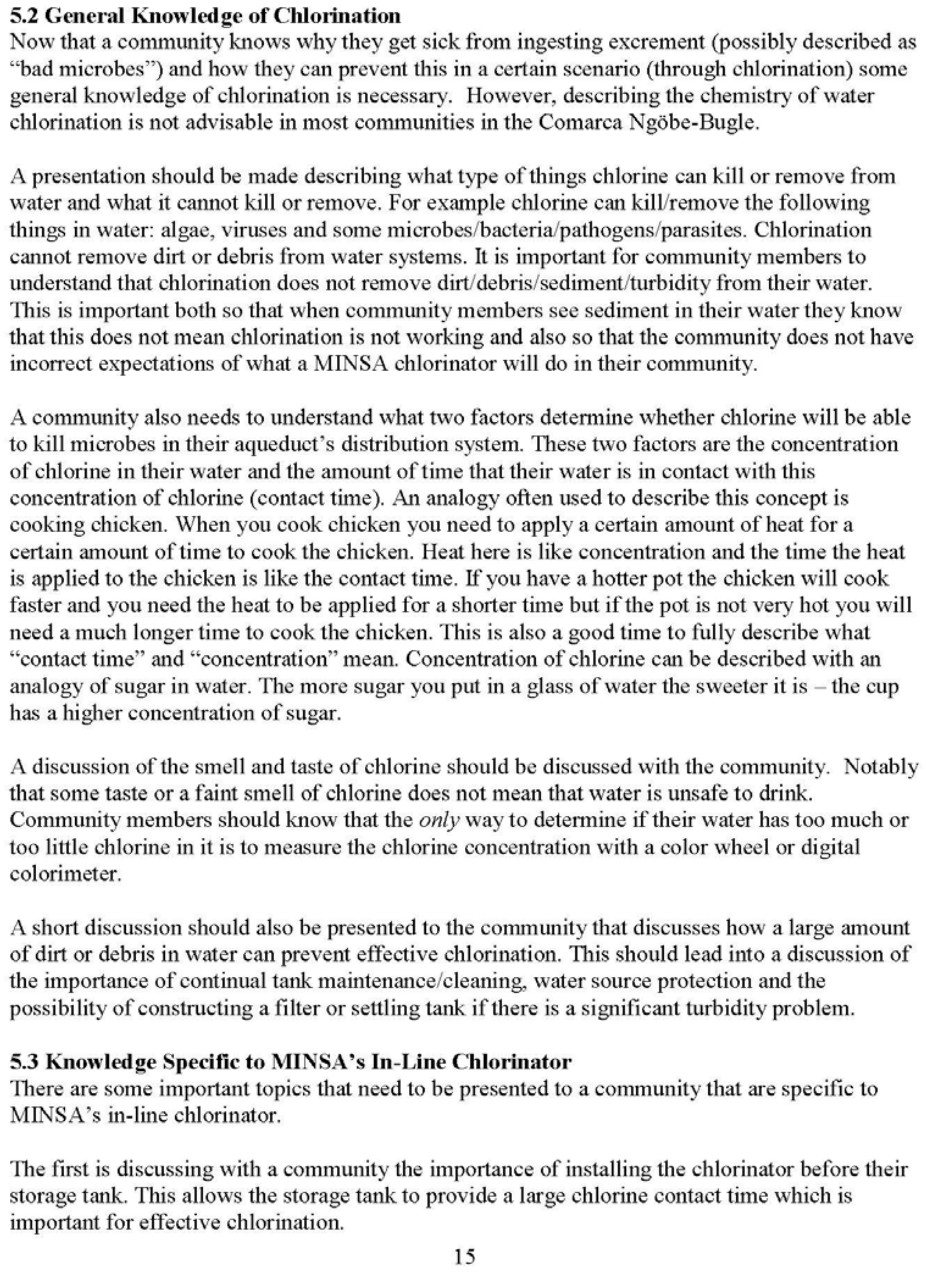
5.1 Transmission Pathways of Sickness

The first topic in any seminar should be a brief overview of the transmission pathways of sicknesses or stated simply as "how and why people get sick." This topic first presents why ingesting excrement will cause a person to be sick and then describes how human or animal excrement can be transmitted in various ways into a person's body thereby causing them to be sick. A few examples of how excrement can enter a person's body (transmission pathways) are:

1. Excrement is left on someone's hand after anal cleansing and then their hand enters their mouth at a later time (when eating or drinking)
2. An animal defecates in a stream and then downstream someone uses that same water for their drinking water source
3. Food is not covered and mosquitos carry nearby excrement onto food thereby contaminating food and later a person eats this food
4. A mother cleans her baby that has defecated and then cooks dinner contaminating the families food

These are just some of many potential scenarios. Different scenarios should be used in different community situations. The key to this topic is to talk about how communities can prevent each scenario so that they do not get sick. This should lead to sanitation practices and in the case of example 2 above lead communities to talk about water source protection and treatment. For example 2 above one way to prevent people getting sick is to chlorinate the water before people drink it. This topic will then lead into the second topic which describes basic general knowledge of chlorination.

Peace Corps Panama has an excellent manual entitled "Vías de transmisión de las enfermedades" translated to *transmission pathways of sicknesses* that describes how this topic can be presented. If you are interested in reading or using this manual (available only in Spanish) please contact: [redacted]. Many similar guides are available online or in print.



5.2 General Knowledge of Chlorination

Now that a community knows why they get sick from ingesting excrement (possibly described as "bad microbes") and how they can prevent this in a certain scenario (through chlorination) some general knowledge of chlorination is necessary. However, describing the chemistry of water chlorination is not advisable in most communities in the Comarca Ngöbe-Bugle.

A presentation should be made describing what type of things chlorine can kill or remove from water and what it cannot kill or remove. For example chlorine can kill/remove the following things in water: algae, viruses and some microbes/bacteria/pathogens/parasites. Chlorination cannot remove dirt or debris from water systems. It is important for community members to understand that chlorination does not remove dirt/debris/sediment/turbidity from their water. This is important both so that when community members see sediment in their water they know that this does not mean chlorination is not working and also so that the community does not have incorrect expectations of what a MINSA chlorinator will do in their community.

A community also needs to understand what two factors determine whether chlorine will be able to kill microbes in their aqueduct's distribution system. These two factors are the concentration of chlorine in their water and the amount of time that their water is in contact with this concentration of chlorine (contact time). An analogy often used to describe this concept is cooking chicken. When you cook chicken you need to apply a certain amount of heat for a certain amount of time to cook the chicken. Heat here is like concentration and the time the heat is applied to the chicken is like the contact time. If you have a hotter pot the chicken will cook faster and you need the heat to be applied for a shorter time but if the pot is not very hot you will need a much longer time to cook the chicken. This is also a good time to fully describe what "contact time" and "concentration" mean. Concentration of chlorine can be described with an analogy of sugar in water. The more sugar you put in a glass of water the sweeter it is – the cup has a higher concentration of sugar.

A discussion of the smell and taste of chlorine should be discussed with the community. Notably that some taste or a faint smell of chlorine does not mean that water is unsafe to drink. Community members should know that the *only* way to determine if their water has too much or too little chlorine in it is to measure the chlorine concentration with a color wheel or digital colorimeter.

A short discussion should also be presented to the community that discusses how a large amount of dirt or debris in water can prevent effective chlorination. This should lead into a discussion of the importance of continual tank maintenance/cleaning, water source protection and the possibility of constructing a filter or settling tank if there is a significant turbidity problem.

5.3 Knowledge Specific to MINSA's In-Line Chlorinator

There are some important topics that need to be presented to a community that are specific to MINSA's in-line chlorinator.

The first is discussing with a community the importance of installing the chlorinator before their storage tank. This allows the storage tank to provide a large chlorine contact time which is important for effective chlorination.

The second topic that is important to discuss with a community is the iterative method to determine the correct amount of chlorine tablets needed in a unique community system. During this time the first four sections of this manual are described. It is important that the community or at least members of the water community understand the iterative process of identifying an appropriate chlorination regimen that is shown visually in Figure 7. It should be stressed to the community that new chlorine tablets need to be replaced once a week at the same time on the same day each week.

Another important topic is to discuss how community members can obtain more chlorine tablets. Community members should know the name and contact number of the technician in their area. If you do not know who is the local MINSA technician in your area (in Panama) contact Fredy or Virgilio (contact information is provided in Section 1). Communities should understand that this technician is the person they should contact if they are having problems with their chlorinator. Communities should also know that this is where and with whom they can purchase a new chlorinator if needed.

Finally a discussion on how a community can clean their chlorinator and how often they can clean their chlorinator needs to be discussed. If a community has very little dirt entering their system (as with many spring capture systems) they may never need to clean their chlorinator. However, if a system has a large amount of dirt entering their system (as with many stream catchment systems) they need to clean their chlorinator once a month and additionally after each large storm event. This is done by configuring the chlorinator in different way as described in the configuration below:

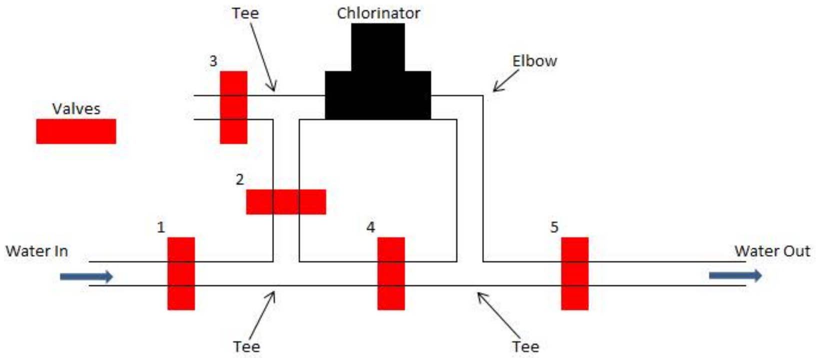


Figure 8: Basic Configuration of Chlorinator for Systems with Turbidity Problems

Note that this configuration requires three PVC Tees, one 90^0 elbow and 5 valves. When the system is in normal operating conditions the configuration would look like the below figure:

Appendix F (Continued)

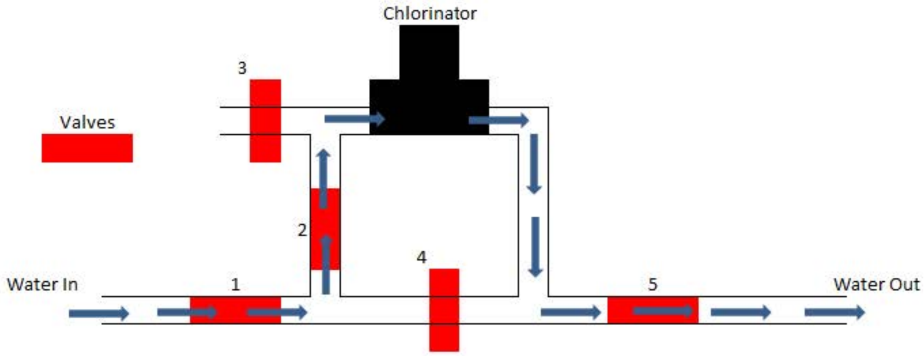


Figure 9: Configuration of Valves when Chlorinator is Being Used

And when the operator needs to clean out the chlorinator the system would be configured as in the figure below:

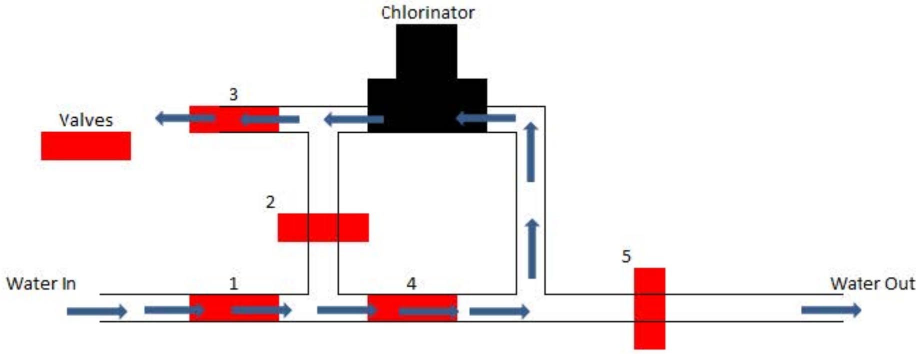
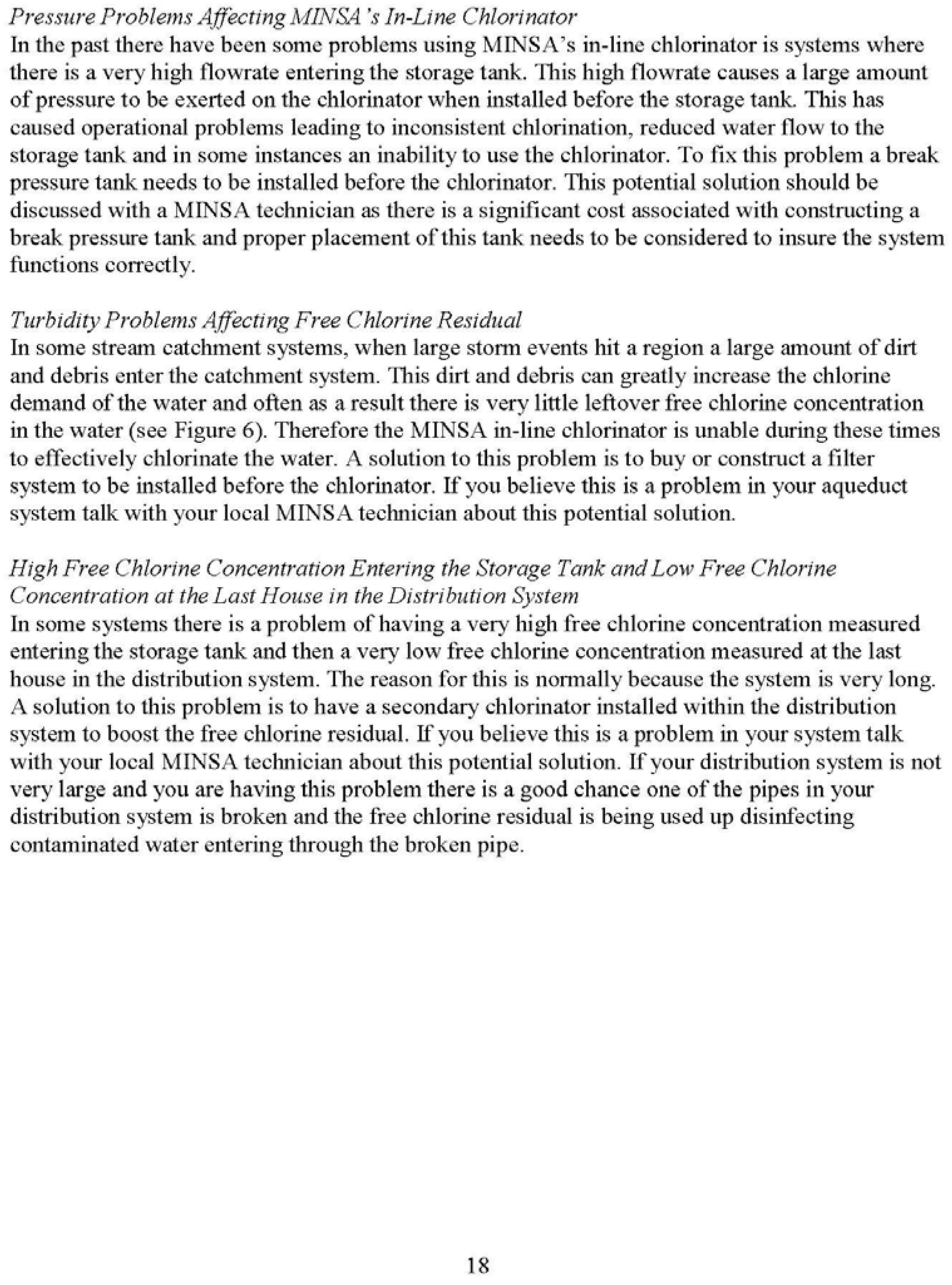


Figure 10: Configuration of Chlorinator when Cleaning/Backwashing the System

6. Common Problems and Solutions Associated with MINSA's In-Line Chlorinator

The following are problems that may arise with the MINSA in-line chlorinator. These problems however will not affect all communities and are therefore left out of the recommended education program that is to be presented to each community (Section 5). If you are having a problem that is not discussed below please contact your local MINSA technician.



Pressure Problems Affecting MINSA's In-Line Chlorinator

In the past there have been some problems using MINSA's in-line chlorinator is systems where there is a very high flowrate entering the storage tank. This high flowrate causes a large amount of pressure to be exerted on the chlorinator when installed before the storage tank. This has caused operational problems leading to inconsistent chlorination, reduced water flow to the storage tank and in some instances an inability to use the chlorinator. To fix this problem a break pressure tank needs to be installed before the chlorinator. This potential solution should be discussed with a MINSA technician as there is a significant cost associated with constructing a break pressure tank and proper placement of this tank needs to be considered to insure the system functions correctly.

Turbidity Problems Affecting Free Chlorine Residual

In some stream catchment systems, when large storm events hit a region a large amount of dirt and debris enter the catchment system. This dirt and debris can greatly increase the chlorine demand of the water and often as a result there is very little leftover free chlorine concentration in the water (see Figure 6). Therefore the MINSA in-line chlorinator is unable during these times to effectively chlorinate the water. A solution to this problem is to buy or construct a filter system to be installed before the chlorinator. If you believe this is a problem in your aqueduct system talk with your local MINSA technician about this potential solution.

High Free Chlorine Concentration Entering the Storage Tank and Low Free Chlorine Concentration at the Last House in the Distribution System

In some systems there is a problem of having a very high free chlorine concentration measured entering the storage tank and then a very low free chlorine concentration measured at the last house in the distribution system. The reason for this is normally because the system is very long. A solution to this problem is to have a secondary chlorinator installed within the distribution system to boost the free chlorine residual. If you believe this is a problem in your system talk with your local MINSA technician about this potential solution. If your distribution system is not very large and you are having this problem there is a good chance one of the pipes in your distribution system is broken and the free chlorine residual is being used up disinfecting contaminated water entering through the broken pipe.

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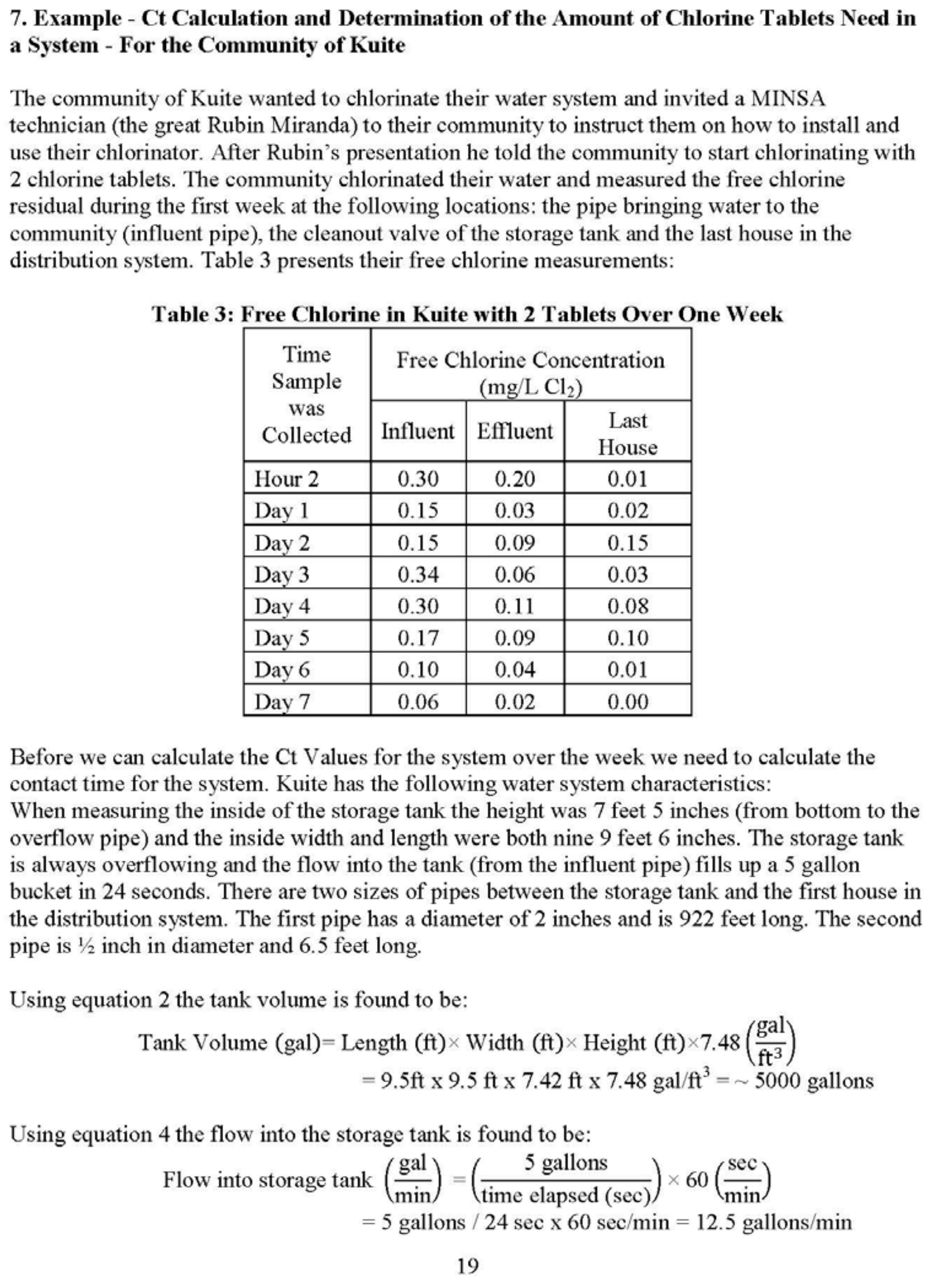


7. Example - Ct Calculation and Determination of the Amount of Chlorine Tablets Need in a System - For the Community of Kuite

The community of Kuite wanted to chlorinate their water system and invited a MINSA technician (the great Rubin Miranda) to their community to instruct them on how to install and use their chlorinator. After Rubin's presentation he told the community to start chlorinating with 2 chlorine tablets. The community chlorinated their water and measured the free chlorine residual during the first week at the following locations: the pipe bringing water to the community (influent pipe), the cleanout valve of the storage tank and the last house in the distribution system. Table 3 presents their free chlorine measurements:

Table 3: Free Chlorine in Kuite with 2 Tablets Over One Week

Time Sample was Collected	Free Chlorine Concentration (mg/L Cl_2)		
	Influent	Effluent	Last House
Hour 2	0.30	0.20	0.01
Day 1	0.15	0.03	0.02
Day 2	0.15	0.09	0.15
Day 3	0.34	0.06	0.03
Day 4	0.30	0.11	0.08
Day 5	0.17	0.09	0.10
Day 6	0.10	0.04	0.01
Day 7	0.06	0.02	0.00

Before we can calculate the Ct Values for the system over the week we need to calculate the contact time for the system. Kuite has the following water system characteristics:
When measuring the inside of the storage tank the height was 7 feet 5 inches (from bottom to the overflow pipe) and the inside width and length were both nine 9 feet 6 inches. The storage tank is always overflowing and the flow into the tank (from the influent pipe) fills up a 5 gallon bucket in 24 seconds. There are two sizes of pipes between the storage tank and the first house in the distribution system. The first pipe has a diameter of 2 inches and is 922 feet long. The second pipe is ½ inch in diameter and 6.5 feet long.

Using equation 2 the tank volume is found to be:

$$\text{Tank Volume (gal)} = \text{Length (ft)} \times \text{Width (ft)} \times \text{Height (ft)} \times 7.48 \left(\frac{\text{gal}}{\text{ft}^3}\right)$$

$$= 9.5\text{ft x } 9.5 \text{ ft x } 7.42 \text{ ft x } 7.48 \text{ gal/ft}^3 = \sim 5000 \text{ gallons}$$

Using equation 4 the flow into the storage tank is found to be:

$$\text{Flow into storage tank } \left(\frac{\text{gal}}{\text{min}}\right) = \left(\frac{5 \text{ gallons}}{\text{time elapsed (sec)}}\right) \times 60 \left(\frac{\text{sec}}{\text{min}}\right)$$

$$= 5 \text{ gallons} / 24 \text{ sec x } 60 \text{ sec/min} = 12.5 \text{ gallons/min}$$

Appendix F (Continued)

The example states that the storage tank is always overflowing and therefore, the flow into the storage tank is used for the max flow. Using equation 5 the contact time in the storage tank is found to be:

$$\text{Contact time in storage tank (min)} = \frac{\text{Tank Volume (gal)}}{\text{Max Flowrate } \left(\frac{gal}{\text{min}}\right)} \times 0.3$$

= 5,000 gallons / 12.5 gallons/min x 0.3 = 120 minutes

We now need to determine the contact time in each of the pipes. Using equation 6 the volume in each of the pipes was found to be:

$$\text{Volume in Pipe (gal)} = \text{Length of Pipe (ft)} \times \pi \times \left(\frac{\text{Pipe Diameter (in)}}{2}\right)^2 \times \left(\frac{7.48 \left(\frac{gallons}{ft^3}\right)}{144 \left(\frac{in^2}{ft^2}\right)}\right)$$

(Pipe 1) = 922ft x π x $(2\text{in}/2)^2$ x (7.48/144) = 150 gallons
(Pipe 2) = 6.5ft x π x $(0.5\text{in}/2)^2$ x (7.48/144) = ~ 0 gallons

Using equation 7 the total volume in the piped system is:

$$\text{Total Volume in Piped System (gal)} = \text{Volume in Pipe of Diameter}_1 + \text{Volume in Pipe of Diameter}_2 + \text{Volume in Pipe of Diameter}_3 \ldots$$

= 150 gallons + 0 gallons = 150 gallons

Using equation 8 the contact time in the pipes is:

$$\text{Contact time in Pipes (min)} = \frac{\text{Total Volume in Piped System (gal)}}{\text{Influent Flowrate } \left(\frac{\text{gal}}{\text{min}}\right)}$$

= 150 gallons / 12.5 gallons/min = 12 minutes

Therefore using equation 9 the total contact time for the system is found to be:

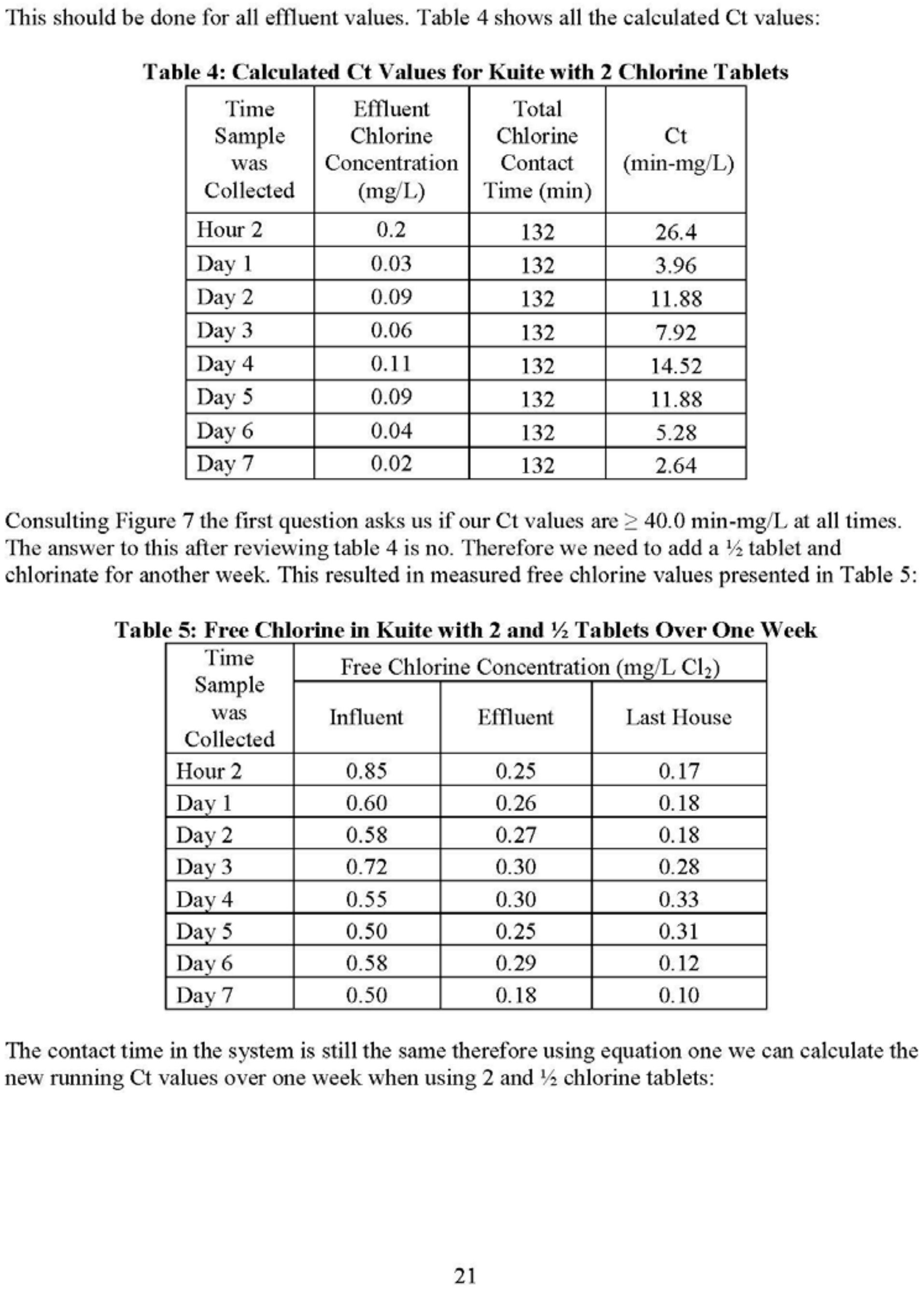
$$\text{Total Contact Time (min)} = \text{Contact time in Tank (min)} + \text{Contact time in Pipes (min)}$$

= 120 minutes + 12 minutes = 132 minutes

Equation 1 can now be used to calculate running Ct values. This is done by using the measured free chlorine values found during the week at the effluent pipe and multiplying them by our calculated total contact time (132 minutes). For example the effluent sample at hour 2 has a calculated Ct value of:

$$\text{Ct} \left(\frac{\text{mg-min}}{\text{L}} \text{Cl}_2\right) = \text{C} \left(\frac{\text{mg}}{\text{L}} \text{Cl}_2\right) \times \text{t (min)}$$

= 0.20 mg/L x 132 minutes = 26.4 mg-mg/L



This should be done for all effluent values. Table 4 shows all the calculated Ct values:

Table 4: Calculated Ct Values for Kuite with 2 Chlorine Tablets

Time Sample was Collected	Effluent Chlorine Concentration (mg/L)	Total Chlorine Contact Time (min)	Ct (min-mg/L)
Hour 2	0.2	132	26.4
Day 1	0.03	132	3.96
Day 2	0.09	132	11.88
Day 3	0.06	132	7.92
Day 4	0.11	132	14.52
Day 5	0.09	132	11.88
Day 6	0.04	132	5.28
Day 7	0.02	132	2.64

Consulting Figure 7 the first question asks us if our Ct values are ≥ 40.0 min-mg/L at all times. The answer to this after reviewing table 4 is no. Therefore we need to add a ½ tablet and chlorinate for another week. This resulted in measured free chlorine values presented in Table 5:

Table 5: Free Chlorine in Kuite with 2 and ½ Tablets Over One Week

Time Sample was Collected	Free Chlorine Concentration (mg/L Cl_2)		
	Influent	Effluent	Last House
Hour 2	0.85	0.25	0.17
Day 1	0.60	0.26	0.18
Day 2	0.58	0.27	0.18
Day 3	0.72	0.30	0.28
Day 4	0.55	0.30	0.33
Day 5	0.50	0.25	0.31
Day 6	0.58	0.29	0.12
Day 7	0.50	0.18	0.10

The contact time in the system is still the same therefore using equation one we can calculate the new running Ct values over one week when using 2 and ½ chlorine tablets:

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Appendix F (Continued)

Table 6: Calculated Ct Values for Kuite with 2 and ½ Chlorine Tablets

Time Sample was Collected	Effluent Chlorine Concentration (mg/L)	Total Chlorine Contact Time (min)	Ct (min-mg/L)
Hour 2	0.25	132	33
Day 1	0.26	132	34.65
Day 2	0.27	132	34.98
Day 3	0.30	132	39.6
Day 4	0.30	132	39.6
Day 5	0.25	132	33
Day 6	0.29	132	38.28
Day 7	0.18	132	23.76

Again, consulting Figure 7 the first question asks us if our Ct values are ≥ 40.0 min-mg/L at all times. The answer to this after reviewing table 6 is again no. Therefore we need to add another ½ tablet and chlorinate for another week. This resulted in measured free chlorine values presented in Table 7:

Table 7: Free Chlorine in Kuite with 3 Tablets Over One Week

Time Sample was Collected	Free Chlorine Concentration (mg/L Cl_2)		
	Influent	Effluent	Last House
Hour 2	1.42	0.33	0.29
Day 1	1.10	0.50	0.35
Day 2	0.94	0.44	0.19
Day 3	1.16	0.63	0.52
Day 4	0.88	0.48	0.57
Day 5	0.90	0.63	0.52
Day 6	0.91	0.54	0.22
Day 7	0.34	0.27	0.20

The contact time in the system is still the same therefore using equation one we can calculate the new running Ct values over one week when using 3 chlorine tablets:

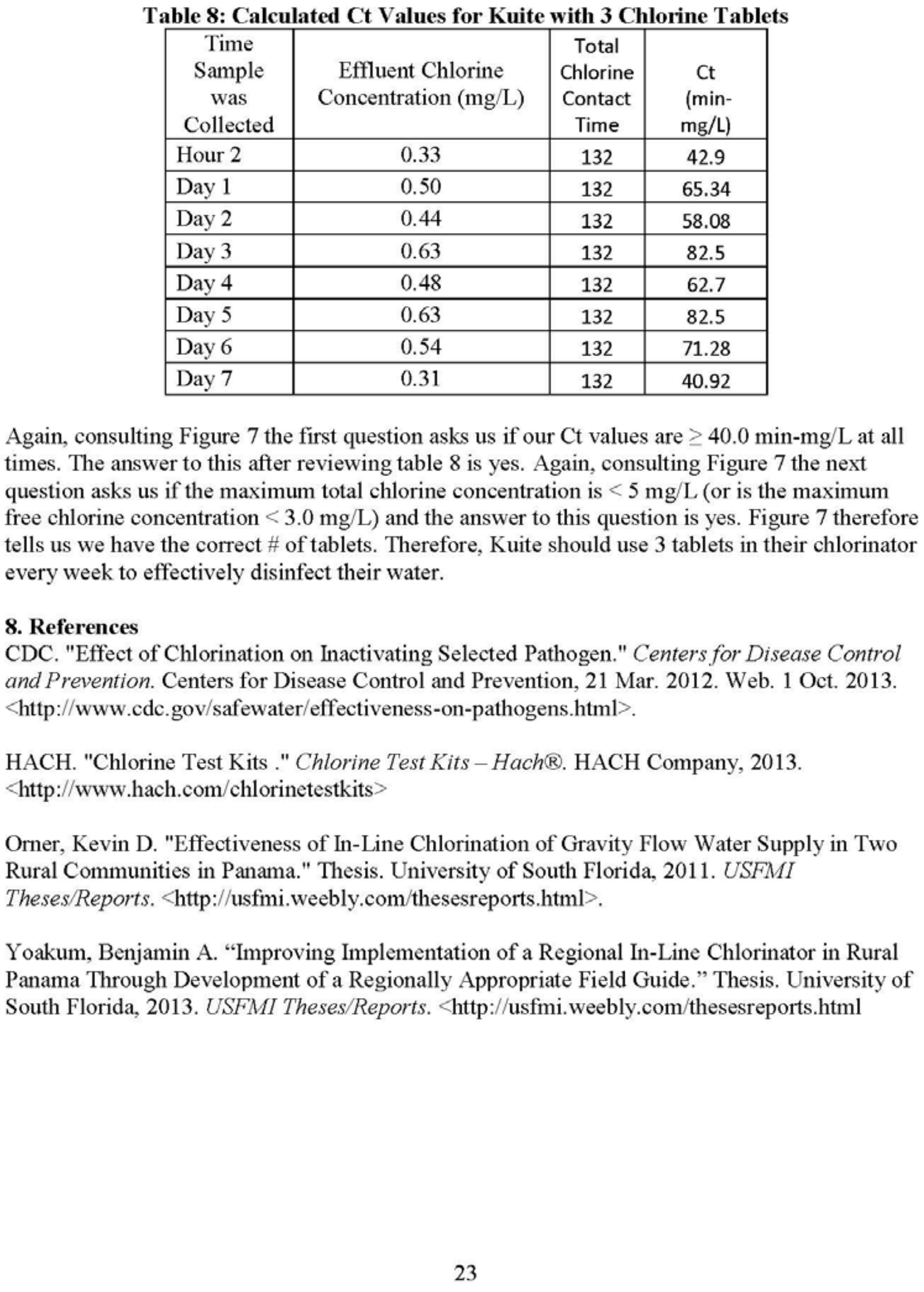

Table 8: Calculated Ct Values for Kuite with 3 Chlorine Tablets

Time Sample was Collected	Effluent Chlorine Concentration (mg/L)	Total Chlorine Contact Time	Ct (min-mg/L)
Hour 2	0.33	132	42.9
Day 1	0.50	132	65.34
Day 2	0.44	132	58.08
Day 3	0.63	132	82.5
Day 4	0.48	132	62.7
Day 5	0.63	132	82.5
Day 6	0.54	132	71.28
Day 7	0.31	132	40.92

Again, consulting Figure 7 the first question asks us if our Ct values are ≥ 40.0 min-mg/L at all times. The answer to this after reviewing table 8 is yes. Again, consulting Figure 7 the next question asks us if the maximum total chlorine concentration is < 5 mg/L (or is the maximum free chlorine concentration < 3.0 mg/L) and the answer to this question is yes. Figure 7 therefore tells us we have the correct # of tablets. Therefore, Kuite should use 3 tablets in their chlorinator every week to effectively disinfect their water.

8. References

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