

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600

UMI[®]

A

**EFFICIENCY OF THE TABLET CHLORINATOR IN
THE INACTIVATION OF PATHOGENIC ORGANISMS
IN DRINKING WATER**

by

Rosa M. Brignoni

A dissertation submitted to the Graduate Faculty in
Earth and Environmental Sciences in partial fulfillment of the
requirements for the degree of Doctor of Philosophy,
The City University of New York

2001

UMI Number: 3008813

UMI[®]

UMI Microform 3008813

Copyright 2001 by Bell & Howell Information and Learning Company.

All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

Bell & Howell Information and Learning Company

300 North Zeeb Road

P.O. Box 1346

Ann Arbor, MI 48106-1346

This Manuscript has been read and accepted for the Graduate Faculty in Earth and Environmental Sciences in satisfaction of the dissertation requirement for the degree of Doctor in Philosophy.

01-18-01

Date

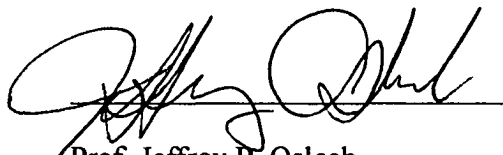


Prof. Arthur M. Langer

Chair of Examining Committee

1/24/01

Date



Prof. Jeffrey P. Osleeb

Executive Officer

Prof. Victor Goldsmith

Prof. Frederick C. Shaw

Prof. Inés A. Miyares

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

ABSTRACT**EFFICIENCY OF THE TABLET CHLORINATOR IN THE INACTIVATION OF
PATHOGENIC ORGANISMS IN DRINKING WATER**

by

Rosa M. Brignoni

Advisor: Prof. Arthur M. Langer

A 5-year study was conducted to determine the vulnerability of Non-PRASA (not pertaining to the Puerto Rico Aqueduct and Sewer Authority) systems to waterborne pathogens and the efficiency of the calcium hypochlorite tablet chlorinator in the inactivation of these particular agents. Non-PRASA systems are small water supplies characterized by the low bacteriological quality of the drinking water served, representing a risk to public health. Several entities are making efforts to install disinfection treatment at these systems; as a result of this effort, 67% of Non-PRASA community systems provide disinfection to their drinking water. From this number, 78% of these systems that provide disinfection use the tablet chlorinator, making these communities an ideal area to determine the efficiency of this technology in the inactivation of organism indicators of microbiological contamination.

An evaluation of Non-PRASA systems to determine characteristics and needs was done through visits, phone calls and reviews of inspections and sanitary surveys. Over 8,000 microbiological results were evaluated to determine the vulnerability of these communities to waterborne pathogens. The Finca Geraldo Pagán system was chosen for a 10-day sampling to determine the efficiency of the tablet chlorinator in

the inactivation of coliform bacteria. Inactivation of viruses and *Giardia lamblia* was also determined.

Two factors were considered as critical when determining the efficiency of the tablet chlorinator: the residual chlorine concentration and the perception of water quality. Over 90% of water samples obtained acceptable bacteriological results when the chlorine concentration was kept at or over 0.2 mg/L. The color, odor and taste of the water in these communities determine the perception of “how good” the water is. Cultural behavior and knowledge of drinking water issues influence also in the perception of water quality, which in turn, will be critical in determining if further treatment is needed and if a specific technology is applicable to a particular population.

This research determined that the calcium hypochlorite tablet chlorinator has the potential to be an effective disinfection agent at drinking water facilities located at the poorest areas where economic resources and knowledge of public health practices are limited.

TABLE OF CONTENTS

	Page
List of Tables	vi
List of Figures	viii
Introduction	1
Literature Review	
A. History of the Use of Chlorine as a Disinfectant	9
B. Use of Chlorine for the Disinfection of Drinking Water: Public Health Implications	10
C. Chlorine Chemistry	33
D. Coliform Bacteria: Indicators of Microbial Contamination	36
E. Commonwealth of Puerto Rico Health Profile and Definition of Non-PRASA Communities	38
Objectives	45
Methodology	47
Hypothesis	54
Data Collection, Discussion and Analysis	
A. Characteristics of Non-PRASA Systems	55
B. Characteristics of the Finca Geraldo Pagán System	65
C. Characteristics of the Tablet Chlorinator	70
D. Inactivation of Microbial Pathogens and Efficiency of the Tablet Chlorinator	75
Conclusions	91
Glossary	99
Appendices	
A: Summary of Non-PRASA Systems Characteristics and 1999 Bacteriological Profile	107
B: Aquaward Tablets Material Safety Data Sheet	116
C: Summary of Data Collection and Statistical Analysis	119
D: Inactivation of <i>Giardia lamblia</i> and Viruses	140
E: Puerto Rico Maps	153
References	157

LIST OF TABLES

		Page
Table 1	WHO's Mortality and Morbidity Rates Related to Drinking Water	3
Table 2	Diseases and Deaths Associated with Waterborne Outbreaks In the United States, 1920-1985	4
Table 3	Etiology of Waterborne Disease Outbreaks in the United States, 1946-1980	6
Table 4	Etiologic Agents Most Frequently Identified in Waterborne Outbreaks in the United States, 1971-1994	7
Table 5	Advantages and Disadvantages of the Most Common Disinfectants Used in Drinking Water	13
Table 6	Advantages and Disadvantages of Chlorine	14
Table 7	Classification of Waterborne Pathogens	15
Table 8	Major Waterborne Diseases of Concern in the United States	16
Table 9	Documented Outbreaks of Waterborne Cryptosporidiosis	20
Table 10	Reported Cases of Cholera, 1995-1998	27
Table 11	Most Common Used Chlorine Compounds for Drinking Water Disinfection	36
Table 12	Leading Causes of Death in Puerto Rico, 1997	39
Table 13	Morbidity Rates in Puerto Rico, 1993	39
Table 14	Morbidity Rates in Children, Puerto Rico, 1993	40
Table 15	Mortality Rates in Children, Puerto Rico, 1993	40
Table 16	List of Notifiable Diseases Related to Waterborne Pathogens and Comparison between Puerto Rico and the United States.	41
Table 17	Classification of Non-PRASA Systems	42
Table 18	Summary of Data Collection	53
Table 19	Distribution of Non-PRASA Systems by Population	55
Table 20	Non-PRASA Systems Providing Disinfection	60
Table 21	Classification of Disinfection Treatment	61
Table 22	Bacteriological Results at Non-PRASA Systems	62
Table 23	Vulnerability of Non-PRASA Systems to Microbiological Contamination	63
Table 24	Bacteriological Results of Non-PRASA Systems with Disinfection by Water Source and Residual Chlorine Concentration	64
Table 25	Climatological Conditions of the Municipality of Orocovis and Puerto Rico	65
Table 26	Bacteriological Results of the Finca Geraldo Pagan System, October 1998 – September 1999	69
Table 27	Advantages and Disadvantages of the Tablet Chlorinator	74

Table 28	pH Profile, Finca Geraldo Pagán System	80
Table 29	Temperature Profile, Finca Geraldo Pagán System	80
Table 30	Turbidity Profile, Finca Geraldo Pagán System	81
Table 31	Disinfection Profile, Residual Chlorine Concentration, Finca Geraldo Pagán System	81
Table 32	Disinfection Profile, Inactivation of <i>Giardia lamblia</i> cysts, Finca Geraldo Pagán System	82
Table 33	Disinfection Profile, Inactivation of Viruses, Finca Geraldo Pagán System	82
Table 34	Disinfection Profile, Inactivation of Total Coliform Bacteria, Finca Geraldo Pagán System	83
Table 35	Disinfection Profile, Inactivation of Fecal Coliform Bacteria, Finca Geraldo Pagán System	83

LIST OF FIGURES

		Page
Figure 1	Deaths Rates for Typhoid Fever in the United States, 1900-1960	2
Figure 2	Deaths Associated with Waterborne Outbreaks in the United States, 1920-1985	5
Figure 3	Reported Cases of Cholera, 1995-1998	28
Figure 4	Reported Cases of Cholera Deaths, 1995-1998	28
Figure 5	Classification of Non-PRASA Systems	43
Figure 6	Distribution of Non-PRASA Systems by Population	56
Figure 7	Typical Non-PRASA Residence, Finca Geraldo Pagán System	57
Figure 8	View of the Finca Geraldo Pagán Community	57
Figure 9	Non-PRASA System Providing Disinfection	60
Figure 10	Classification of Disinfection Treatment at Non-PRASA Systems	61
Figure 11	Bacteriological Results at Non-PRASA Systems	62
Figure 12	Location of the Finca Geraldo Pagán	66
Figure 13	Schematic of the Surface Water System, Finca Geraldo Pagán	67
Figure 14	Schematic of the Groundwater System, Finca Geraldo Pagán	67
Figure 15	View of the Well, Finca Geraldo Pagán System	68
Figure 16	View of the Surface Source Intake, Finca Geraldo Pagán	70
Figure 17	View of the Tablet Chlorinator	71
Figure 18	Schematic of the Tablet Chlorinator	72
Figure 19	Time Between Tablet Refills	73
Figure 20	Aquaward Tablet Chlorinator installed at the Finca Geraldo Pagán System	75
Figure 21	Turbidity Profile, Surface Water Source	84
Figure 22	Turbidity Profile, Groundwater Source	85
Figure 23	Residual Chlorine Concentration at Surface and Groundwater Sources	86
Figure 24	Inactivation of <i>Giardia lamblia</i> cysts, Surface and Groundwater Sources	87
Figure 25	Inactivation of Viruses, Surface and Groundwater Sources	88
Figure 26	Inactivation of Total Coliform Bacteria, Surface and Groundwater Sources	89
Figure 26	Inactivation of Fecal Coliform Bacteria, Surface and Groundwater Sources	90

INTRODUCTION

On July 15, 1999, the Chlorine Chemistry Council (CCC) and the Pan American Health Organization (PAHO) signed a Memorandum of Understanding (MOU) to join efforts in order to improve water safety in 19 nations in Latin America. This Agreement provides training that focus on the protection and treatment of drinking water supplies, including disinfection, watershed protection and water treatment during emergencies. One of the main objectives of this effort is to reduce the incidence of diarrheal diseases in Latin America, one of the first five leading causes of death for infants under one year of age. These diseases are due to contaminated water and inadequate sanitation (88).

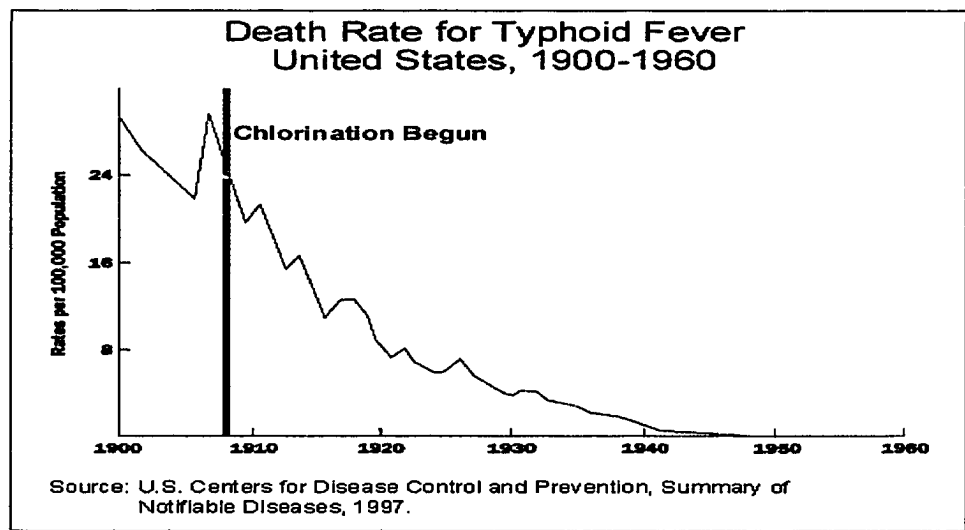
A critical factor in the treatment of water is disinfection. This has become traditional and is a very important element in the protection of public health during the 20th century, especially in developed countries (93).

During the 19th century and before the widespread use of disinfection in drinking water treatment, common waterborne diseases such as cholera, typhoid fever and dysentery were responsible for a high mortality in the United States and other developed countries. For example, in 1900, typhoid fever accounted for 25,000 deaths in the United States (Figure 1) (93). Due to the introduction and use of disinfection, a significant reduction in the number of waterborne disease outbreaks has been observed.

Unfortunately, the reduction in the occurrence of waterborne diseases has not decreased in the same way in developing countries. In these countries, disinfection has not been widely used and untreated or inadequately treated drinking water still

represents a threat to public health. A major problem is water scarcity, caused by contaminated sources and inadequate capacity of treatment plants. Other factors that play a critical role in the incidence and transmittal of waterborne diseases in these areas are the lack of sanitary practices, cultural behavior, lack of health education, overcrowding, poverty, inadequate disposal of wastes and limited or absent wastewater treatment (39).

Figure 1: Deaths Rates for Typhoid Fever in the United States, 1900-1960



It is estimated that 1.5 billion persons around the world still lack access to clean water supplies, increasing the risk of pathogen ingestion (24). The ingestion of pathogens in contaminated water results in waterborne diseases, one of the greatest health risks worldwide. Vulnerable population are infants, young children, elderly, pregnant women, sick and debilitated persons and those living under unsanitary conditions (40). The vulnerability of the population to waterborne diseases increases through exposure to many other infectious diseases, contaminants in the environment

and malnutrition.

A major cause of morbidity and mortality in infants and young children in developing countries is diarrheal disease associated with unsafe water. Diarrheal diseases dramatically affect the health of children on a worldwide level; they are so widespread and are so common in developing countries that parents often fail to recognize the danger signs. Children die because their bodies are weakened through the rapid dehydration and the underlying state of malnutrition.

Diarrheal diseases constitute one of 6 diseases causing 90% of the infectious diseases worldwide. The other five infectious diseases are HIV/AIDS, tuberculosis, malaria, pneumonia and measles (39). Diarrheal diseases account for half of all premature deaths in developing countries, killing mostly children and young adults.

Table 1: WHO's Mortality and Morbidity Rates Related to Drinking Water

Disease	1995		1996		1997	
	Morbidity (x 1000)	Mortality (x 1000)	Morbidity (x 1000)	Mortality (x 1000)	Morbidity (x 1000)	Mortality (x 1000)
Diarrhea	4,002,000 (1)	3,115 (4)	4,002,000 (1)	2,473 (6)	4,000,000 (1)	2,455 (6)
Amebiasis	0	0	48,000	70	48,000	70
Typhoid	16,000	>600	0	0	0	0
Cholera Reported	208	5	145	6	145	6
Estimated	0		500	0	500	0
Giardiasis	200,000 ©	0	50	0	500	0

Source: Ford, 1999 & WHO

Numbers in parentheses refer to WHO's ranking for selected causes of morbidity and mortality. ©Number of individuals with symptoms of giardiasis in Asia, Africa and Latin America.

Diarrheal diseases ranked first in the 1995 WHO's Assessment Report of Causes of Morbidity and fourth in Causes of Mortality (Table 1). Thirty percent of diarrheal episodes are caused by contaminated water and 70% are probably caused

by contaminated food. Low levels of pathogens in drinking water may multiply to infectious doses when associated with food, increasing the risk of the occurrence of a food borne outbreak. A vulnerable host can become infected from drinking water and spread the infection to others through person to person contact or through the unsanitary handling of food. Therefore, the microbiological quality of the drinking water has a critical impact in the incidence of waterborne diseases as well as in secondary transmission pathways.

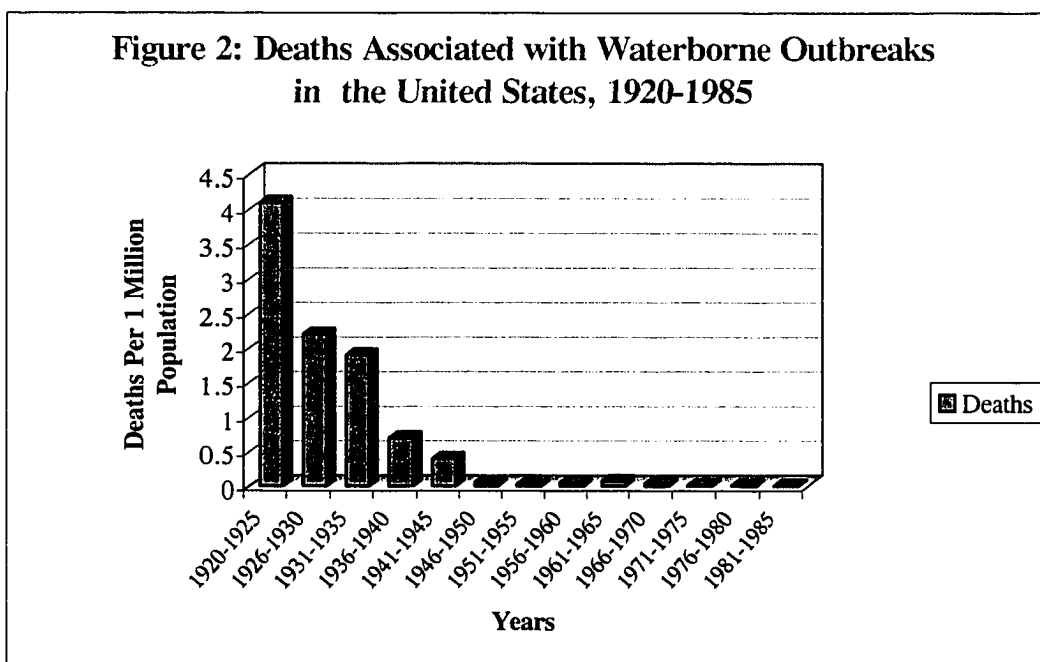
Table 2: Diseases and Deaths Associated with Waterborne Outbreaks in the United States, 1920-1985

Years	Outbreaks	Cases Per 10⁶ Population	Deaths Per 10⁶ Population
1920-1925	138	330.6	4.10
1926-1930	117	631.7	2.20
1931-1935	112	91.1	1.90
1936-1940	163	715.0	0.70
1941-1945	196	306.0	0.40
1946-1950	117	102.1	0.05
1951-1955	52	43.1	0.02
1956-1960	59	39.8	0.05
1961-1965	56	212.6	0.07
1966-1970	75	46.1	0.04
1971-1975	124	136.9	0.01
1976-1980	202	246.3	0.01
1981-1985	176	136.6	0

Source: CF Craun, 1990

Diarrheal diseases impose a heavy burden on developing countries, accounting for 1.5 billion cases of illness/year in children under 5 years old. Considering that the world population was estimated at 5.9 billion persons in 1998 (81), morbidity rates caused by diarrheal diseases affects a considerable percent of the world's population. The burden is highest in deprived areas where there is poor sanitation, inadequate hygiene and unsafe drinking water.

The WHO estimates for morbidity from diarrheal diseases in 1997 are very similar to 1995 but there has been a reduction in mortality cases (Table 1). It is estimated that more than 80% of the morbidity cases are children under age 5 (39). Although remaining first in WHO's morbidity ranking, diarrheal diseases dropped to the sixth cause of mortality, after tuberculosis and chronic obstructive pulmonary disease.



A considerable reduction in the incidence of waterborne diseases in developing countries could be observed if sanitary practices are followed and reliable, low cost methods of disinfection treatment are provided in these regions. Source water protection, proper treatment techniques, improvements in the quality and availability of water, in excreta disposal and general hygiene education are also important factors in achieving reduction in mortality and morbidity rates of

waterborne diseases.

Table 3: Etiology of Waterborne Disease Outbreaks
In the United States, 1946-1980

Etiologic Agent		Outbreaks	Cases of Illness
Bacterial	<i>Campylobacter</i>	2	3,800
	<i>Pasteurella</i>	2	6
	<i>Leptospira</i>	1	9
	<i>Escherichia coli</i>	5	1,188
	<i>Shigella</i>	61	13,099
	<i>Salmonella</i>	75	18,590
Virus	<i>Parvovirus-like</i>	10	3,147
	Hepatitis A	68	2,262
	Poliovirus	1	16
Protozoa	<i>Entamoeba</i>	6	79
	<i>Giardia lamblia</i>	42	19,734
Chemical	Organic/Inorganic	49	3,616
Unknown	Unknown	350	84,939
Total		672	150,475

In developed countries, waterborne diseases are reported, but in different numbers of occurrences and due to different causes. Even though waterborne diseases have not represented health risks in developed countries since the beginning of the 20th century, waterborne disease outbreaks still occur when inadequate treatment is provided. Usual causes of outbreaks are cross connections, back siphonage with non-potable water and deficiencies in storage, treatment and/or operation.

With a few notable exceptions, reported waterborne outbreaks in developed countries tend to occur in small water systems, affecting fewer people. The number of deaths associated with waterborne outbreaks has decreased dramatically since 1920 and no deaths due to this cause were reported during 1981-1985 (Table 2).

Most previous deaths were due to typhoid fever; however, the primary causes of death for the period of 1946-1975 were shigellosis and chemical poisoning. For the more recent outbreaks, it is common to see “new pathogens” like *Giardia lamblia* and *Cryptosporidium parvum* as the main etiologic agents of waterborne outbreaks in the United States (Table 4) (29).

Table 4: Etiologic Agents Most Frequently Identified
in Waterborne Outbreaks in the United States, 1971-1994

Etiologic Agent	Outbreaks	Illnesses
<i>Giardia lamblia</i>	123	27,118
<i>Shigella</i>	59	10,230
Norwalk-like-virus	24	10,908
Hepatitis A	29	807
<i>Campylobacter</i>	16	5,480
<i>Salmonella</i>	13	2,995
<i>Cryptosporidium parvum</i>	12	420,465
<i>Vibrio cholera</i>	1	11
All others	36	4,831
Total	313	482,845

Source: Chlorine Chemistry Council

Note: Numbers presented are lower than the actual cases due to unreporting.

The future microbiological quality of the drinking water is still a concern for public health authorities. Drinking water facilities and their distribution systems age and deteriorate, processes that are accelerated if maintenance is poor. Many treatment facilities are overloaded, reducing the efficiency of inactivation and/or removal of waterborne pathogens. At a worldwide level, water sources constantly receive discharges from the agricultural, industrial and municipal sectors, causing a degradation of the water quality. Finally, there has been an increase in the identification of “new” pathogens responsible for the latest outbreaks. These new pathogens have emerged due to one of the following reasons: a) the etiologic agent

recently evolved into a disease-causing organism for humans; b) the human population may have become more sensitive to the agent, or c) the ailment may have been only recently recognized (69).

A considerable reduction in the number of waterborne diseases could be observed if sanitary practices are followed and efficient, low-cost disinfection treatment is installed. One of the possible candidates for the disinfection of drinking water is the tablet chlorinator, characterized by its easy operation and low cost.

In summary, the disinfection of drinking water is an important tool in the protection of public health. Unfortunately, there are still areas where diarrheal diseases caused by contaminated water account for high morbidity and mortality. The introduction of sanitary practices and disinfection treatment at these areas could result in a reduction of waterborne diseases.

The benefits of chlorine have been observed and implemented in the 20th century. However, it was during the second half of the 19th century that scientists discovered the impact of its use in the control of waterborne diseases.

LITERATURE REVIEW

A. History of the Use of Chlorine as a Disinfectant

The epidemiological relation between water and disease was first suggested in the 1850s. However, it was not until the establishment of the germ theory of disease by Pasteur in the 1880s that water as a carrier of disease-producing organisms was understood (125).

The earliest known mention of chlorine for purifying water was made by Dr. Robley Dunginon in his book "*Human Health*", published in 1835 in Philadelphia. In his document, Dr. Dunginon suggested that a small quantity of chlorine-based chemicals was effective to make "the water of marshes potable" (64).

In 1850, John Snow, physician to Queen Victoria, attempted to disinfect the Broad Street Pump Water Supply in London after a cholera outbreak. Snow determined that the spread of the disease was connected to a cross connection of drinking water and sewage. He understood that the disease was spread more easily by contaminated water than by person-to-person contact and that the rate of death was higher in the population served by one water supply. By shutting off the public water supply, the epidemic subsided. Dr. Snow's actions represent the first recorded implementation of an appropriate public health measure to prevent the transmission of a waterborne disease.

In 1897, in Kent, England, Sims Woodhead used "bleach solution" to sterilize water distribution mains after a typhoid outbreak. After this event, chlorination was used continuously in Great Britain, reducing the occurrence of typhoid death (22).

The first recorded use of chlorine in the United States was in Louisville, Kentucky, in 1896 (93). William M. Jewell applied chlorine gas to drinking water during a filter-testing program (64).

The first use of chlorine as a continuous process in drinking water treatment was in a small town in Belgium in the early 1900s. In that system, chloride of lime and perchloride of iron were fed into the water before filtration (132).

In 1908, at Boonton, New Jersey, hypochlorite was used by first time in a continuous basis in the United States. Chlorine gas was commercially available by 1909 and was first used at Niagara Falls, New York in 1912 (93). The use of chlorine as a drinking water disinfectant was adopted soon in other cities across the United States, resulting in the elimination of waterborne diseases such as cholera, typhoid fever, dysentery and hepatitis A. At the present time, it is estimated that more than 200 million persons across the United States and Canada receive chlorine-disinfected water every day (22).

B. Use of Chlorine for the Disinfection of Drinking Water:

Public Health Implications

The primary goal for disinfection is the inactivation of organisms that may cause disease (24). Disinfection, one of the barriers used against microbiological contamination, is one of the most important steps in the treatment of drinking water (118). The other two barriers are source protection and filtration (16).

Although the inactivation of pathogenic organisms is a primary function, disinfectants are also used for other functions such as minimization of disinfection by products (DBPs); control of Asiatic clams and zebra mussels; oxidation of iron

and manganese; destruction of hydrogen sulfide; water main sterilization; improvement of coagulation and filtration efficiency; restoration and preservation of pipeline capacity; prevention of regrowth in the distribution system; maintenance of biological stability and removal of taste, odor and color (125).

Among the disinfectants used to treat water (Table 5), chlorine is the most used in the United States, where more than 98% of water treatment facilities disinfect with chlorine and chlorine-based chemicals (23). Chlorine provides a residual that ensure the inactivation of organisms throughout the distribution system, reducing or limiting the risk of recontamination before it reach its consumers (63). In addition, chlorine is used for the control of color/odor in the water caused by algae secretions, decaying vegetation, ammonia and hydrogen sulfide. Other attributes of chlorine are that it effectively inactivates a wide range of pathogens, is economical and has been successful in improving water treatment operations (24).

Chlorine is highly effective in the inactivation of most waterborne pathogens and in the prevention of diseases including cholera, typhoid fever, amoebic dysentery, bacterial gastroenteritis, shigellosis, salmonellosis, *Campilobacter* enteritis, *Yersinia* enteritis, *Pseudomonas* infections, schistomiasis and various viral infections such as Hepatitis A. However, some pathogens such as *Cryptosporidium parvum* and *Giardia lamblia* are resistant to disinfection and require additional treatment (93).

The three primary mechanisms of pathogen inactivation are: (a) destruction or inactivation of cellular structural organization; (b) interference with energy-yielding metabolism; and (c) interference with biosynthesis and growth (125).

Depending on the disinfectant and microorganism type, combinations of these mechanisms are responsible for pathogen inactivation. Research has shown that chlorine is capable of producing lethal events at or near the cell membrane of pathogenic organisms. Chlorine kills the bacteria by forming hypochlorous acid, which attacks the respiratory, transport and nucleic acid activity of bacteria, with nucleic acids the critical site (85).

During recent years, public health and safety concern has arisen about the use of chlorine in drinking water (83). The reaction of chlorine with organic and inorganic compounds in water produces undesirable disinfection by products (DBPs), some potentially carcinogenic. The hazards associated with the application and handling of chlorine gas, and possible taste and odor problems caused by high chlorine doses question the applicability of chlorine as a main disinfectant on drinking water. However, because the risks to health from the use of chlorine are extremely small when compared to its benefits, chlorine and chlorine-based compounds are still the most used disinfectants, especially in the United States (62).

Unfortunately, disinfection of drinking water is either not carried out or is inadequately carried out, especially in small systems (13). At a worldwide level, disinfection has been found to be one of the most important deficiencies in the treatment of community water supplies, increasing the risk of occurrence of waterborne diseases.

A waterborne disease outbreak occurs when two or more persons experience a similar illness after consumption or use of drinking water and epidemiological information implicates the water as the source of illness (51).

Table 5: Advantages and Disadvantages of the Most Common Disinfectants Used in Drinking Water

Disinfectant	Advantages	Disadvantages
Ultraviolet Light	Short contact time, no odor or taste problems, avoid storage and chemical treatment, no identified DBPs, easy to operate and maintain, effective against coliform bacteria.	Not effective for virus, spores and cysts, high electric costs, no residual capability. Affected by turbidity, hardness, wavelength of the UV radiation or power failure.
Ozone	Control taste, odor and color. Excellent virucide, inactivate <i>Giardia</i> and <i>Cryptosporidium</i> . Removes iron, sulfides and manganese. Requires short CT and dosage. Effective disinfectant, enhance clarification and turbidity removal.	High electric costs, no residual capability. Production of DBPs. Low solubility in water. Cannot be stored. Equipment to generate ozone is expensive.
Chlorine	Economical, reduce taste and odor, residual capability. Effective against bacteria and virus. Provides some protection against protozoan.	Possible production of DBPs. At higher concentrations leave a "chlorine" taste. Chlorine gas is dangerous.
Chloramine	Residual, reduce taste and odor, low formation of THMs, effective disinfection of biofilm. Provides a stable and long lasting residual, inexpensive.	Present problem to dialysis patients, eye irritation, requires high dosage and CT, promote algae growth, can produce Halo Acetic Acids and DBPs, on site generation.
Chloride Dioxide	Excellent virucide. No DBPs formation. Disinfects and oxidize effectively. Enhance clarification process. Control taste/odor/color. Removal of iron, sulfide and manganese. Residual capability.	Requires on-site generation equipment. Exposure to heat, sunlight or UV light may decrease product strength.
Potassium Permanganate	Control taste/odor, biological growth and DBPs formation. Remove iron and manganese. Easy to transport, store and apply. Effective against certain viruses. Strong oxidant.	Poor disinfectant. Long contact time required. Imparts a pink color to water. Toxic, irritate skin and mucous membranes. Over dosing may cause drop in blood pressure and jaundice.

Table 6: Advantages and Disadvantages of Chlorine

Advantages	Disadvantages
<ul style="list-style-type: none"> • Enhance coagulation and filtration • Enhance color removal • Enhance taste and odors • Oxidize iron, manganese and sulfide • Effective biocide • Is the easiest and least expensive disinfection method • It is the most widely used disinfection method and the best known • Available as calcium and sodium hypochlorite, which are more advantageous for smaller systems than chlorine gas because they are easier to use, safer and need less equipment 	<ul style="list-style-type: none"> • Form DBPs • Finished water could have taste and odor problems, depending on the water quality and dosage • Chlorine gas is a hazardous corrosive gas • Special leak containment and scrubber facilities could be required for chlorine gas • Typically, sodium and calcium hypochlorite are more expensive than chlorine gas • Sodium hypochlorite is a corrosive chemical, degrades over time and with exposure to light • Is less effective at high pH

Waterborne pathogens that may cause diseases fall into 3 general classes: viruses, bacteria and parasitic protozoa (Table 7). Bacteria and viruses contaminate both surface and groundwater sources, while parasitic protozoa appear predominantly in surface water. In terms of occurrence, protozoan infections are the most common, followed by bacterial infections and then viral infections. All waterborne microbial pathogens are potentially infectious and capable of causing illness depending on the dose and the physical condition of the person exposed (24). Symptoms of waterborne disease vary but most include diarrhea. The severity of illness ranges from mild gastrointestinal upset, fever, vomiting, intermittent to chronic diarrhea, dehydration, liver damage, acute respiratory illness, adverse neurological effects, depressed immune system and death (Table 8). Most healthy

individuals usually experience only mild gastroenteritis that is easily controlled and of short duration. However, vulnerable population can exhibit high rates of morbidity and mortality. Bacteria and protozoa generally induce gastrointestinal disorders with a wide range of severity. Viruses cause serious diseases such as aseptic meningitis, encephalitis, poliomyelitis, infectious hepatitis and upper respiratory infections. Exposure to these pathogens does not always result in infection, nor does infectivity always lead to clinical illness.

Table 7: Classification of Waterborne Pathogens

Organism	Size (microm)	Mobility	Point of Origin	Resistance to Disinfection
Bacteria	0.1-10	Motile Nonmotile	Humans, animals, water & food.	Bacterial spores typically have the highest resistance whereas vegetative bacteria have the lowest resistance
Virus	0.01-0.1	Nonmotile	Humans, animals, water & food.	Generally more resistant than vegetative bacteria
Protozoa	1-20	Motile Nonmotile	Humans, animals, sewage, decaying vegetation & water.	More resistance than viruses or vegetative bacteria

Source: EPA Guidance Manual – Alternatives Disinfectants and Oxidants, 1999.

Waterborne pathogens are diverse in terms of occurrence, size and resistance to drinking water disinfection. The primary source of almost all pathogens is the intestinal tract of humans and animals. The exception is *Legionella pneumophila*, a respiratory pathogen that multiplies, apparently in association with amoeba, in warm water environments, including drinking water distribution systems.

Table 8: Major Waterborne Diseases of Concern in the United States

Disease	Microbial Agent	General Symptoms	Water Mode of Transmission	Remove, Inactive by...
Cryptosporidiosis	Protozoan <i>Cryptosporidium parvum</i>	Diarrhea, fever, nausea, headache, abdominal pain, vomit	Water contaminated by feces of infected humans/animals	Filtration
Giardiasis	Protozoan <i>Giardia lamblia</i>	Diarrhea, nausea, fatigue, blood in the stool, vomit, abdominal pain, weight loss, fever	Water contaminated by feces of infected humans/animals	Disinfection Filtration
Viral Gastroenteritis	Viruses Rotavirus Hepatitis A Norwalk	Fever, headache, abdominal pain, fatigue, diarrhea, darkening of the urine, jaundice	Water contaminated by feces of infected humans	Filtration Coagulation Flocculation Disinfection
Cholera	Bacteria <i>Vibrio Cholerae</i>	Diarrhea, pain, vomiting, coma, dehydration, rice water stool, thirst	Water contaminated by feces/vomits of infected humans	Disinfection
Typhoid Fever	Bacteria <i>Salmonella typhi</i>	Fever, headache, diarrhea, fatigue, loss of appetite, nose bleeding, pain, insomnia, cough, rose spots on trunk	Water contaminated by feces/urine of infected humans	Disinfection
Amoebiasis	Protozoan <i>Entamoeba Hystolytica</i>	Diarrhea, constipation, dysentery	Water contaminated by feces of infected humans	Disinfection
Campylobacteriosis	Bacteria <i>Campylobacter jejuni</i>	Fever, diarrhea, abdominal pain	Water contaminated by feces of infected humans/animals	Disinfection
Shigellosis	Bacteria <i>Shigella</i> species	Fever, vomiting, bloody stool, nausea, diarrhea, abdominal cramps	Water contaminated by feces of infected humans/animals	Disinfection
Leptospirosis (Well's disease)	Bacteria <i>Leptospira</i>	Fever, headache, thirst, muscular pain, vomiting, nausea, jaundice, prostration	Water contaminated by feces/urine of infected humans/animals	Disinfection
Gastroenteritis	Bacteria <i>Escherichia coli</i>	Watery diarrhea, nausea, prostration and dehydration	Water contaminated by feces of infected humans/animals.	Disinfection

Waterborne pathogens are transmitted through the fecal-oral route, and human sewage is an important source of contamination. Major changes has been observed in the occurrence of waterborne diseases since the turn of the century that indicates the need of new strategies in order to prevent waterborne outbreaks. The important waterborne outbreaks in the earlier part of the century were typhoid fever and cholera; pathogens susceptible to disinfection. The more recently identified waterborne diseases, such as giardiasis and cryptosporidiosis, are caused by protozoa that are resistant to disinfection. In addition to be transmitted by human sewage, wild and domestic animals are important sources of infection. Since animals can not be excluded from watersheds, emphasis must be placed on water treatment barriers, filtration and disinfection, to ensure adequate margins of safety (29).

Waterborne disease outbreaks are estimated to occur 3 to 10 times more often than reported. This may be due to patients not seeking medical attention or physicians failing to properly diagnose, test for specific infectious agents or failing to report the cases to health authorities.

Cryptosporidiosis. Cryptosporidiosis is a disease caused by *Cryptosporidium parvum*, a parasitic protozoa that lives in the gastrointestinal tract of humans and animals. It is shed in the feces in the form of an “oocyst” which has a hard shell that protect it from the environment. Transmission of *Cryptosporidium* can occur through ingestion of the oocyst from contaminated food or water, from contact with infected persons or animals and from exposure to contaminated feces or surfaces. Water is the largest potential common source of transmission (4).

Cryptosporidiosis can be difficult to diagnose and it is often mistaken for the flu or other intestinal problem. Two to three days after ingestion, the parasite causes watery diarrhea, abdominal pain, fatigue, nausea, vomiting, dehydration, weight loss, fever, headache, abdominal cramps and also contribute to the premature death of immunosuppressed individuals, such as persons with AIDS, organ-transplant recipients, malnourished children and persons receiving treatment for certain types of cancer (57). *Cryptosporidium* is the most commonly detected enteropathogen affecting acquired immunodeficiency syndrome patients (75). In healthy individuals cryptosporidiosis cause abdominal cramps, fever, diarrhea and vomiting, which can result in dehydration and even hospitalizations (81). Sometimes it is self-limiting (70), with a duration of less than one month (112). There is no reliable or curative treatment for cryptosporidiosis. Over the counter medicines for diarrhea are unlikely to help.

Cryptosporidium is widespread in the environment. It infects 70 species of mammals, including cattle, sheep, pigs, goats, dogs, cats, deers, raccoons, foxes, coyotes, beavers, muskrats, rabbits and squirrels (30). When animals live near water bodies, they may serve as carriers of the parasite and may contaminate the water supply. Oocysts from human and animal wastes have been found in rivers, streams, lakes, reservoirs, raw and treated sewage and treated surface water.

The small size and buoyancy of oocysts prevent rapid settlement, allowing them to travel long distances and to be flushed rapidly throughout a water distribution system, preventing timely detection (72). As a result, *Cryptosporidium* has caused massive epidemics and has become recognized as the most important

water contaminant in the United States.

In 1993, a waterborne outbreak of *Cryptosporidium* in Milwaukee, Wisconsin, United States, was responsible for an estimated 403,000 illnesses, 4,400 hospitalizations and 110 deaths. Of those who died, the vast majority were people with HIV/AIDS. The others who died also had weakened immune systems, including people who received chemotherapy to treat cancer and people who had organ transplants. Hundreds of people with HIV/AIDS became severely ill, with *Cryptosporidium* affecting their health and allowing other opportunistic infections to settle in and eventually cause death. While *Cryptosporidium* was not the official cause of death, it was a significant contributing factor (32).

Surveys suggest that *Cryptosporidium* is a problem throughout the world but is more prevalent in developing countries. *Cryptosporidium* oocysts have been identified in human feces from more than 50 countries on 6 continents (15). It is estimated that between 250 and 500 million infections of *Cryptosporidium parvum* occur annually in Africa, Asia and Latin America (107). It is estimated that, only in 1995, 45 million Americans drank tap water from sources that contained *Cryptosporidium parvum* (81).

Chlorine based formulations are not effective against *Cryptosporidium*, making chlorination of the water unable to inactivate the pathogen (43). Protection of the watershed, filtration, use of ozone as a disinfectant and boiling water for 5 minutes are the best protective practices.

Table 9: Documented Outbreaks of Waterborne Cryptosporidiosis

Year	Country	Cases	Reasons for Outbreak Occurring
1984	Texas, USA	117	Sewage contamination of well water
1986	Sheffield, UK	49	Sewage from cattle in water
1987	Georgia, USA	13,000	Operational deficiencies
1988	Scotland, UK	27	Post-treatment contamination
1989	Oxfordshire, UK	516	Contamination of water by cattle
1989	Scotland, UK	442	Unknown
1990	N. Humberside, UK	477	Filters Bypass
1990	Thanet Island, UK	47	Unknown
1991	Pennsylvania, USA	551	Wells influenced by surface water
1992	Oregon, USA	15,000	Chlorine is the only treatment for spring water
1992	Torbay, UK	108	Contaminated well
1992	Warrington, UK	47	Surface contamination during heavy rain & monitoring deficiencies
1992	Yorkshire, UK	125	Contamination during heavy rain
1993	Dorset, UK	40	Unknown
1993	Ontario, CA	193	Wells influenced by surface water
1993	Minnesota, USA	27	Cross connection with wastewater
1993	Wisconsin, USA	403,000	Possible contamination from sewage or agricultural waste.
1993	Washington, USA	7	Well influenced by surface water
1994	Nevada, USA	103	Unknown
1994	Washington, USA	134	Seepage of water from irrigation into well.
1994	South England, UK	229	Unknown
1994	Kanagawa, Japan	461	Cross connection & wastewater pump malfunction
1995	Florida, USA	72	Inadequate backflow prevention
1995	Devon, UK	575	Unknown
1996	British Columbia, CA	29	Sewage from cattle in unfiltered water
1996	British Columbia, CA	100	Sewage from cattle in unfiltered water
1996	Ontario, CA	39	High turbidity in lake water
1996	Saitama, Japan	8,705	Unknown

Sources: Craun, 1998 & Smith/Rose, 1998

Giardiasis. During the past years, giardiasis has been recognized as one of the most frequently occurring waterborne diseases in the United States. It is caused by the one-celled parasite named *Giardia lamblia* that can infect warm-blooded animals and humans. *Giardia* is protected by an outer shell called a cyst that allows

it to survive outside the body for long periods of time. Transmission of *Giardia lamblia* can occur by person-to-person, by activity of animals in the watershed area or by the introduction of sewage into the water supply.

The disease is characterized by one or more of the following symptoms: diarrhea, nausea, anorexia, fever, abdominal cramps, bloating, flatulence, fatigue, weight loss, vomiting and mucus or blood in the stool. Giardiasis is often asymptomatic, but infection may also be chronic. Immunodeficient patients (young children, elderly persons, those receiving immunosuppressive treatment, AIDS patients) may have difficulty in clearing the parasites, leading to prolonged diarrhea, which may be life-threatening (112).

Giardia lamblia occurs everywhere, including arctic locations. Fecal contamination at the source can occur by humans as well as by infected animals such as beavers, coyotes, deers, cattle, dogs and cats. Thirteen percent of adults and up to 50% of children may be infected but are asymptomatic. In the United States and Great Britain, *Giardia lamblia* is the most identified protozoan parasite.

The combination of filtration and disinfection is the most effective process to reduce the risk of a waterborne disease outbreak caused by *Giardia lamblia*. Chlorine and ozone are two of the disinfectants known to effectively kill *Giardia lamblia* cysts, while filtration is effective in trapping and removing the parasite from the water supply.

Viral Gastroenteritis. Viruses are a group of infectious microorganisms that enter through the mouth, multiplies in the body and are passed in the feces. The virus can then be carried on an infected person's hands and can be spread by direct

contact, by consuming food that has been handled by the infected individual, by consuming water contaminated by improperly treated sewage or in fecally contaminated fomites and other objects. If the feces enter a surface water system, there is potential for the spread of a waterborne disease. Enteric viruses of particular concern in water are hepatitis A, hepatitis E, rotaviruses and Norwalk virus.

Hepatitis A is an acute, usually self-limiting disease of the liver caused by hepatitis A virus (HAV). HAV is transmitted from personal contact with an infected person or ingestion of contaminated food and water. Transmission by infectious blood is not common. While water is an important vehicle of HAV transmission, the food route accounts for the majority of reported cases of illness.

A child infected with hepatitis A usually presents no symptoms and could develop a life-long resistance to the infection, but can easily spread the virus. An older child or adult usually develops typical symptoms of hepatitis: fever, poor appetite, nausea, abdominal pain, vomiting, fatigue, malaise, anorexia, darkening of the urine, yellowing of skin and eyes (jaundice) and inflammation and necrosis of the liver. Although the disease is mostly self-limiting and rarely fatal, it may represent a substantial economic burden, especially in poor countries. An estimated 1.5 million clinical cases of HAV occur each year (154).

HAV is one of the most resistant viruses to a variety of physical, chemical and biological agents. It is quite stable at temperatures of 60-80°C and tolerates pH from 1 to 10. However, HAV can be removed from drinking water through coagulation, flocculation and filtration.

Hepatitis E virus (HEV) may cause infectious hepatitis that is nearly indistinguishable from HAV. It is transmitted by the fecal-oral route through the ingestion of water contaminated by fecal material. Infection may also occur by ingesting bivalve molluscan shellfish, including clams, mussels and oysters.

HEV is rare in the human population of the United States, but it is widespread in India, North Africa, Eastern Europe and Asia. HEV seems to be responsible for the majority of cases of hepatitis occurring in Asian countries. The greatest risk of death seems to be associated with women who develop the illness in their third trimester of pregnancy, causing a mortality rate of 20% or more among them, or causing miscarriages and infant deaths (69).

Rotaviruses are transmitted by the fecal-oral route. The disease is characterized by acute onset of vomiting, fever and profuse watery diarrhea. Although infection is usually mild, severe disease may rapidly result in life-threatening dehydration if not appropriately treated.

Rotaviruses are the primary cause of childhood gastroenteritis and adult "traveler diarrhea" (155). They cause more than 25-million cases/year and approximately 800,000 to 900,000 deaths/year among 1 to 4 year old children worldwide (72). The greatest disease burden is in developing countries, where 20-40% of annual hospitalizations for childhood diarrhea are associated with this infection. In these areas, acute diarrhea can turn marginally nourished children into undernourished ones, reducing resistance to infection by other pathogens. In developing countries, most cases of severe rotavirus disease occur in infants, whereas in the industrialized world the majority of severe cases occur beyond the

first year of life. In Australia, England, Japan and the United States, rotavirus infection is shown to be responsible for 34-52% of hospitalizations for childhood gastroenteritis, but mortality from rotavirus diarrhea is extremely rare in those countries.

Like HAV, rotaviruses can be removed from drinking water through coagulation, flocculation and filtration.

Norwalk gastroenteritis is transmitted by the fecal-oral route via contaminated water and food. Water is the most common source of outbreaks and may include water from municipal supplies, wells, recreational lakes, swimming pools and water stored aboard cruise ships. These viruses are easily spread also from human to human. Symptoms may include: nausea, vomiting, diarrhea, abdominal pain, headache and fever. Norwalk virus typically produces vomiting in children but diarrhea in adults. Persons with this infection usually recover within 2-3 days without serious or long-term health effects.

Norwalk viruses are important causes of sporadic and epidemic gastrointestinal disease in the United States, where an estimated 181,000 cases occur annually. Human fatality is rare if the patient is in good health and proper supportive care is available.

Cholera. Cholera is an acute intestinal infection caused by the bacteria *Vibrio Cholerae*. The bacteria enter the body by eating food or drinking water contaminated with the feces or vomitus of someone infected with cholera. In rare occasions, cholera is transmitted by person-to-person contact. It produces an enterotoxin that causes watery diarrhea that can quickly lead to severe dehydration

and death if treatment is not provided promptly. Vomiting also occur in most patients (148). Most persons infected with *Vibrio cholerae* do not become ill, although the bacterium is present in their feces for 7-14 days. Sudden large outbreaks are usually caused by a contaminated water supply.

The vibrio responsible for the seventh pandemic is known as *V. cholerae* O1, biotype El Tor. The pandemic began in 1961 when it first appeared as a cause of epidemic cholera in Indonesia, spreading rapidly to Asia in 1963, India in 1964, USSR, Iran and Iraq in 1965-1966, Africa in 1970 and Latin America in 1991 (148).

Seventy-eight countries reported cholera to the World Health Organization in 1995 (149), 71 countries in 1996 (143) and 74 countries in 1998 (144). During 1996, a total of 143,349 cholera cases were reported, with 6,689 deaths (Table 10). A dramatic increase was observed when compared with the 1998 numbers; 293,121 cases reported with 10,586 deaths. The increase in cholera cases on all continents seems to be related to climate changes following the El Niño phenomenon that creates conditions favorable for cholera outbreaks worldwide. The resulting devastation is so severe that it may take decades before the infrastructure and basic services regain their previous levels. As a result, the number of persons vulnerable to cholera has dramatically increased worldwide, creating favorable conditions for a global cholera crisis.

Africa is the continent accounting for the largest proportion of all reported cholera cases, with 108,535 cases in 1996 and 211,748 cases in 1998. In Africa, mass population movements of refugees and internally displaced persons represent

conditions that increase the risk of large outbreaks of epidemic diarrheal diseases and facilitate the transmission of cholera to previously unaffected areas.

The Americas reported an important decrease in the number of cases, from 85,809 in 1995 to 24,643 in 1996. Efforts to improve living conditions had been focused on water distribution, sewage treatment systems, health education campaigns and food safety. Unfortunately, the disease re-emerged along the Peruvian coastline during 1998, increasing the numbers from 17,760 in 1997 to 57,106 in 1998. This increase was primarily attributable to the continuing effects of major disasters caused by the El Niño phenomenon and Hurricane Mitch.

Typhoid Fever. This gastrointestinal illness is caused by *Salmonella typhi*, a bacteria that is widely distributed in nature and closely associated with animals. Consumption of contaminated poultry and meat products are the most common sources of transmission. When the bacteria are excreted in the feces, contamination of food and water permits transmission of the infection to humans. Person-to-person, fecal-oral transmission does occur and has been a problem in health care facilities due to inadequate hand washing.

Salmonella typhi is a great problem in developing countries, where they have poor hygiene practices and contaminated water supplies, especially Mexico and India. Symptoms may include sustained fever, abdominal pain, fatigue, cough, headache, sore throat and constipation alternated with diarrhea. It may involve fatal liver, spleen, respiratory and neurological damage.

Table 10: Reported Cases of Cholera, 1995-1998

Country/Area	1995		1996		1997		1998	
	Cases	Deaths	Cases	Deaths	Cases	Deaths	Cases	Deaths
Africa	71,081	3,024	108,535	6,216	118,349	5,853	211,748	9,856
Americas	85,809	845	24,643	351	17,760	225	57,106	558
(United States of America)	19*	0	3*	0	4*	0	15*	0
Asia	50,921	1145	10,142	122	11,293	196	24,212	172
Europe	937	20	25	0	18	1	47	0
Oceania (Australia, Guam)	7	0	4	0	5	0	8	0
World Total	208,755	5,034	143,349	6,689	147,425	6,274	293,121	10,586

*Imported cases

Source: World Health Organization

Figure 3: Reported Cases of Cholera, 1995-1998

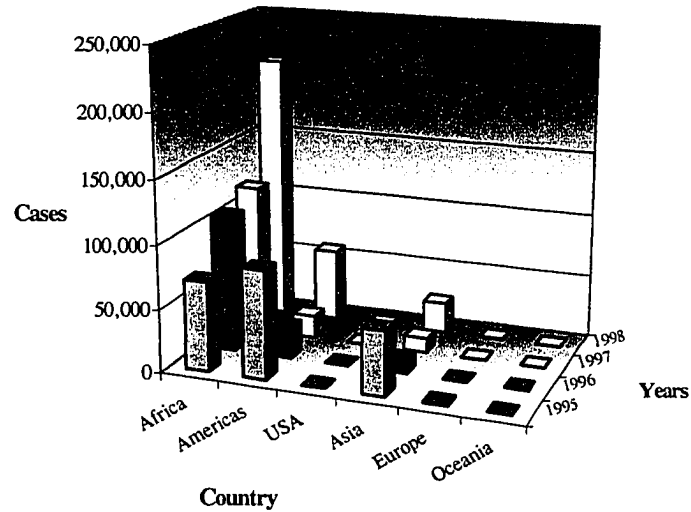
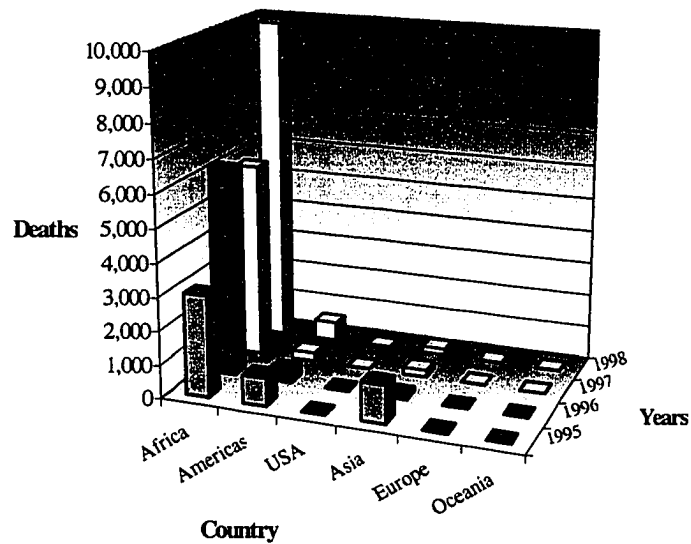


Figure 4: Reported Cholera Deaths, 1995-1998



The annual occurrence of typhoid fever is estimated at 17 million cases, with 600,000 deaths (AWWA). Typhoid fever still remains one of the primary health problems in developing countries. Outbreaks have become rare in industrialized nations and often involve an asymptomatic carrier (44). Most cases observed in North America and Central Europe are associated with travel to places where *Salmonella typhi* is still endemic. Disinfection is an important barrier in the prevention against *Salmonella typhi*. Studies have shown that *S. typhi* is as susceptible to chlorine disinfection as *Escherichia coli*.

Amebiasis. Intestinal illness caused by infection with the protozoan parasite called *Entamoeba histolytica*. Individuals infected with amebiasis may experience recurrent diarrhea, fever, abdominal pain, abdominal cramps, chills, headache and tenesmus. Transmission is by the fecal-oral route, reflecting person-to-person spread or exposure to contaminated food, water or fomites. Cysts can also be spread by flies. It is known that many people infected with *E. histolytica* never develop symptoms and spontaneously clear the infection (153).

Amebiasis is ranked as the third leading killer among parasitic diseases (behind malaria and schistosomiasis) responsible for up to 40,000 deaths per year worldwide (AWWA). In 1986, it was estimated that 480,000,000 people (slightly over 10% of the global population) were infected, with the majority (>80%) asymptomatic.

Campylobacteriosis. Infection caused by the bacteria of the genus *Campylobacter*. It is the most frequent causative agent of acute bacterial enterocolitis worldwide (109). The disease is generally spread by eating or drinking

contaminated food or water and by contact with infected people or animals. It is estimated that this illness affects over 2 million persons every year.

Individuals infected by *Campylobacter jejuni* may experience mild to severe diarrhea, abdominal pain, nausea, fever, vomiting, cramping, traces of blood in the stool and malaise. Most infections are self-limited and usually clear in about a week. Immunodeficient individuals may develop severe, persistent or relapsing infections.

Campylobacter jejuni and related species are members of the intestinal flora of a wide variety of wild and domestic animals (8). Many animals including swine, cattle, dogs and birds carry *Campylobacter* in their intestines. Surface water and mountain streams can become contaminated from infected feces. These sources in turn may contaminate meat products, water supplies, milk and other items in the food chain.

Specific protective practices to reduce the risk of a waterborne disease caused by campylobacteriosis are boiling the water for 5 minutes and adding disinfectants. *Campylobacter jejuni* seems to be more susceptible to chlorine than *Escherichia coli*.

Shigellosis. A highly contagious type of gastroenteritis caused by the bacteria *Shigella*. These bacteria are present in the stool of infected humans. It is spread by direct contact with an infected person's feces or by eating or drinking contaminated food or water.

Shigella dysenteriae type 1 (Sd1) is an unusually virulent enteric pathogen that causes dysentery with high death rates. *Shigella* is the most common cause of

acute bloody diarrhea (dysentery). Apart from bloody stools, symptoms include fever, nausea, vomiting, abdominal cramps, rectal pain, sepsis, seizures, renal failure and watery diarrhea. In almost half of the cases, *Shigella* causes acute non-bloody diarrhea that cannot be distinguished clinically from diarrhea caused by other enteric pathogens (142).

Infection with Sd1 is most common in overcrowded areas with poor sanitation, sub-standard hygiene and unsafe water supplies. Illness tends to be seasonal, occurring during hot, wet weather. Sd1 is most often severe or fatal in young children, infants, elderly and malnourished populations. Approximately 5-15% of Sd1 cases are fatal.

Sd1 is the only *Shigella* species that causes large-scale regional and prolonged outbreaks of dysentery and more frequently fatal illness than does infection with other *Shigella* serogroups. In recent years, Sd1 has caused epidemic dysentery in Central America, South Asia and Central and Southern Africa. An epidemic in Central America from 1969 to 1973 was responsible for more than 500,000 cases and 20,000 deaths. It is likely that most developing countries are at risk of epidemic dysentery due to Sd1 (145).

Leptospirosis. Leptospirosis, also known as Swineherd's Disease, is an acute infectious disease. It is transmitted by the bacteria *Leptospira*, carried by wild and domestic animals including pigs, cattle, dogs, deer, foxes and rats. Humans pick up the infection when they have contact with water, moist soil or vegetation contaminated with the urine or body tissue of infected animals. Cuts in people's skin or splashes of infected fluid to the eye increase the risk of infection. Occasionally,

the bacteria is inhaled when handling contaminated fluids, or it may be ingested by eating food contaminated with the urine of infected rats. The disease is very rarely passed from person to person (150).

Leptospirosis causes a wide range of symptoms, and some infected persons may be asymptomatic. Symptoms include fever, headache, chills, severe muscle pain (in the calves and thighs) and bloodshot eyes. Sometimes the fever may fluctuate and other symptoms, like rash, jaundice, confusion, depression, kidney failure and meningitis may occur. In other cases, it attacks the respiratory system and sometimes causes victims to “drown” as blood or fluid fills their lungs (151).

Bacterial Gastroenteritis. The majority of bacterial gastroenteritis cases is caused by the pathogenic strain of *E. coli*. Fecally contaminated food or water as well as direct contact are the primary modes of transmission. Pathogenic *E. coli* causes travelers and pediatric diarrhea in developing countries. Symptoms include watery diarrhea, abdominal pain, fever and vomiting (156). Fever, if present, is generally low-grade.

The first documented case of waterborne disease outbreak in the United States associated with enteropathogenic *E. coli* occurred in the 1960s. Various serotypes of *E. coli* have been implicated as the etiological agent responsible for disease in newborn infants, usually the result of cross contamination in nurseries. There has been also well documented outbreaks of *E. coli* associated with adult waterborne diseases.

One of the largest waterborne pathogenic *E. coli* outbreaks in the United States occurred in 1975 at Crater Lake National Park in Southern Oregon. More

than 2,000 individuals experienced gastrointestinal disease. The bacteria were found in both the water and fecal samples. It was found that a shallow spring supplying the park's drinking water supply was contaminated by sewage. Although chlorination was used, areas of the distribution system were found to contain no detectable chlorine residual (9). Sporadic infections and outbreaks have been reported from many parts of the world, including North America (Canada, USA), Western Europe (Italy, United Kingdom, Germany), Australia, Asia (Japan) and Southern Africa.

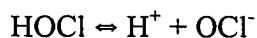
C. Chlorine Chemistry

The application of various forms of chlorine to water in order to disinfect has come into such common acceptance that "chlorination" and "disinfection" are almost considered synonymous.

Chlorine is a strong oxidant that is applied to water in one of 3 forms: elemental chlorine, hypochlorite salts or chlorine dioxide (87). When elemental chlorine is applied to water, it forms hypochlorous acid (HOCl) and hypochloric acid (HCl) according to the following hydrolysis reaction:



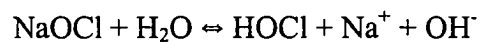
This equation is usually displaced to the right leaving little amounts of chlorine in solution (122). After this reaction takes place, the HOCl is dissociated into hydrogen and hypochlorite ions (135).



This reaction is strongly dependent on the pH. At a pH of 6.5, 10% of the HOCl is dissociated. If the pH is raised to 8.5, then 90% of the hypochlorous acid is dissociated. Between 6.5 and 8.5, any chlorine present will be as both hypochlorous

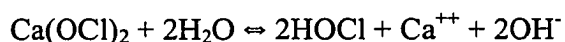
acid and hypochlorite ions. Chlorine existing in these two forms is defined as “free available chlorine”.

In addition to chlorine gas, chlorine is also available in hypochlorite form as both aqueous solutions and dry solids. Sodium hypochlorite is the most common aqueous hypochlorite solution and calcium hypochlorite is the most common dry form of solid hypochlorite. Sodium hypochlorite is produced when chlorine gas is dissolved in a sodium hydroxide solution. Sodium hypochlorite solution typically contains 12.5% available chlorine. One gallon of 12.5% sodium hypochlorite solution typically contains the equivalent dose of one pound of chlorine. The reaction between sodium hypochlorite and water is shown in the following reaction:



This equation shows that the application of sodium hypochlorite to water produces hypochlorous acid, similar to chlorine gas hydrolysis. However, unlike chlorine hydrolysis, the addition of sodium hypochlorite to water yield a hydroxyl ion that will increase the pH of the water.

Calcium hypochlorite is formed from the precipitate that results from dissolving chlorine gas in a solution of calcium oxide (lime) and sodium hydroxide. Granular calcium hypochlorite commercially available typically contains 65% available chlorine (135). This means that 1.5 pounds of calcium hypochlorite contains the equivalent of one pound of chlorine. The reaction between calcium hypochlorite and water is as follows:



The application of calcium hypochlorite to water also produces hypochlorous acid. Similar to sodium hypochlorite solution, the addition of calcium hypochlorite to water yields hydroxyl ions that will increase the pH of the water.

The chlorine inactivation efficiency will depend on the following factors: pH, mixing, concentration of chlorine, interfering organic substances, concentration of ammonia, type of microorganism, contact time, temperature, type of chlorination and turbidity (139). In general, the highest levels of pathogen inactivation are achieved with high chlorine residuals, long contact times, good mixing, low turbidity, high temperatures, low pH and absence of interfering substances. Of the environmental factors, pH and temperature have the most impact on pathogen inactivation by chlorine.

The inactivation efficiency of gaseous chlorine and hypochlorite is the same at the same pH after chlorine addition. However, the addition of gaseous chlorine will decrease the pH while the addition of hypochlorite will increase the pH of the water. Therefore, without pH adjustment, gaseous chlorine will have greater disinfection efficiency than hypochlorite.

Several chlorine-containing compounds (Table 11) are available for drinking water disinfection. The appropriate compound will depend on the characteristics regarding the water supply. Municipal and industrial waters use mostly gaseous chlorine, while small utilities apply hypochlorite. Hypochlorite will be the most economical disinfectant for the majority of small systems with a capacity less than 0.75 million gallons per day (mgd). The decision to use calcium or sodium

hypochlorite should be based on an economic analysis and on other considerations such as storing, feeding and handling.

Table 11: Most Commonly Used Chlorine Compounds for Drinking Water Disinfection

Compound	Chemical Formula	Available Chlorine (%)
Chlorine	Cl ₂	100.0
Calcium Hypochlorite Commercial Preparations	Ca(OCl ₂)	99.2 70-74
Sodium Hypochlorite (Unstable) Commercial Bleach (Industrial) Commercial Bleach (Sodium)	NaOCl	95.2 12-15 3-5

D. Coliform Bacteria: Indicators of Microbial Contamination

Freshwater bodies polluted with fecal discharges from man and animals may transport a variety of pathogens such as bacteria, viruses and protozoans. These pathogens increase the risk of a waterborne disease outbreak. The detection of these pathogens in water is difficult; indicators of fecal contamination are used, such as the Coliform bacteria (total Coliform, fecal Coliform) and *Escherichia coli* (*E. coli*) (59). *E. coli* and fecal coliform are the most commonly accepted indicators and have been used for many decades to assess the microbiological quality of drinking water (28).

An indicator organism should provide evidence of recent fecal contamination from warm-blooded animals. The general criteria for an indicator organism are:

- (a) The indicator organism should be present when the pathogenic organism is present only when the presence of the pathogen represents an imminent danger and come from the same source.
- (b) The indicator organism should be present in fecal material in greater

number than the pathogen.

- (c) The indicator organism should respond similarly to the pathogen to natural environmental conditions and treatment, but has to be more resistant to them.
- (d) The indicator organism should be easy to isolate, identify and enumerate.

Coliform bacteria are used as an indicator of water treatment efficacy, distribution system integrity and as a screen for fecal contamination. These bacteria are present in the normal intestinal flora of humans and other warm-blooded animals and are found in large numbers in fecal wastes (71). Except for a few strains, coliforms are not considered pathogenic. They are common in the environment and are generally not harmful. Complete removal of Coliform bacteria can be achieved by intensive chlorination, even if averages of raw water exceed 10^5 or 10^6 coliform/100ml (36). The presence of these bacteria in drinking water indicates that the water may be contaminated with organisms that may cause disease. A total Coliform test measures the presence or number of living aerobic bacteria in a water sample. If the total coliform test on a drinking water sample is positive, then a fecal coliform or an *E. coli* test must be performed. If a fecal coliform or *E. coli* test is positive, this is a strong indication that the water may be contaminated with fecal material.

Fecal Coliform/*E. Coli* are generally not harmful. *E. Coli* is a rod-shaped bacteria that is an inhabitant of the gastrointestinal tract of humans and warm-blooded animals. The presence of fecal Coliform and/or *E. coli* in drinking water is serious because it is usually associated with organisms that may cause disease. The

presence of these organisms in drinking water is therefore a great concern to health authorities.

Even when coliforms are used as indicators, a coliform test may not be indicative of other organisms such as *Cryptosporidium parvum*, *Giardia lamblia* and virus, which are very resistant to disinfection. Other treatment process should be applied (coagulation, flocculation and filtration) to ensure the removal of these organisms.

A second indicator of microbial water quality is turbidity. Turbidity is a measure of the amount of suspended particles in water. Turbidity is considered to be a better measure of the potential for some protozoan diseases than are coliforms (12).

E. Commonwealth of Puerto Rico Health Profile and Definition of Non-PRASA Communities

The Commonwealth of Puerto Rico underwent a social transformation over the last 50 years that has resulted in a significant increase in longevity and life expectancy. The transition from agricultural society to an urban industrial society has led to changes in the epidemiological profile and the patterns of morbidity and mortality. Chronic degenerative diseases now coexist with acute infectious diseases and the prevalence of cancer and cardiovascular diseases is high, reaching levels characteristics of developed, industrial countries.

In 1997, the first cause of mortality in Puerto Rico was coronary and vascular diseases, followed by cancer (Table 12). The first cause of morbidity in 1993 was diseases of the respiratory system, followed by infectious and parasitic diseases (Table 13).

Table 12: Leading Causes of Death in Puerto Rico, 1997

Causes	Number	%
Heart diseases	6,828	23.6
Cancer	4,527	15.6
Diabetes mellitus	2,169	7.5
Cerebrovascular diseases	1,698	5.9
Accidents and adverse effects	1,493	5.2
Pneumonia & Influenza	1,126	3.9
Homicide & legal intervention	877	3.0
Injury by Firearms	863	3.0
Chronic liver disease & cirrhosis	847	2.9
Others	8,535	29.4
Total	28,963	

Source: Center for Disease Control, 1999

Even when gastroenteritis is not a leading cause for mortality, it is one of the leading causes of morbidity among children (Table 14). One of the factors that may be contributing to this situation could be the drinking water quality. From the 52 notifiable diseases reported weekly to the United States Center for Disease Control, 8 are related to drinking water (Table 16).

Table 13: Morbidity Rates in Puerto Rico, 1993

Disease	Number	%
Diseases of the Respiratory System	2,828,844	48.6
Infectious and Parasitic Diseases	1,036,996	17.8
Diseases of the Digestive System	427,498	7.3
Diseases of the Eyes and Ears	410,365	7.0
Others	1,118,977	19.3
Total	5,822,680	

Source: Puerto Rico Department of Health

In 1977, the reported occurrence of 7,800 cases of gastroenteritis in the Municipality of Comerío drew attention to the phenomenon of epidemic outbreaks of fever with acute gastroenteritis. Investigations concluded that the cause of the outbreak was the bacteriological contamination of a surface water source not

properly disinfected. In the same year, 14,000 cases were reported island-wide by the Puerto Rico Department of Health (PRDOH). As with other waterborne outbreaks, the number of cases were considered low due to unreported cases (54).

Table 14: Morbidity Rates in Children
Puerto Rico, 1993

Disease	Number	%
Common Cold and Influenza	365,488	33.0
Respiratory systems infections*	121,916	11.0
Pneumonia	85,150	7.7
Ear Diseases	36,679	3.3
Dengue	36,591	3.3
Dysentery and Gastroenteritis	36,591	3.3
Non-specific Gastroenteritis and colitis	24,365	2.2
Others	401,726	36.2
Total	1,108,506	

Source: Puerto Rico Department of Health

Table 15: Mortality Rates in Children
Puerto Rico, 1993

Condition	Number	Percentage (%)
Conditions related to prematurity and low birthweight	214	24.5
Congenital Anomalies	171	19.6
Respiratory distress symptoms	144	16.5
Conditions developed in the perinatal period	32	3.7
Pneumonia and Influenza	23	2.6
Others	290	33.1
Total	874	

Source: Puerto Rico Department of Health

Reported cases of acute gastroenteritis at an island-wide level increased from 24,000 in 1986 to 62,000 in 1987. One of the reasons for this increase in the reporting may be community concern and consciousness about water pollution. Even when transmission was through consumption of food or by person-to-person

contact, the general feeling was that contaminated water and sewage treatment plants were responsible for these outbreaks.

In 1987, an outbreak of acute gastroenteritis in Yauco resulted in 800 reported cases in 3 rural barrios. *E. coli* was identified as the main etiologic agent, and inspection revealed the existence of 30 pipe ruptures and other faults in the water distribution system. Even the aquifers of the north coast limestones are not immune from fecal bacteriological contamination. During a community outbreak of acute gastroenteritis in the Municipality of Florida in 1985, the source of infection was discovered to be the local sewage treatment facility. Build in 1964 with a biofiltration capacity of 0.167mgd, the daily flow was 2.4 times greater than the capacity of the existing infrastructure. Raw sewage was periodically discharged by the treatment plant into an adjoining limestone sinkhole and then to the supply of underground drinking water. The public well was closed in 1985, its water unfit for human consumption.

Table 16: List of Notifiable Diseases Related to Waterborne Pathogens and Comparison between Puerto Rico and the United States.

Disease	1997			1998			1999		
	PR	USA	%	PR	USA	%	PR	USA	%
Cholera	0	6	0.0	0	17	0.0	NR	NR	NR
Cryptosporidiosis	0	2566	0.0	0	3793	0.0	0	2379	0.0
<i>E. coli</i> Gastroenteritis	41	3868	1.0	5	5333	0.1	9	5959	0.2
Hepatitis A	270	28305	1.0	94	23229	0.4	236	16919	1.4
Legionellosis	0	1102	0.0	0	1355	0.0	0	956	0.0
Shigelosis	70	23117	0.3	69	23626	0.3	113	16015	0.7
Typhoid Fever	0	365	0.0	2	375	0.5	NR	NR	NR
	381	59329	0.6	170	57728	0.3	358	42228	0.8

Since 1987 two notable outbreaks were reported in Puerto Rico, both in August 1991, one of 202 cases in a penitentiary, the other occurred in Las Piedras,

resulting in 9,847 cases in a community water system. Together, these outbreaks amounted to 78% of all U.S. cases reported in 1991. Partial explanations include the resumption of water supply following interruption by drought, discharges of waste into the source, lack of chlorination and filtering, insufficient flushing of old water from pipes and tanks, cross-connections, back-siphonage and contamination of the mains during repairs and construction. Etiological agents were not identified.

All the outbreaks described below have been related to public water supplies owned by the Puerto Rico Aqueduct and Sewer Authority, also known as PRASA. From the estimated population of Puerto Rico, 3.7 million persons, 97% receives drinking water from PRASA. PRASA is a public corporation responsible for the provision of drinking water and the administration of sanitary sewage systems. The PRDOH maintains active monitoring of drinking water quality in public water systems.

The remaining population receives drinking water from Non-PRASA systems. In general, Non-PRASA systems are public water supplies operated and/or owned by small communities.

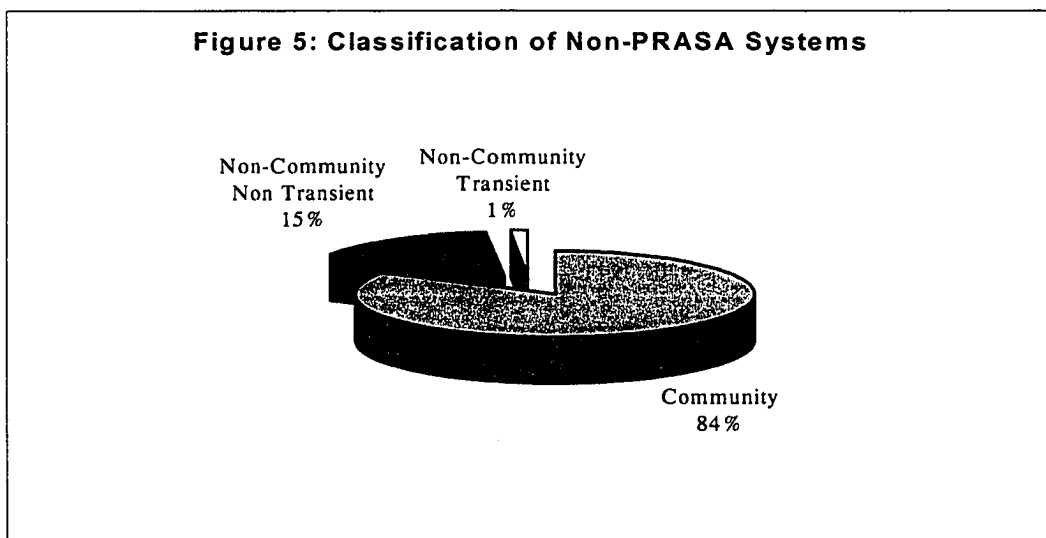
Table 17: Classification of Non-PRASA Systems

Classification	Total of Systems
Community	232
Non-Community Non Transient	42
Non-Community Transient	4
Total	278

The term Non-PRASA means that the water system is not part of the Puerto Rico Aqueduct and Sewer Authority (PRASA). At the present time, there are 278

Non-PRASA systems (Table 17), classified as community and non-community water supplies. Non-PRASA community systems serve approximately 97,000 persons.

A community public water supply is a system that serves drinking water to at least 15 service connections or 25 residents on a year-round basis (121). A Non-Community Non-Transient system serves regularly 25 persons over 6 months/year. A Non-Community Transient water system serves at least 25 different persons over 6 months/year. In Puerto Rico, Non-Community Non-Transient systems are basically industries and they usually comply with drinking water regulations. Non-Community Transient systems have less influence over the population due to the limited time they provide water to a particular person. Based on these factors, this research focuses on the Non-PRASA Community systems.



Non-PRASA community systems are characterized by the low bacteriological quality of the water served. Like many small public water supplies throughout the United States, Non-PRASA systems are in great need of

improvements, especially in the areas of certified personnel, economic stability and water treatment technology (120). Non-PRASA systems represent a risk to the public health of their consumers. The low bacteriological quality of the water served and the limited treatment provided constitute a great concern to health authorities. Several factors are main contributors of the poor quality of the drinking water provided at Non-PRASA systems: a) poor sanitary conditions, b) lack or minimum water treatment, c) lack of maintenance and operation programs, d) unqualified operators, e) limited financial resources, f) easy access of livestock and unauthorized persons to the water source, g) lack of knowledge regarding drinking water regulations, h) lack of interest, i) poor community organization and j) minimum cooperation and participation of the members of the community in water related issues. In addition, the financial pressure of serving a small number of customers and the need to make economic investments to comply with stringent regulations, make it very difficult for them to provide safe drinking water.

In summary, chlorine benefits for the water industry goes beyond the disinfection of drinking water, however, this is their main benefit toward the protection of public health. Chlorine can be applied to the water as gas, liquid or solid; an evaluation of the different available chlorine disinfection methods will determine which one is appropriate to the conditions of a specific water supply. One of these methods, the calcium hypochlorite tablet chlorinator, has gained popularity among Non-PRASA systems. Even when the cost of this technology is low and the maintenance/operation required is minimal, is critical to determine the efficiency of the tablet chlorinator in the inactivation of bacteriological contamination.

OBJECTIVES

The objectives of this research are to determine the vulnerability of Non-PRASA consumers on the Island of Puerto Rico to waterborne pathogens and to determine the efficiency of the tablet chlorinator in the inactivation of these microbiological agents. During the development of this research, the adequacy of this technology for small communities, where economic resources and knowledge of drinking water issues are limited, will also be evaluated. Efficiency will be determined based on the following:

- A. Analysis of the improvement in water quality in relation to the installation of disinfection treatment and vulnerability of Non-PRASA consumers to microbiological contaminants. Analysis will be based on data collected by the Puerto Rico Department of Health (PRDOH) during the 5 years period of 1995-1999.
- B. Evaluation of the appropriateness of the tablet chlorinator on Non-PRASA systems. Analysis will be performed based on the cost, effectiveness, level of operation and maintenance and appropriateness of the technology to the particular characteristics of the Non-PRASA systems. An evaluation of the factors that limit the performance of the tablet chlorinator will be determined and recommendations will be developed to improve or eliminate those factors.

- C. Inactivation of total coliform and fecal coliform bacteria in the distribution system (treated water) compared with the source (raw water). Data will be based on samples taken at the source and throughout the distribution system for 10 days.
- D. Inactivation of viruses and *Giardia lamblia*, according to formulas and procedures indicated by the Surface Water Treatment Rule (SWTR) and the Interim Enhanced Surface Water Treatment Rule (IESWTR) of the United States Environmental Protection Agency (USEPA (132)). Data will be based on measures performed on the field and information provided in the Federal Regulation.

METHODOLOGY

To determine the vulnerability of Non-PRASA communities to waterborne pathogens, an evaluation of the history of waterborne outbreaks in Puerto Rico was carried out. An evaluation of the PRDOH Annual Reports for the period of 1990 to 1999 was also undertaken in order to determine if there were special investigations that correlate Non-PRASA communities to waterborne outbreaks. Finally, all bacteriological sampling results for Non-PRASA systems for the 1994-1999 period were evaluated in order to determine the correlation on the installation of disinfection treatment and improvement in water quality.

To determine the efficiency of the tablet chlorinator in the inactivation of microbiological contamination, a 10-day monitoring was conducted in a Non-PRASA system. The selection of the Finca Geraldo Pagán system was based on a one-year evaluation process in which several factors were taken into account. Since 1995, 52 Non-PRASA surface systems were visited. From these visits, information was obtained to determine the specific characteristics, needs, problems and factors that affect the drinking water quality at Non-PRASA systems. In addition, information from all the systems was obtained through phone calls or through copies of inspections and sanitary surveys performed by the PRDOH. From the initial 232 Non-PRASA systems, only 121 systems use tablet chlorinators to disinfect their drinking water. After this considerable reduction in the number of possible candidates, the following factors were considered: distance from the public water supply to the laboratory, walking distance and access to the sources, cooperation of the community and distance between the groundwater and the surface water sources.

Systems suggested by the PRDOH were also considered. By January 2000, a final list of approximately 20 systems was prepared. The Finca Geraldo Pagán community was the first system contacted and the community accepted immediately to be part of the research.

The Finca Geraldo Pagán system was selected for this Research because the community is working to improve their water supply, they have general knowledge about drinking water issues, they showed a great interest in determining the efficiency of the tablet chlorinator and they have an identified individual who is in charge of the operation and maintenance of their water system. In addition, the community provided a key to facilitate the access to the facilities, the distance between the surface source and the groundwater source was approximately 25 minutes away and the distance from the system to the laboratory was approximately 2.5 hours, making it possible to take the samples and carry them to the laboratory within the timeframe of 5 hours required. Bacteriological samples were required to be kept at 4°C and taken to the laboratory in a 5-hour period of time to avoid bacteriological activity in the sample.

Data were collected for a period of 10 days. The 10-day sampling period was selected according to the actual procedures of the PRDOH, which requires a 10-15 days monitoring period to determine efficiency and viability of new technologies. Sampling points in the distribution system selected for this research are the sampling points the PRDOH use to determine the water quality of these systems every month. These sampling points are representative of the water quality throughout the distribution system.

Sampling was conducted during weekdays, from May 31, 2000 to June 13, 2000. A visit was performed to the facility prior to the sampling period to determine the location of the certified sampling points and to determine the measures of the distribution tanks in order to calculate water volumes.

In summary, the methodology used to determine the vulnerability of Non-PRASA communities to waterborne diseases and the efficiency of the tablet chlorinator was the following:

- A. Community visits, phone calls, evaluation of inspections and sanitary surveys to determine specific characteristics, needs, problems and factors that affect drinking water quality at Non-PRASA systems.
- B. Statistical evaluation of data collected by the PRDOH to correlate the installation of disinfection treatment, its effect on the microbiological quality of the drinking water and the vulnerability of Non-PRASA systems to contamination with waterborne pathogens.
- C. Drinking Water Quality Monitoring. Collection of data from the field performed during a 10-day period in order to determine performance effectiveness and inactivation ratio of coliform bacteria, *Giardia lamblia* and viruses. Parameters measured were:
 1. Density of coliform bacteria. The Most Probable Number (MPN) Method was used to determine the density of total coliform and fecal coliform in raw and treated water, as indicated in the “Standard Methods for the Examination of Water and Wastewater” (5). Analysis of this parameter

was performed at the Environmental Quality Lab, located in Santurce, Puerto Rico, approximately 2 hours and 30 minutes from the Finca Geraldo Pagán system. The density of coliform bacteria was determined in colonies/100mL. Finally, the inactivation of colonies was compared in treated water vs. raw water and efficacy of the disinfection treatment measured.

2. **Residual Chlorine Concentration.** The residual chlorine concentration will ensure the bacteriological quality of the water throughout the distribution system in case of a potential problem. The residual chlorine concentration was measured at certified sampling points throughout the distribution system using a chlorine meter (Hach Pocket Colorimeter, Accuracy ± 0.02 mg/L at 25 °C). Drinking water regulations require a minimum of 0.2 mg/L of disinfectant concentration at the entrance to the distribution system and it is important to allow adequate contact time to assure the inactivation of pathogens.
3. **CT (Concentration/Time) Value.** The CT value is an important factor in determining or predicting the efficiency of any disinfectant. It is defined as the product of the residual disinfectant concentration, C, in mg/L, and the contact time, T, in minutes, that the chlorine is in

contact with water.

4. pH. The pH of the water affects the efficiency of the disinfection treatment. pH values were measured in both raw and treated water using a pH meter.
5. Turbidity. Turbidity is defined as the optical property that causes light to be scattered and absorbed rather than transmitted through a liquid. It is caused by the presence of suspended matter. Particles responsible for turbidity in water can surround and shield pathogenic microorganisms from a disinfectant, interfering with the action of disinfectants and allowing pathogenic organisms in the water to survive and multiply. High turbidity levels in treated water can be an indicator of possible water contamination, inadequate filtration or other water system problems. Turbidity values were measured in the field using a turbidity meter (Hach Portable Turbidimeter, Accuracy $\pm 2\%$ of reading).
6. Temperature. High temperatures increase the rate of disinfection. Temperature is also a critical factor in the growth of microorganisms in drinking water. Even when no significant difference in temperature range has been reported in Puerto Rico, the worldwide patterns of temperature change have begun to affect the island.

Temperatures were measured in the field using a Hach Portable Thermometer. (Accuracy ± 0.1 °C).

7. Water Flow. Water flow is critical in determining the concentration of disinfectant needed to inactivate pathogens in the water, especially during peak hours of water consumption. Water flow measurement was assessed using the system flow meter at the entrance of the distribution tank.
8. Inactivation of *Giardia lamblia* and viruses. Estimated log inactivation was calculated by assuming that the relationship between CT and log inactivation is linear. To determine the log inactivation of *Giardia lamblia* cysts and virus, the following parameters were determined: peak flow, volume, residual chlorine concentration at the distribution system, temperature, pH and CT values. During the 10-day monitoring, 6 points were visited: surface water distribution tank, groundwater distribution tank, river (raw surface water), well (raw groundwater) and 2 residences in the community, one served by the surface source and the other served by the groundwater source. The inactivation of *Giardia lamblia* and viruses is represented by the following mathematical equations:

$$\text{Estimated Log Inactivation}_{\text{Giardia}} = 3 * \text{CT}_{\text{Actual}} / \text{CT}_{\text{Required}}$$

$$\text{Estimated Log Inactivation}_{\text{Virus}} = 4 * \text{CT}_{\text{Actual}} / \text{CT}_{\text{Required}}$$

Table 18: Summary of Data Collection

Parameter	Raw Water	Treated Water
pH	X	X
Temperature (°C)	X	X
Turbidity (NTU)	X	X
Total Coliform Density (colonies/100mL)	X	X
Fecal Coliform Density (colonies/100mL)	X	X
Chlorine Concentration (mg/L)		X
Flow (GPD)	X	
Disinfection Time (min)		X
CT Value		X
Giardia/Virus Log Inactivation		X

Statistical analysis was performed to evaluate if there was significant difference in the averages of the groundwater results vs. surface water results for the chlorine concentration and inactivation of viruses, total coliform, fecal coliform and *Giardia lamblia*. Difference in the average of the raw and treated water for the pH, temperature and turbidity were also evaluated. To perform these determinations, analysis of variances (ANOVA) was used with a 95% confidence level.

In summary, this study determined the vulnerability of Non-PRASA consumers to microbiological contamination and the efficiency of the calcium hypochlorite tablet chlorinator in the inactivation of those agents. The tablet chlorinator was evaluated as a candidate for drinking water disinfection for small public water supplies. If the inactivation of coliform bacteria is proven to be high, the tablet chlorinator will represent an important tool in the protection of public health at developing countries through the reduction of waterborne pathogens in drinking water.

HYPOTHESIS

Amendments to the Safe Drinking Water Act requires the total inactivation of coliform bacteria in drinking water samples taken at certified points throughout the distribution system. The determination of presence/absence of coliform bacteria is an accepted method, substituting the traditional determination of coliform density. Although the presence/absence method is more economic and takes less time, it does not provide detailed information on the performance and efficiency of the water treatment provided.

In terms of public health protection, it is important that the treatment provided at any water supply achieve a virtual 100% inactivation of coliform bacteria. This study expects that the tablet chlorinator will achieve a 100% inactivation of total and fecal coliform bacteria, $\mu = 100\%$, where μ is the inactivation efficiency of total and fecal coliform bacteria for surface and groundwater sources. Regardless of the water source, it is anticipated that the disinfection treatment will achieve the levels of inactivation of *Giardia lamblia* (log 3) and virus (log 4) at levels established in the Safe Drinking Water Act.

DATA COLLECTION, DISCUSSION AND ANALYSIS

A. Characteristics of Non-PRASA Systems

Most Non-PRASA systems serve communities with an average population of about 300 persons, with a range of 28 to 3,500 people (Table 19). Most of the members of these communities are related through family. They have a strong sense of community and provide for each other.

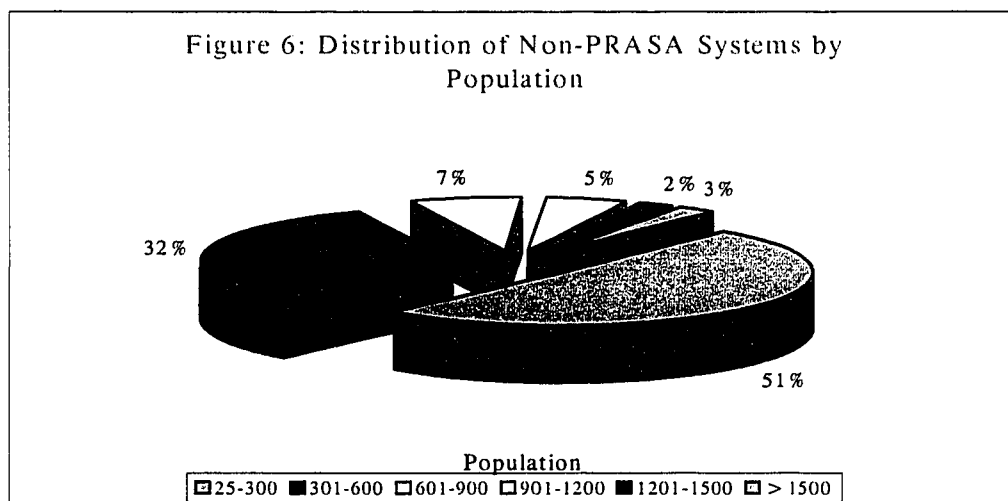
Table 19: Distribution of Non-PRASA Systems by Population

Population Served	Number of Systems
25-300	117
301-600	75
601-900	17
901-1200	12
1201-1500	5
>1500	6

With few exceptions, the person in charge of the public water supply has a limited knowledge about drinking water issues. His main function is to collect the monthly fee, to repair or replace any broken pipes and to clean the distribution tank periodically (several times per year). This person is usually unsalaried. Some communities have a Board of Directors overseeing their water supply. These communities are usually well organized and incorporated. Unfortunately, the organization structure is often temporary.

A monthly fee, between \$2-40 dollars is collected for maintenance charges. The fee is a fixed amount per residence, regardless of the quantity of water consumed. There are no water meters. The fixed fee and the problem of non-

payment, creates conflict among members of the community. In many of the communities, there is a lack of interest regarding improvements in their water system and water conservation practices.



Contrary to what is expected, most of the Non-PRASA houses are of high quality construction and exceed in monetary value most of their urban counterparts (Figure 7). Some members in these communities have a great knowledge of construction practices, thereby reducing construction costs considerably.

One of the main problems of Non-PRASA systems is their location in the mountainous regions of Puerto Rico (Figure 8) (Appendix E). The specific geographical location and topography makes it very difficult and expensive for PRASA to provide drinking water to these communities. Based on Non-PRASA evaluation, the major problem in connecting these communities is that it is not a cost-effective project when a small population is connected, as compared to a large one. The costs required to run pipelines through the mountains, in the areas where

these communities are located, is prohibited. Even when in some cases PRASA is available, a general resistance of the community members to connect to PRASA has been observed (73).

Figure 7: Typical Non-PRASA Residence
Fca. Geraldo Pagán System, Orocovis, Puerto Rico



Figure 8: View of the Finca Geraldo Pagán Community



The lack of interest by community members in water issues can be related to the lack of knowledge of what a positive bacteriological result means and how it could affect their health. Monthly bacteriological monitoring is seen as a requirement and not as a surveillance program to protect themselves from waterborne diseases. This lack of appreciation results in a lack of maintenance of the disinfection equipment, including the replacement of chlorine tablets on a routine basis, increasing the risk of bacterial regrowth throughout the distribution system.

It also has been observed that people dislike the taste that chlorine imparts to the water. Complaints of stomach pain, odor and taste of the water have been received, resulting in the disconnection of the disinfection treatment.

From the factors mentioned above, it is important to mention a common cause: the perception of drinking water quality in the community. Water quality is associated with the physical characteristics of the water. The color, odor and taste of the water are critical factors in the determination of “how good” the water is.

Community members do not relate their drinking water to gastroenteritis occurrence in the community. Even when the occurrence of diarrhea has been reported as once per week (73) in these communities, it is not considered related to their drinking water. Gastroenteritis occurrence is considered as “normal” and treated with medicines that do not require prescriptions, such as “*Pepto Bismol*” and “*Imodium*”. Due to this situation, cases of gastroenteritis are not reported to the Centers for Diagnosis and Treatment.

The limited number of gastroenteritis cases reported results in inaccurate epidemiological information and presents an erroneous point of view of the actual

situation. Non-PRASA members will not see water quality reports and public notification in the press, as they would see for PRASA systems. This gives them a sense of “security” and belief that their water is “not as bad” as the water provided by PRASA. As a result, no epidemiologic information has been documented that associates waterborne disease outbreaks with these communities.

Information collected from outbreaks throughout the United States concluded that there was a high incidence of waterborne cases in areas where an isolated or rare event of contamination occurred. High number of cases was registered in groundwater systems and filtered surface systems with unusual problems of contamination (29). It is possible then to infer that the level of immunity is a key factor in the occurrence of waterborne diseases and that Non-PRASA consumers may have developed a high level of immunity against the prevalent pathogens in their drinking water. Immunity may be acquired through low-level and sporadic exposures to pathogens in drinking water and that may be another reason why no outbreaks of gastroenteritis have been reported in Non-PRASA systems.

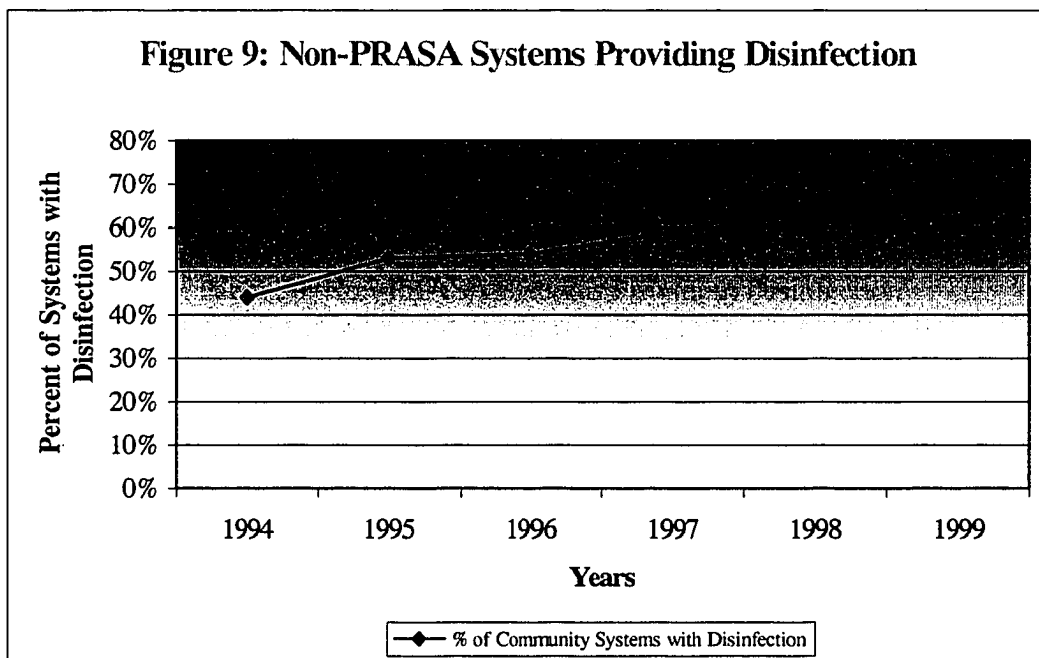
The involvement and participation of women is crucial in safe water programs. In those communities where a woman is an active member of the Board of Directors, there is a sense of responsibility regarding the quality of the water and its possible effect on child health. However, women’s roles in the community are more administrative; the operation of the system is mostly carried out by men.

Due to the urgent need of these systems to provide safe drinking water and to protect public health, several agencies in Puerto Rico and the United States have joined efforts to improve the conditions of the Non-PRASA systems. This effort

focuses on special assistance to the communities in the technical and financial areas. One of the main goals of this effort is the installation of disinfection treatment devices in all Non-PRASA systems. Improvement in the bacteriological quality of the water is expected.

Table 20: Non-PRASA Systems Providing Disinfection

	1994	1995	1996	1997	1998	1999
Community Systems	237	234	232	228	222	232
Community Systems with Disinfection	105	124	125	135	147	156
% of Community Systems with Disinfection	44%	53%	54%	59%	66%	67%



Data provided from the PRDOH show a major increase in the number of Non-PRASA systems providing disinfection from 1994 to 1999 (Table 20). One of

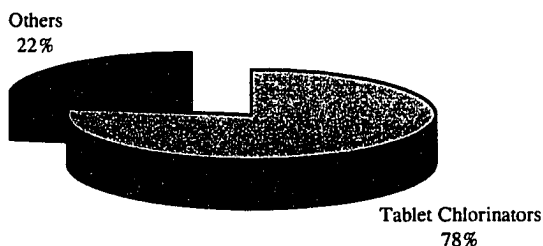
the most used forms of disinfection treatment in Non-PRASA systems is the calcium hypochlorite tablet chlorinator (Table 21).

One of the main problems in determining the efficiency of the tablet chlorinator is that new regulations do not require a coliform density test; a determination of the presence/absence of coliform bacteria may be performed instead. The presence/absence test limits the information that can be obtained regarding the efficiency of this technology in terms of pathogen inactivation.

Table 21: Classification of Disinfection Treatment at Non-PRASA Systems

	Number of Systems	Percentage
Tablet Chlorinators	121	78%
Others	35	22%
Total	156	

Figure 10: Classification of Disinfection Treatment at Non-PRASA Systems

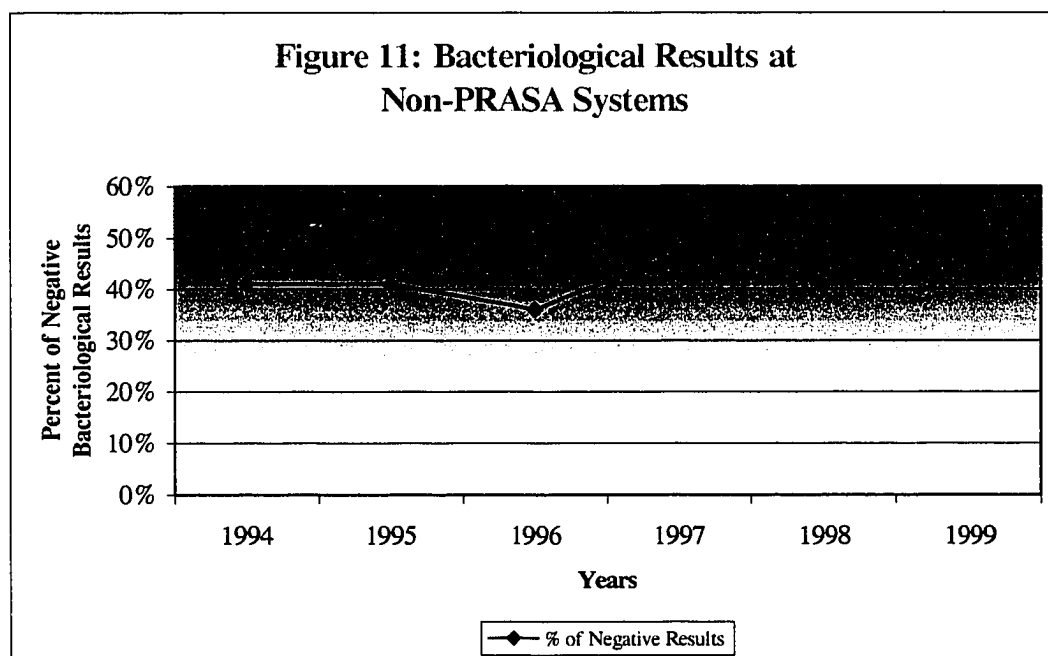


Based on the major increase on systems providing disinfection, it is expected that a similar increase in the number of negative bacteriological results will be seen.

The microbiological water quality in these systems shows an improvement as the number of systems providing disinfection increase.

Table 22: Bacteriological Results at Non-PRASA Systems

	1994	1995	1996	1997	1998	1999
Number of Negative Results	544	560	511	738	1093	1085
Total Number of Samples	1334	1370	1409	1566	2118	2040
% of Negative Results	41%	41%	36%	47%	52%	53%



As shown in Table 23, Non-PRASA surface water systems show a considerably higher level of microbiological contamination (71%) that is significantly reduced when disinfection is provided (39%). However, even when a significant improvement in the water quality is observed, approximately 40% of the water samples contaminated with fecal material are not inactivated by the

disinfection treatment. It is critical to mention at this point that only 5 surface water systems out of 116 provide disinfection and filtration. The remaining 111 systems are in violation of the Surface Water Treatment Rule (SWTR) that requires the installation of filtration treatment at all surface water sources and groundwater sources with direct connection to surface water.

Groundwater sources show a low level of fecal contamination (34%) even when no disinfection is provided. However, it is observed that disinfection treatment reduce significantly this level of contamination (12%).

Table 23: Vulnerability of Non-PRASA Systems to Microbiological Contamination

Bacti Results	Groundwater Systems		Surface Systems	
	With Disinfection	Without Disinfection	With Disinfection	Without Disinfection
A	777 (67)	29 (26%)	249 (46%)	30 (13%)
PA	239 (21%)	46 (40%)	79 (15%)	37 (16%)
PP	139 (12%)	39 (34%)	213 (39%)	163 (71%)
Total Number of Samples	1155	114	541	230
Total Number of Systems	97	19	59	57

During 1998, the Puerto Rico Department of Health performed a special monthly monitoring on Non-PRASA systems providing disinfection. As a result of this monitoring, it was determined that both disinfection methods used in Non-PRASA systems, tablet chlorinators and hypochlorinators, can be effective if optimum chlorine levels are maintained throughout the distribution system to ensure the complete inactivation of pathogens in water. One of the most important

variables that determined the bacteriological quality of the drinking water in this study was the residual chlorine concentration at the distribution system (Table 24).

Table 24: Bacteriological Results of Non-PRASA Systems with Disinfection by Water Source and Residual Chlorine Concentration

Source	Chlorine Concentration (mg/L)	Coliform Samples	Samples	(%)
Ground Water	≥ 0.2	Negative Total Coliform (A)	295	91
		Positive Total Coliform/Negative Fecal Coliform (PA)	21	7
		Positive Total Coliform/Positive Fecal Coliform (PP)	7	2
		Total	323	
	<0.2	Negative Total Coliform (A)	183	43
		Positive Total Coliform/Negative Fecal Coliform (PA)	147	34
		Positive Total Coliform/Positive Fecal Coliform (PP)	99	23
		Total	429	
Surface Water	≥ 0.2	Negative Total Coliform (A)	123	84
		Positive Total Coliform/Negative Fecal Coliform (PA)	14	9
		Positive Total Coliform/Positive Fecal Coliform (PP)	10	6
		Total	147	
	<0.2	Negative Total Coliform (A)	79	24
		Positive Total Coliform/Negative Fecal Coliform (PA)	46	14
		Positive Total Coliform/Positive Fecal Coliform (PP)	202	62
		Total	327	

As part of this research, all the results from the PRDOH were evaluated. One important observation is that, if the residual chlorine concentration is kept

consistently at 0.2 mg/L or over, the number of positive samples can be dramatically reduced (2% for groundwater sources and 6% for surface water sources).

B. Characteristics of the Finca Geraldo Pagán System

The Finca Geraldo Pagán System is located at the 143rd Street, Ramal 590, in the Barrio Bauta Abajo in Orocovis. The system serves water to 210 residences, composed of a population of 1,000 persons and has an approximate consumption rate of 30,000 gallons per day. The system provides water from 2 different sources, a groundwater and a surface source, which are not mixed. It has been recommended that residences receiving water from surface sources boil their water before consumption.

The Finca Geraldo Pagán system is located in the Municipality of Orocovis, in the central area of Puerto Rico, over 1,600 feet above sea level (Figure 12). The mean annual temperature is 76°F (24.4°C), annual precipitation is 70 inches and the annual humidity index is 40% (Table 25).

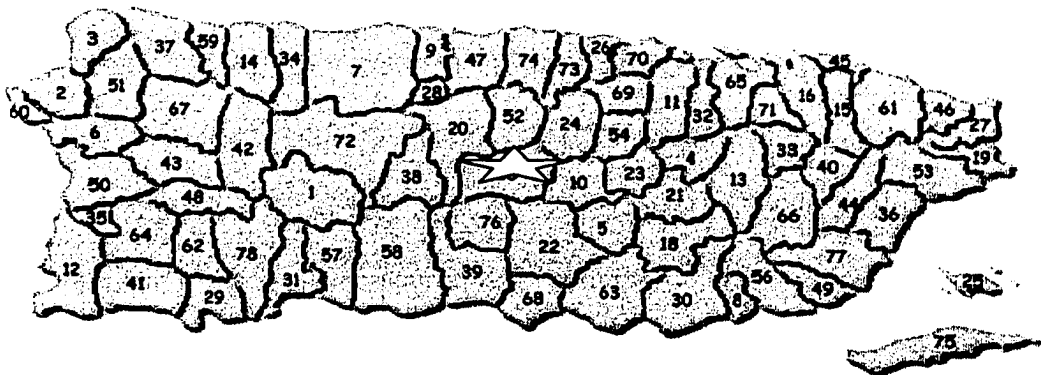
Table 25: Climatological Condition of the Municipality of Orocovis and Puerto Rico

	Orocovis	Puerto Rico
Mean Annual Temperature	76 °F (24.4 °C)	78 °F (25.6 °C)
Annual Precipitation	70 inches	68 inches
Annual Humidity Index	40%	78%

The public water supply system has suffered important changes since its construction in 1977, when the Rural Development Corporation and the community joined efforts to provide water to this area. The original system provided water only from a surface source. In the last 5 years, the Municipality of Orocovis, the Rural

Development Corporation and the community have been working together to substitute the surface water source in order to improve the water quality. As a result of this effort, two wells were drilled. Unfortunately, the amount of water produced from one of the wells is not enough to satisfy the water demand of the community. The community is still working together with several entities to seek alternatives to eliminate the surface water source. In addition to a lower water quality that characterizes the surface water source at the Finca Geraldo Pagán system, during raining periods (higher during the months of May, September and October) the turbidity of the water reach high levels, making the water unsuitable for human consumption.

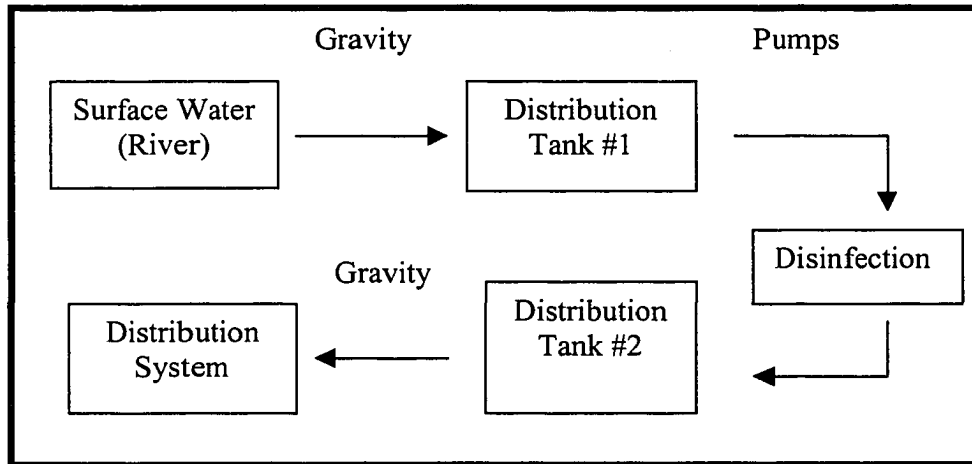
Figure 12: Location of the Finca Geraldo Pagán in the Municipality of Orocovis



The surface water source is a small stream located at the Km. 4.1, Ramal 590 of the Barrio Bauta Abajo (Figure 16). The stream discharges into the Rio Grande. No sources of contamination were detected in the vicinity of the source. However, there is free access to the stream by humans and animals. Water from the stream gets into a distribution tank that is located close to the stream. Through the use of

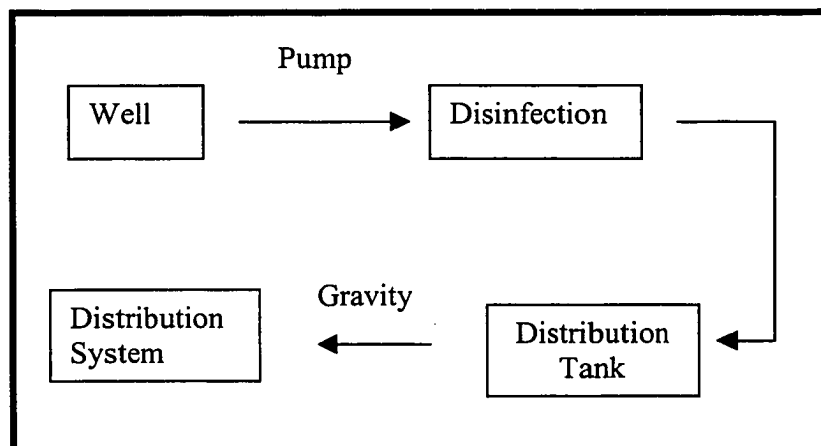
pumps, the water is sent to a second distribution tank where disinfection takes place. From there, water is distributed to the residences by gravity flow (Figure 13).

Figure 13: Schematic of the Surface Water System, Finca Geraldo Pagán



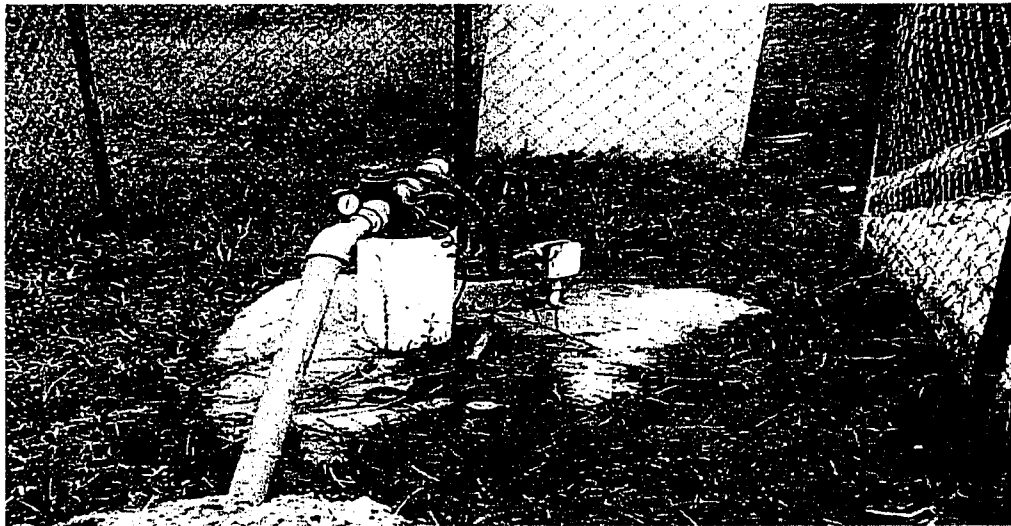
The groundwater source is located at the community park (Figure 15). A fence protects the well from intruders. There was no source of contamination close to the well. Water from the well is sent into a distribution tank, where disinfection takes place. The water is then sent to the community also by means of gravity flow.

Figure 14: Schematic of the Groundwater System, Finca Geraldo Pagán



There is another Non-PRASA system close to the Finca Geraldo Pagán system. Although it shares the same surface source, it has different distribution systems. PRASA is also close and it is possible that they serve water to some residents of the Finca Geraldo Pagán system located at the lowest areas of the community.

Figure 15: View of the Well, Finca Geraldo Pagán System



A Board of Directors is in charge of the administration of the public water supply. The president of the Board, Ms. Marianna Pagan, is a professional nurse who has knowledge of water issues and its potential effects on public health. The operational part of the public water supply is in the charge of Mr. Andrés Rodriguez, who receives \$100 weekly for the maintenance of the system. Some of Mr. Rodriguez duties are replacing chlorine tablets, cleaning the dam, daily monitoring of chlorine and making minor repairs in the distribution system. Mr. Rodriguez has a strong knowledge of the water system and his great sense of responsibility in

dealing with the operation and maintenance of the system has resulted in a better water quality. Mr. Rodriguez and Ms. Pagán were the contact persons during the performance of the research.

No record of a reported outbreak of disease related to waterborne pathogens was found for this community. The Finca Geraldo Pagán consumers feel their water is “OK”, but they are still working together to eliminate the surface source. Community members do not remember either of the occurrences of waterborne diseases in the community, but they commented on hearing about events that occurred at other public water systems, such as a community where a dead dog was found in the distribution tank.

The president of the community showed special interest in this Research, because she is concerned about the efficiency of the tablet chlorinator. The community wanted to evaluate this technology and determine if it was good enough or if they need to begin to generate funding sources to substitute the current disinfection for another. According to Mr. Rodriguez, if chlorine levels are kept too high, he receives complaints of water taste.

Table 26: Bacteriological Results of the Finca Geraldo Pagán System
October 1998 – September 1999

Coliform Samples	Samples
Negative Total Coliform	11
Positive Total Coliform/Negative Fecal Coliform	2
Positive Total Coliform/Positive Fecal Coliform	5
Total	18

One of the remarkable aspects of this community is that they work together to improve their water system. They receive the assistance of the Municipality of

Orocovis, which pays the monthly electrical bill. The Rural Development Corporation assisted them in the well drilling. At the present time, the community is looking for funds from the Senate to complete the improvements at the water system.

The community members with whom I interacted, expressed their concern about the water quality of the surface source, especially when it rains. They also asked for assistance in how they can obtain funds to improve their water system and indicated their plans to substitute the surface water source with a well.

Figure 16: View of Surface Source Intake, Finca Geraldo Pagán System



C. Characteristics of the Tablet Chlorinator

The most commonly used disinfection treatment at Non-PRASA systems is the Aquaward tablet chlorinator, which consists of 2 5/8" diameter calcium hypochlorite tablets in an erosion feeder (Figure 17). The use of the calcium hypochlorite in tablet form eliminates the safety and handling problems associated with the use of gas cylinders and drums of liquid sodium hypochlorite.

Calcium hypochlorite is an off-white material available in powder, granular or compressed tablet form. Commercial high-level calcium hypochlorite contains 70% available chlorine. Under normal storage conditions, about 3-5% of the available chlorine content is lost in a year. Calcium hypochlorite should be stored in dry and cool areas.

Figure 17: View of the Tablet Chlorinator



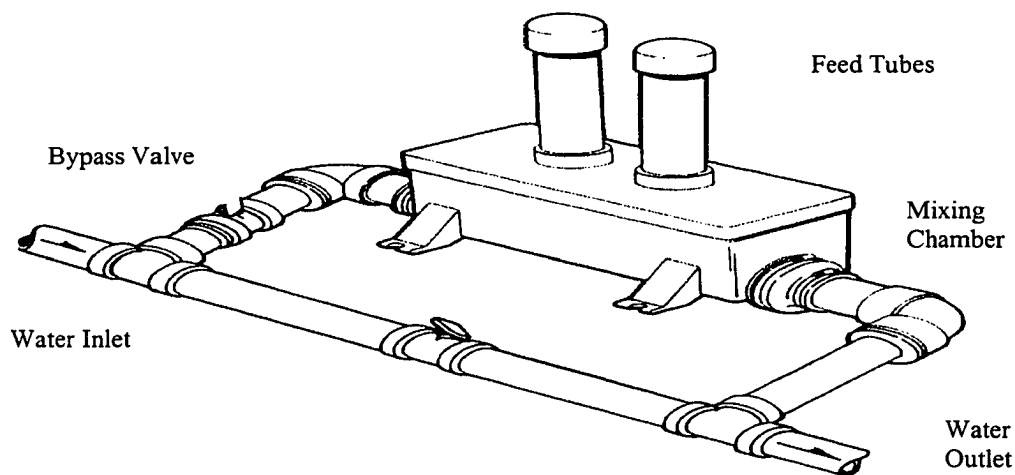
The existing tablet chlorinators can treat up to 10,000 gallons of water/day. The tablet feeder has no moving parts and no metal parts that are susceptible to corrosion. The tablets drop into 2 vertical tubes. At the bottom of the tube water comes in contact with the tablets and slowly dissolves them. The remaining tablets slide down the tube.

A plate located at the outlet of the unit provides chlorine dosage control at different flow rates. Generally, the water flow is divided evenly between the tablet feeder and the bypass valve. An increased flow causes water to rise and contact more

tablets. Flow entering through the system can be adjusted through the bypass valve and consequently sets the chlorine dosage to the required level.

Maintenance procedures required are very rudimentary and consist of refilling the tubes with tablets and an occasional internal inspection of the unit for clogging. The unit can operate automatically for months between tablet refills; the length of time depends upon the water flow rate and the chlorine dosage required (Figure 19). Since each application is different, simple adjustments make the system release the proper amount of chlorine for safe water treatment. Tube arrangements provide rough calibration and adjusting the bypass provides regulation of chlorine dosage levels.

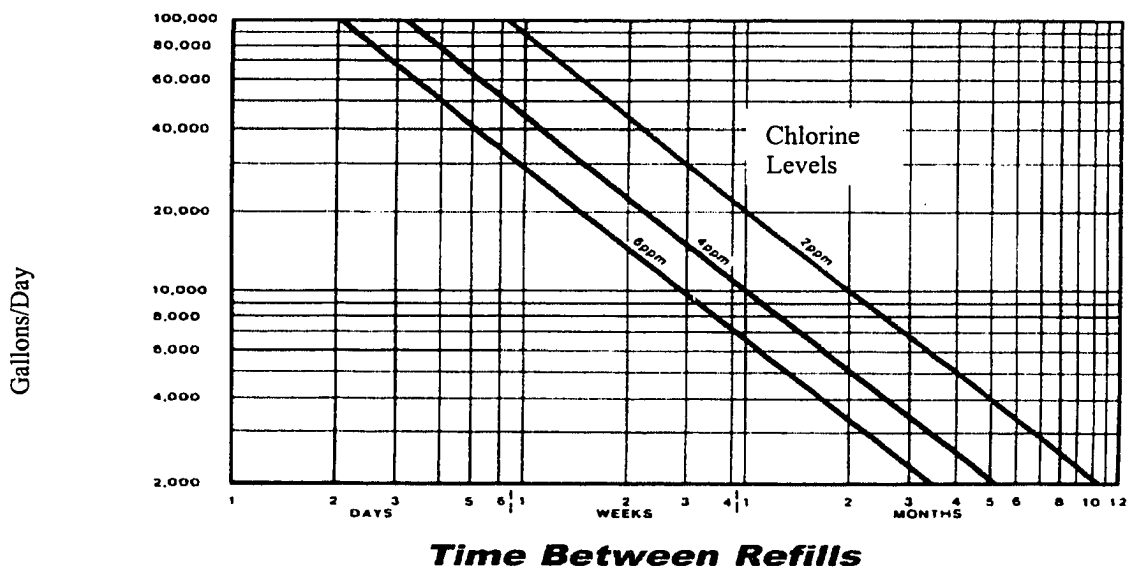
Figure 18: Schematic of the Tablet Chlorinator



Non-PRASA systems have indicated several problems with the tablet chlorinator. One of the most common problems is the expansion and clogging of the tablet in the tube. In the specific case of the Non-PRASA systems, this problem increases when the tablet chlorinator is protected in a cement or zinc structure. When high temperature conditions exist inside the cement or zinc structure, the

water coming through the feeder evaporates, stays trapped in the top of the tube, condenses and the water vapor makes the tablets to expand. A question at this point is, when this situation happens, how much of the chlorine is lost and how effective are the expanded tablets? This problem can be eliminated or reduced if the diameter of the tube is increased and if some aeration is provided to the tube to dissipate the vapor.

Figure 19: Time Between Refills



The tablet chlorinator cannot be used for every system. Floatable systems (serves some residences before it fills the distribution tank) and systems without distribution tank are not candidate for this type of disinfection. In communities with a floatable system, residences located before the distribution tank will not receive treated water. For these communities, the sodium hypochlorite (liquid) chlorinator is a better alternative, in which chlorine solution is injected to the main lines directly, making possible the disinfection treatment at any part of the system.

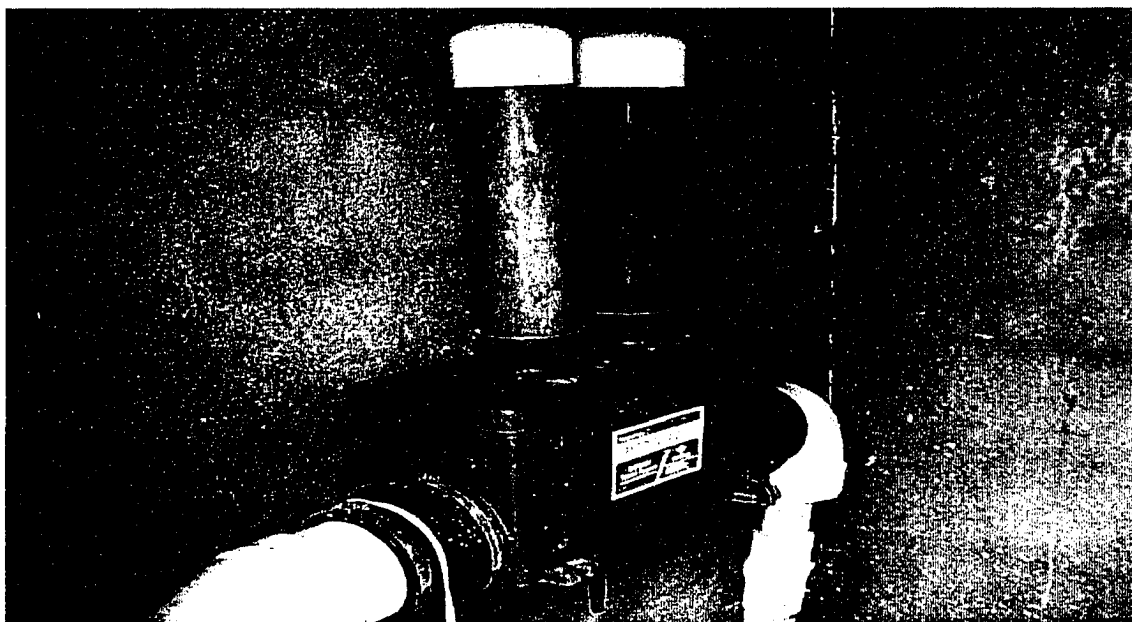
At some communities it was found that the tablet used was manufactured and designed for swimming pools, not for human consumption. Another problem is that the bypass and the tablet feeder are usually installed parallel with the floor (flat) instead of perpendicular to the floor. When the tablet feeder is positioned parallel to the floor, there is an increase in the amount of water passing through the tablet feeder, dissolving all the tablets at the same time and increasing considerably the concentration of chlorine in water. The over chlorination may cause a strong chlorine odor and gastric pain. As a result of this situation, some communities had rejected the use of chlorine in their systems.

The initial cost of the chlorinator unit is approximately \$400.00. Forty-five pounds of tablets cost approximately \$175.00 and, in a community like Finca Geraldo Pagán, it can last up to 6 months. Since the system does not use electricity, no further operational and maintenance costs are required.

Table 27: Advantages and Disadvantages of Tablet Chlorinator

Advantages	Disadvantages
<ul style="list-style-type: none"> • Chlorine tablets are safer to handle and store than gaseous or liquid forms of chlorine • Easy to install, no complex piping, metering valves, mixing tanks or electrical connections required • Minimal investment, minimal operating and maintenance cost. • Unattended operation • Units build with non-corrosive polyethylene and PVC plastics • Transparent tubes let you see when to add more tablets • Provide continuous and controlled release of chlorine 	<ul style="list-style-type: none"> • In systems where there is no controlled flow, chlorine concentrations may be too high or too low • Floatable systems and systems with no distribution tank are not eligible for this technology • Clogging problems may occur. • Water vapor reacts with the tablet, releasing chlorine gas

Figure 20: Aquaward Tablet Chlorinator installed at the Finca Geraldo Pagán System



D. Inactivation of Pathogens and Performance Efficiency of the Tablet Chlorinator

Tables 28-35 summarize the data collected. Parameters measured were pH, temperature, turbidity, residual chlorine concentration, inactivation of *Giardia lamblia* cysts, viruses and coliform bacteria (total and fecal). Each parameter will be discussed by separate.

The pH of the water affects the efficiency of the disinfection treatment. According to the literature, the efficiency of the disinfection treatment will increase when pH levels are lower. That means that the pH of the water is inversely proportional to the disinfection efficiency. Literature indicates that calcium hypochlorite is less effective than the addition of chlorine gas because it increase the pH of the water and reduces the efficiency of the disinfection treatment. Due to this, an evaluation was made regarding the addition of calcium hypochlorite and its

effects on the pH levels for the surface and groundwater sources (Table 28). For the surface water source, pH levels range from 7.3 to 7.9, with an average of 7.6, while for the groundwater source the range was from 7.6 to 8.4 with an average of 7.9. In the groundwater samples, there was no significant difference between the means of the raw and treated water samples. In the surface water samples there were significant differences between the pH of raw and treated water. However, pH levels were lower for treated water, contrary of what was expected. No factors were determined as the main contributor of this situation. An evaluation of the water quality, including the organic content of the surface water, could determine the specific factors that decrease the pH of the water, eliminating the effects of the addition of the calcium hypochlorite in the pH of the water. It can be concluded at this point, and only for the specific conditions of this study, that pH levels were not affected by the addition of calcium hypochlorite to drinking water and that the pH is not a limiting factor in the efficiency of the tablet chlorinator. All the pH results fall into the normal range for pH in drinking water (6.5-8.5).

The water temperature is a critical factor in the biological activities of microorganisms. At the same time, higher temperatures increase the rate of disinfection. Table 29 presents temperature results in °C. Temperature measures were used in the determination of inactivation rates of *Giardia lamblia* cysts and viruses. Surface water temperatures ranged from 21 to 24°C, while groundwater temperatures ranged from 20.5 to 23 °C. Groundwater temperatures (average 21.5 °C) were, as expected, slightly lower than the surface water temperatures (average 22.0 °C). There was significant difference in the mean of the surface raw and treated

water. For the groundwater source, there was no difference between the mean of the raw and treated water.

A turbidity profile is shown in Figures 21 and 22. Turbidity is a critical factor in the inactivation of indicator organisms. High levels of turbidity in water can interfere with the disinfectant action of chlorine. Turbidity results for surface water range from 2.1 to 4.6 NTU, with an average of 3.4 NTU, while in the groundwater samples the turbidity levels vary from 0.1 to 4.4, with an average of 0.61 NTU. For the surface water, there was significant difference between the means of the raw and treated water. For the groundwater source, there was no difference between the means of the raw and treated water. In the surface water samples, it is interesting to observe that turbidity levels of the raw water (average 3.8 NTU) are higher than the treated water (Average 3.0 NTU). A possible explanation to this situation is that chlorine is reacting with the turbidity present in the water resulting in a precipitate and that there is a sedimentation process through the piping system. In the case of the groundwater source, it was observed during two days (days 2 and 10) when turbidity levels were high. A possible explanation for this situation is that this well has direct influence of surface water and that environmental conditions, like rain, have an immediate effect in the physical characteristics of the water.

A disinfection profile is shown in Figure 23 for the residual chlorine concentration at the distribution system for the ground and surface sources. Chlorine concentration values for the surface source range from 0.5 to 1.7 mg/L and from 0.6 to 1.3 mg/L for the groundwater source. The average chlorine concentration for the surface water was 1.06 mg/L while for the groundwater system was 1.01 mg/L. The

difference between the means of the chlorine concentration for the surface and ground water sources is not significant.

Chlorine concentrations at the distribution system were kept over the concentration required by the Safe Drinking Water Act (0.2 mg/L) to ensure adequate inactivation of waterborne pathogens. It can be concluded at this point, that chlorine concentration levels are not a limiting factor in the performance of the tablet chlorinator.

Table 32 summarizes the inactivation rates of *Giardia lamblia* cysts at the Finca Geraldo Pagán system. The effects of the residual chlorine concentration in the inactivation of these protozoa were observed, indicating the importance of adequate chlorine concentration to achieve high levels of pathogen inactivation. During the first 3 days of sampling, the minimum inactivation of *Giardia lamblia* cysts at the surface source was not achieved. For the groundwater source, the same situation occurred during 4 days. This situation occurred because it was observed that, during some days, there was not enough water in the distribution tank. As a result of this situation, the time the chlorine reacts with the water is minimal due to the high water demand and low flow. This situation affects the CT value, which affects the inactivation ratio of *Giardia lamblia* cysts. An additional possible explanation is that the pumps were not working at their full capacity, due to insufficient flow at the source or to a pump mechanical problem.

Table 33 summarizes the results for viruses inactivation. For the surface source, results of virus inactivation vary from 22.3 to 143.7, with an average of 89.9. For the groundwater source, results vary from 13.1 to 157.1, with an average of 82.6.

Chlorine concentration at the distribution system and the contact time were enough to achieve a high level of inactivation of viruses in water. Analysis of variance determined that there was no significant difference in means of the inactivation of viruses between the surface and groundwater sources.

Results for inactivation of total coliform bacteria are shown in Figure 26. The presence of total coliform bacteria in drinking water is considered as an indicator of microbiological contamination, even when the bacteria are not harmful. The average inactivation rate for total coliform bacteria for the surface source was 96.5% and 100.0% for the groundwater sources. No difference was found in the means of both sources.

Figure 27 presents the results for the inactivation of fecal coliform bacteria in the water samples taken. Even when few strains of these bacteria are harmful, the presence of fecal coliform in drinking water indicates that the water is contaminated with fecal material from warm-blooded animals and that it may carry waterborne pathogens. Table 35 summarizes the results of the inactivation rates for fecal coliform bacteria due to the disinfection treatment. The average inactivation rate for the surface source was 96.3% and for the groundwater source was 100.0%. The difference between both averages was non-significant. Additional treatment may be needed at the Finca Geraldo Pagán surface source to increase inactivation ratios for coliform bacteria. Another option to improve the performance of the tablet chlorinator at this system is to fill the 2 tubes with chlorine tablets, instead of the one used, to increase the chlorine concentration levels throughout the distribution system.

**Table 28: pH Profile
Finca Geraldo Pagán System, May - June, 2000**

			Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
pH	Surface Water	Raw Water	7.8	7.5	7.7	7.9	7.6	7.6	7.9	7.6	7.6	7.6
		Treated Water	7.3	7.8	7.4	7.4	7.4	7.4	7.7	7.5	7.5	7.6
	Ground Water	Raw Water	7.9	8.0	8.3	8.2	7.6	7.8	7.8	7.9	7.9	7.6
		Treated Water	8.4	7.7	7.6	8.1	7.8	7.9	7.9	7.9	8.0	7.8

**Table 29: Temperature Profile
Finca Geraldo Pagán System, May - June, 2000**

			Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	
Temperature (°C)	Surface Water	Raw Water	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	22.0	
		Treated Water	23.0	22.0	23.0	22.0	22.0	23.0	23.0	24.0	23.0	23.0	
	Ground Water	Raw Water	21.0	20.5	22.0	21.0	22.0	21.0	21.0	21.0	21.0	22.0	21.0
		Treated Water	22.0	21.0	21.0	22.0	22.0	21.0	22.0	22.0	22.0	22.0	23.0

**Table 30: Turbidity Profile
Finca Geraldo Pagán System, May – June, 2000**

			Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Turbidity (NTU)	Surface Water	Raw Water	4.1	4.0	3.8	3.6	3.7	4.5	3.5	3.1	3.7	3.8
		Treated Water	3.2	3.2	3.0	2.7	2.6	4.6	3.2	2.6	2.1	2.4
	Ground Water	Raw Water	1.1	4.4	0.2	0.7	0.2	0.1	0.4	0.1	0.3	2.1
		Treated Water	0.1	0.1	0.1	0.8	0.3	0.1	0.1	0.1	0.7	0.2

**Table 31: Disinfection Profile
Residual Chlorine Concentration at Distribution System
Finca Geraldo Pagán System, May – June, 2000**

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Residual Chlorine Concentration (mg/L)	Surface Water	1.0	0.5	0.9	1.7	1.1	1.2	1.0	1.2	1.0	1.0
	Ground Water	0.6	1.1	1.3	1.2	1.1	1.1	0.9	0.9	0.9	1.0

**Table 32: Disinfection Profile
Inactivation of *Giardia lamblia* cysts
Finca Geraldo Pagán System, May – June, 2000**

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Log Inactivation of <i>Giardia lamblia</i>	Surface Water	2.7	1.0	2.4	6.7	4.1	5.4	4.3	5.2	3.0	3.9
	Ground Water	3.3	6.0	8.7	5.0	5.1	2.9	0.6	4.1	0.6	1.7

**Table 33: Disinfection Profile
Inactivation of Viruses
Finca Geraldo Pagán System, May – June, 2000**

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Log Inactivation of Viruses	Surface Water	48.0	22.3	57.5	137.1	95.4	114.2	106.2	143.7	76.2	98.5
	Ground Water	80.6	128.6	157.1	142.3	96.9	62.1	13.1	92.3	16.9	36.1

**Table 34: Disinfection Profile
Inactivation of Coliform Bacteria (Total)
Finca Geraldo Pagán System, May – June, 2000**

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Inactivation of Total Coliform (%)	Surface Water	100.0	100.0	100.0	100.0	75.0	100.0	100.0	100.0	96.0	94.0
	Ground Water	*	*	100.0	100.0	*	100.0	100.0	100.0	*	*

* No colonies found in Raw Water

**Table 35: Disinfection Profile
Inactivation of Coliform Bacteria (Fecal)
Finca Geraldo Pagán System, May – June, 2000**

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Inactivation of Fecal Coliform (%)	Surface Water	100.0	100.0	100.0	100.0	99.4	100.0	100.0	100.0	82.0	82.0
	Ground Water	*	*	100.0	100.0	*	100.0	100.0	*	*	*

* No colonies found in Raw Water

**Figure 21: Turbidity Profile
Surface Water Source
Fca. Geraldo Pagán System**

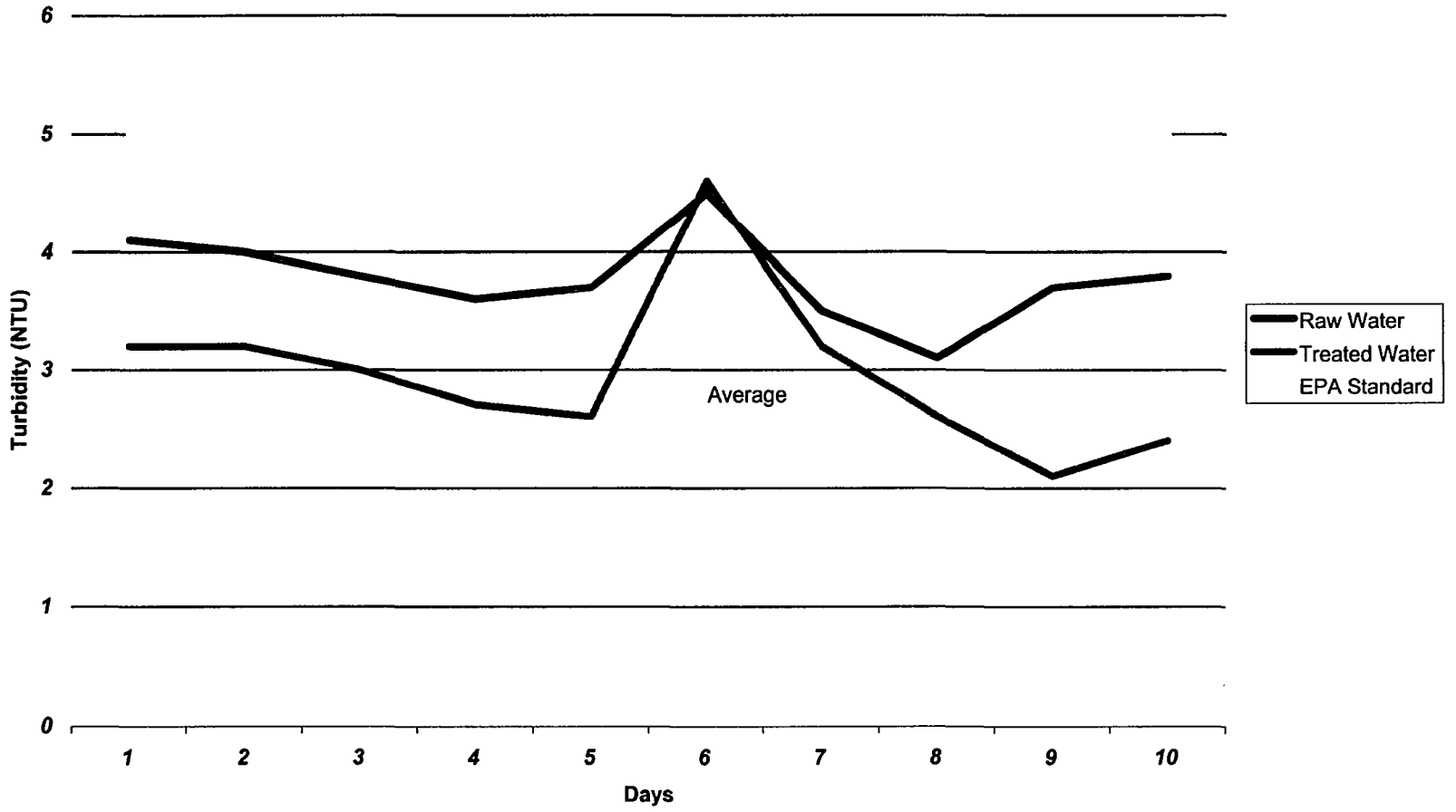


Figure 22: Turbidity Profile
Groundwater Source
Fca. Geraldo Pagán System

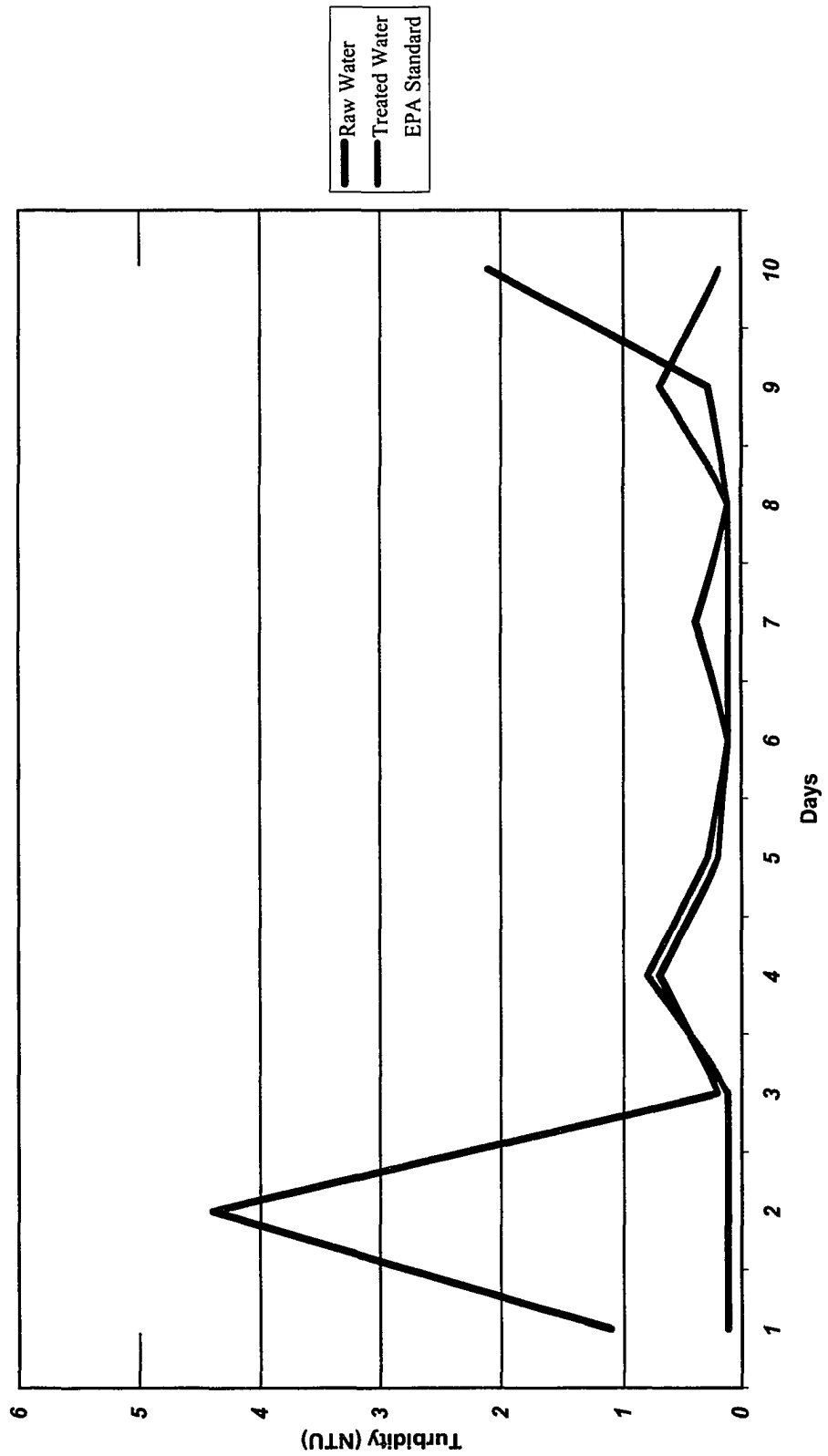
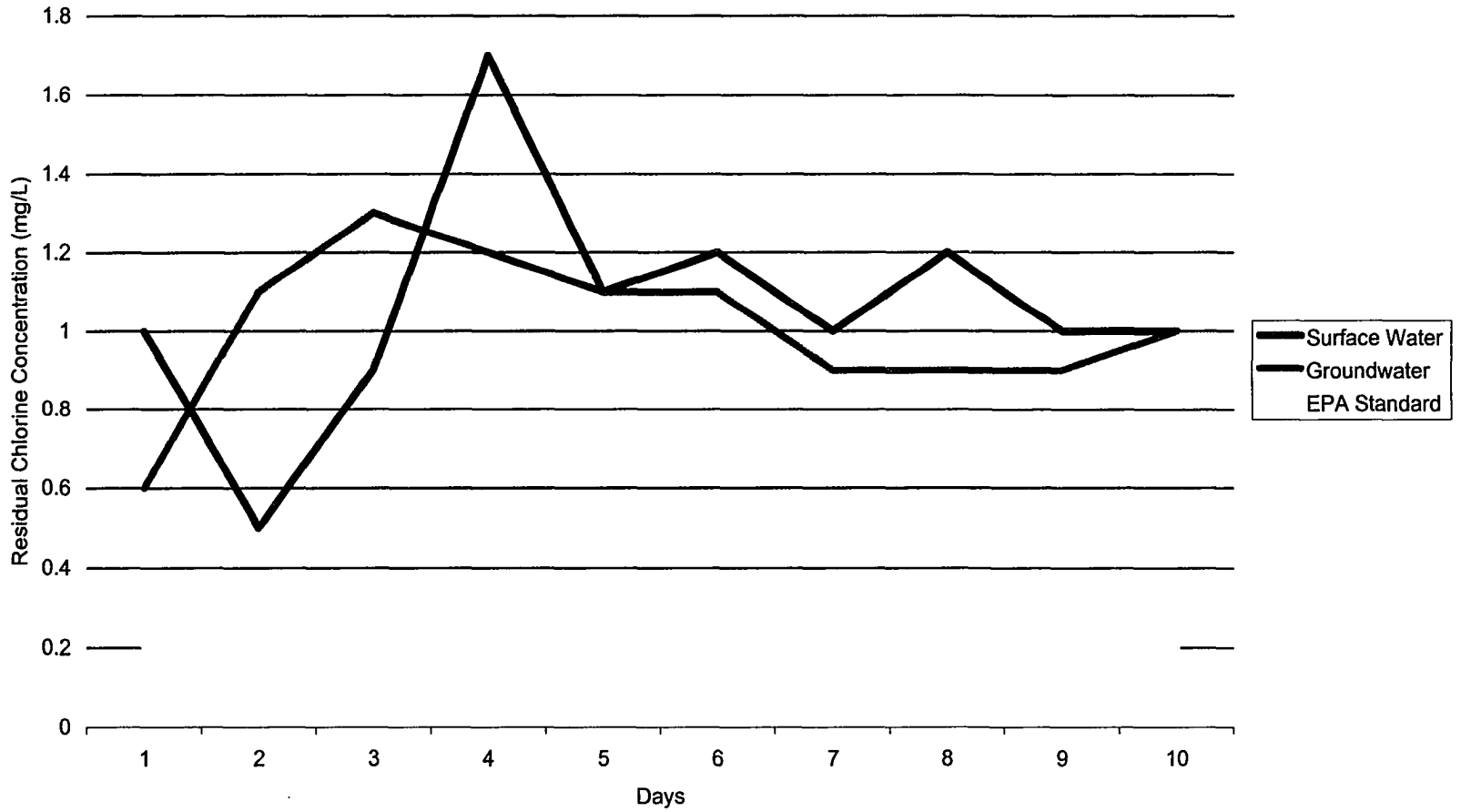
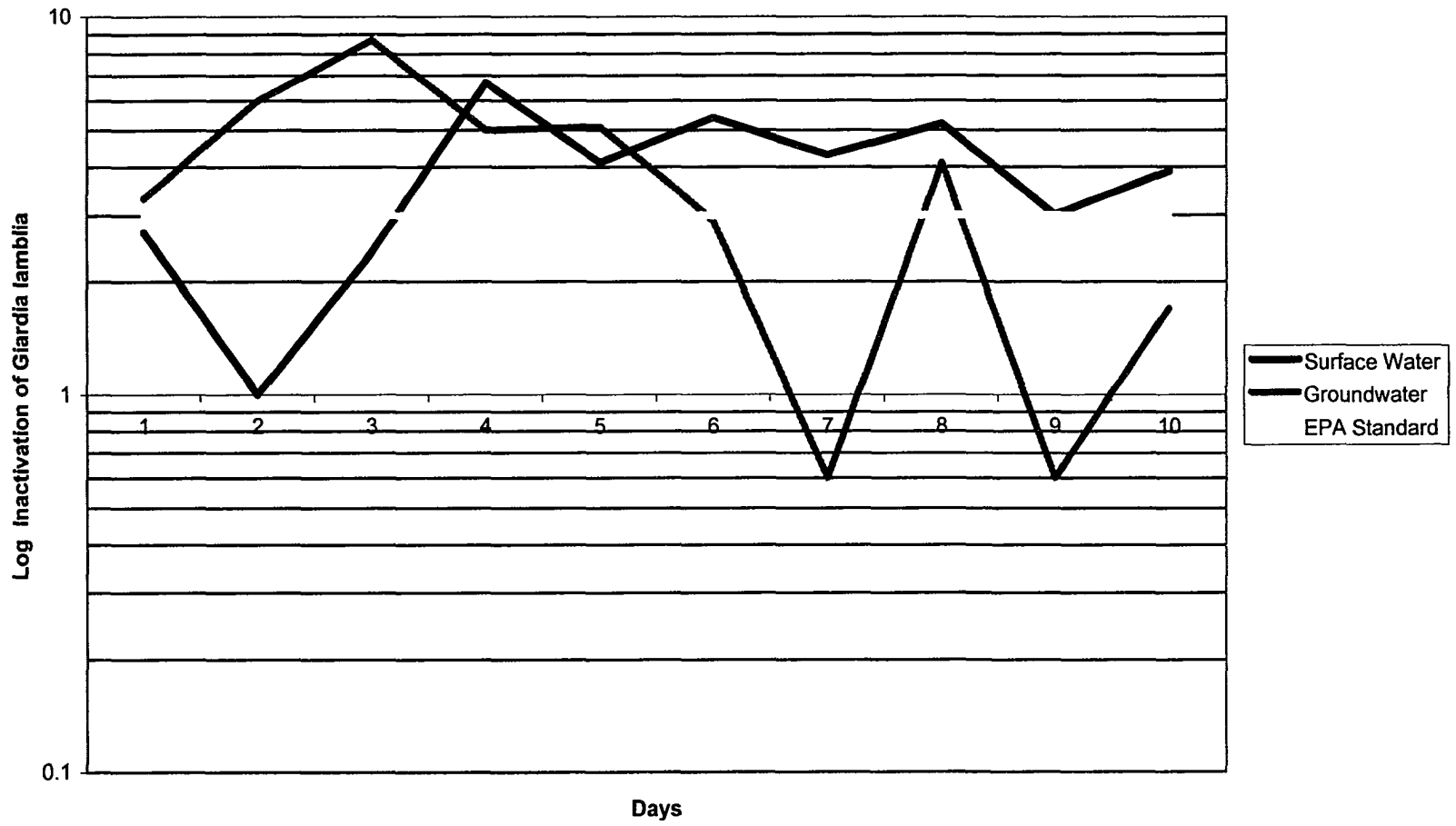


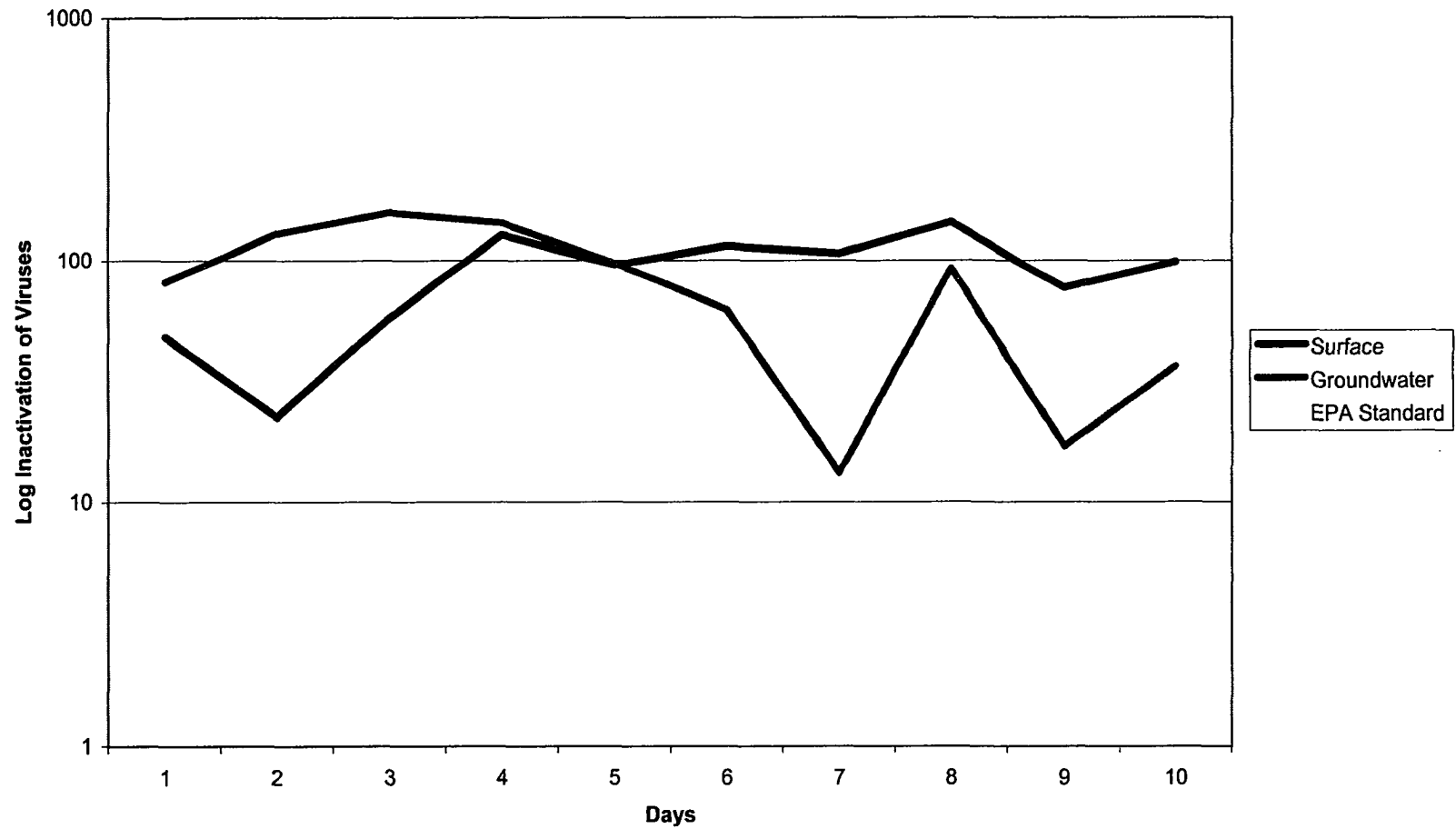
Figure 23: Disinfection Profile
Residual Chlorine Concentration at Surface and Groundwater Sources
Fca. Geraldo Pagán System



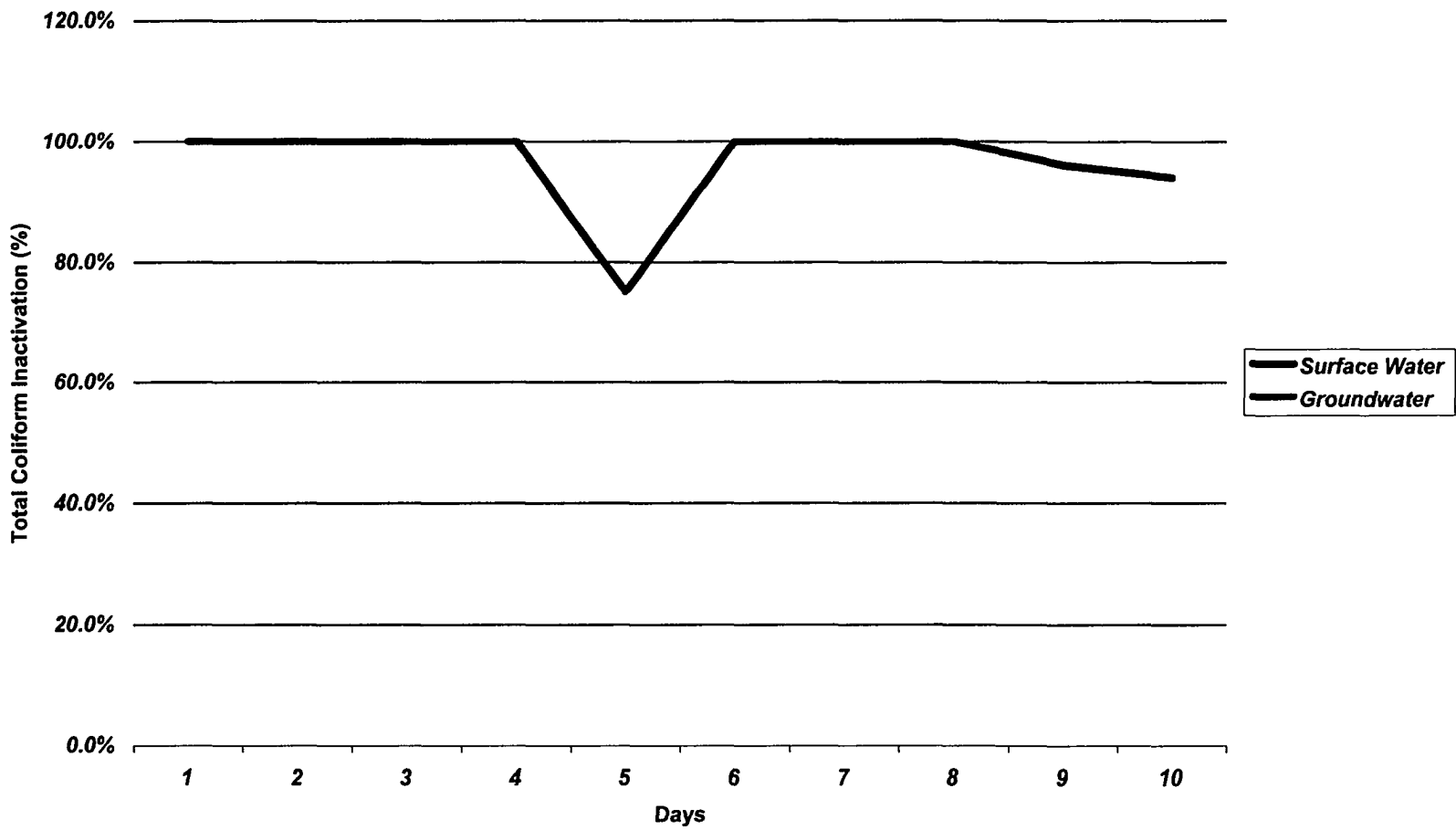
**Fig. 24: Estimated Log Inactivation of Giardia lamblia
Surface and Grounwater Sources
Fca. Geraldo Pagán System**



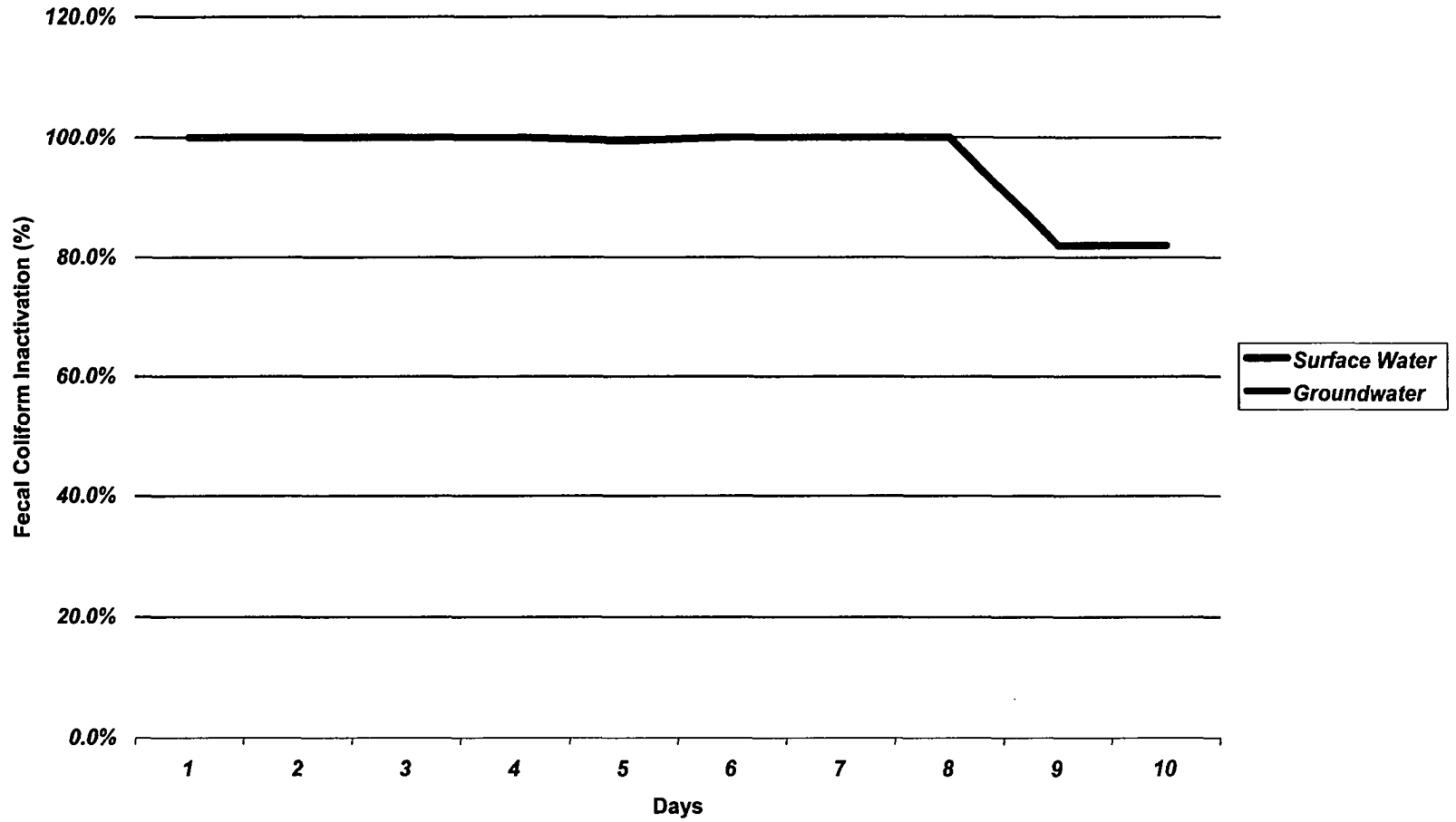
**Fig. 25: Estimated Log Inactivation of Viruses
Surface and Groundwater Sources
Fca. Geraldo Pagán System**



**Fig. 26: Inactivation of Total Coliform Bacteria
Surface and Groundwater Sources
Fca. Geraldo Pagán System**



**Fig. 27: Inactivation of Fecal Coliform Bacteria
Surface and Groundwater Sources
Fca. Geraldo Pagán System**



CONCLUSIONS

The chlorination of drinking water is considered as one of the most important public health interventions in the fight against waterborne diseases. Chlorine's main benefit is the protection of public health through the inactivation/control of waterborne pathogens.

The United States and many developed countries have experienced a reduction in the number of waterborne diseases since the introduction of chlorine for drinking water disinfection. Technological advances, proper disposal of sewage, vaccination, the implementation of drinking water regulations and the development of public health services are also factors that have contribute to the reduction in waterborne diseases.

Unfortunately, in developing countries, the lack of disinfection treatment and sanitary practices is still one of the major threats to public health. Untreated or inadequately treated water results in a great number of waterborne diseases, especially in the poorest areas. Water scarcity, cultural behavior, lack of health education, overcrowding, poverty and inadequate waste disposal are factors that aggravate the difficult situation at these countries. The introduction of sanitary practices and the installation of water treatment facilities are critical in order to significantly reduce the number of waterborne diseases in these regions.

One of the possible alternatives for the disinfection of drinking water is the calcium hypochlorite tablet chlorinator. This study's objective was to evaluate the efficiency of the tablet chlorinator in the inactivation of pathogenic agents. Non-PRASA communities in Puerto Rico were selected for this study. An evaluation of

the vulnerability of these communities to microbiological contamination was also performed.

The vulnerability study performed at Non-PRASA systems shows that Non-PRASA consumers are exposed to microbiological contamination, especially in those communities served by surface water sources. During 1999, 71% of the water samples taken at 57 surface water systems and 34% of water samples taken at 19 groundwater systems were found to be contaminated with fecal material when no treatment was provided. When disinfection treatment was applied, 12% of groundwater samples and 39% of surface water samples showed fecal contamination. The reduction in the number of contaminated samples is strong evidence that disinfection treatment is an important tool in the protection of public health among Non-PRASA consumers.

Non-PRASA consumers are at a high risk of waterborne diseases due to the poor microbiological quality of the water served. The high levels of fecal contamination, especially from surface water sources, represent a special risk to public health. However, no data are available regarding the occurrence of waterborne diseases at these areas. Several factors are associated with this situation, two of them are the perception of the drinking water quality and the possible level of immunity that Non-PRASA consumers may have developed when constantly exposed to specific waterborne pathogens.

Technical assistances and installation of disinfection treatment at these communities by various entities are beginning to show excellent results in the water quality. The main objective during the last few years has been to install disinfection

treatment whenever possible. The tablet chlorinator is one of the preferred choices for disinfection treatment due to its low cost and easy operation/maintenance.

The second part of this study consisted on the determination of the efficiency of the calcium hypochlorite tablet chlorinator in the inactivation of coliform bacteria, viruses and *Giardia lamblia*. The Finca Geraldo Pagan system was selected for a 10-day monitoring. Sampling results showed high levels of inactivation of viruses and coliform bacteria. However, high levels of *Giardia lamblia* were not achieved. The main reason for this situation is that the volume of water was greatly reduced during monitoring. At peak hours, the water demand was so high that it did not allow the water to be in contact with the chlorine for enough time to inactivate *Giardia lamblia* cysts. This problem is the result of engineering deficiencies at the system and is not attributable to the tablet chlorinator itself.

Even when the tablet chlorinator achieved the expected levels of inactivation of coliform bacteria in the groundwater source, it did not achieve the levels expected for the surface water source. Even when chlorination is considered as one of the most important barriers against the transmission of waterborne pathogens, it should not be the only one, especially at surface water sources. The installation of filtration plants can make disinfection more effective by removing turbidity and microbiological contamination. When a multiple barrier approach is applied, lower concentrations of chlorine can be used.

The tablet chlorinator could represent a viable alternative for small systems located in the poorest areas of developing countries. It can be used as a main tool for the protection of public health through the control/inactivation of water pathogens at

small communities. The excellent bacteriological water quality as a result of the use of this technology could be a key in the reduction of waterborne diseases. The low cost of the tablet chlorinator, its easy installation and the fact that it does not require electricity, make this technology an ideal alternative for remote locations. The advantages of the tablet chlorinator are greater than its disadvantages. However, this technology is not applicable to every water system. One of the most important restrictions is that the tablet chlorinator has to be installed over a distribution tank. The second restriction is that the tablet chlorinator is not a good alternative for floatable systems.

One of the main problems found regarding the use of the tablet chlorinator was the constant clogging of the unit. This situation results in the release of chlorine gas and in the interruption of disinfection treatment. To minimize this problem, the tablet chlorinator should be installed in a ventilated structure and inspection of the unit for clogging should be done on a daily basis. Determination of chlorine levels throughout the distribution system could be another action that the community could perform on a daily basis to evaluate the performance of the tablet chlorinator.

The tablet chlorinator has proven to be an excellent disinfection treatment. However, the final decision will depend on the interest of the community in maintaining the system operating with the required chlorine concentration needed to ensure the adequate inactivation of waterborne pathogens. If the residual chlorine concentration is kept at a level of 0.2 mg/L or above, the microbiological quality of the water would be excellent, even with surface water sources.

The success of the tablet chlorinator in the inactivation of waterborne pathogens will be determined by a complex interaction of factors related to the community, the source water quality and the technology itself. The cultural behavior of the community, their knowledge of sanitary practices and public health issues are factors that will determine the acceptability of the technology in that population. Factors related to the water quality such as turbidity, pH, temperature and density of pathogens, will determine the applicability and efficiency of the technology. Finally, the proper installation, operation and maintenance of the system will determine also the highest rates of efficiency that the technology may achieve. An evaluation of the community where the technology will be installed will show variability of the factors mentioned above as well as the inclusion of new factors that will be critical in the performance of the tablet chlorinator.

Like any other technology, the success of the tablet chlorinator will depend also on the human factor. It is important to study the characteristics of the community where the technology will be applied, in order to determine which factors are key elements in possible successful or failure of the tablet chlorinator in that particular population. Pilot studies can be developed at selected locations throughout a country to evaluate the adaptability of this technology. In the specific case of the Non-PRASA system selected for this study, the community selected demonstrated that, even when they did not have a deep knowledge in water issues, they had interest in the improvement of the water system. The involvement and participation of women in the water decision-making of the Finca Geraldo Pagán system was observed to be a key factor because the interest of the community in the

water system goes beyond of what “is required” by the Puerto Rico Department of Health. In this community, the protection of public health, especially child health is a priority and the successful operation of the disinfection treatment is an important tool in the reduction of the risk of waterborne diseases. So, it is important that the community involved “buy” the concept of what the technology is and understand the benefits it would bring to them.

The future of Non-PRASA communities on Puerto Rico is uncertain. Stringent regulations made it impossible for these communities to be in compliance with PRDOH Drinking Water Regulations. However, the first priority should be to reduce the number of these systems through their connection to PRASA. Knowing how hard is to reach this objective, it can be said that over 90% of the Non-PRASA communities will remain as such. For these systems, the priority should be to change the surface source to a groundwater source, to install disinfection treatment and to assist the communities in the operation and maintenance of the systems. Unfortunately, it is clear that some communities will be confronting civil penalties due to their constant violations to the Safe Drinking Water Act.

Progress in Non-PRASA communities is very slow due to the high economic burden imposed on these communities. The constant changes in the Board of Directors and the lack of economic and technical capabilities make some people think that working at these communities is a “lost fight”. However, while Non-PRASA communities exist, there will be entities working to ensure the public health of these consumers. One possible alternative for Non-PRASA system is that PRASA

take control over the system, providing the public water supply with economic and technical stability.

One of the biggest challenge at Non-PRASA communities is to make them aware of the importance of the quality of their drinking water and the adverse effects that can result if they do not get involved in the operation and maintenance of their public water supply. It is important to educate communities about the microbiological safety of their drinking water and their responsibilities as a public water supply regarding the public health of the community members. The participation and involvement of community members in drinking water issues are critical factors in the successful operation and maintenance of the systems.

In the case of the Finca Geraldo system, the community is working on the substitution of the surface water source and they already have a reliable disinfection system. Contrary to other Non-PRASA systems, the community has a worker who performs the operation and maintenance duties of the public water supply for several years. The community has the economic output of the Municipality, which pays the electrical bill generated by the operation of the well. The main problem of this system is the high water demand compared to the water production. While the substitution of the surface water source takes place, water conservation practices should be in place to satisfy the water demand of all the consumers and to ensure the contact time in order to inactivate *Giardia lamblia*. They may also increase the amounts of chlorine applied at the entrance of the distribution system every time the water volume decreases, increasing the contact time between water and chlorine. This can be done through minor adjustments of the tablet chlorinator. In addition, an

evaluation of the pumps and the well should be made in order to determine the reasons of the low flow.

During the performance of this study some other questions arose that could be the basis for future research. A different kind of disinfection treatment using on-site generation of chlorine from salt will be installed at 8 Non-PRASA systems during the year 2001, making it an ideal research area for the comparison between different forms of disinfection treatment at Non-PRASA systems. Also, Non-PRASA systems are in great need of epidemiological studies. This is an area that can help the communities to reach an understanding of the microbiological situation of the water served at these public water supplies.

GLOSSARY

1. **Acute:** Referring to a disease of rapid onset, short duration and pronounced symptoms.
2. **Algae:** Microscopic plants that contain chlorophyll and live floating or suspended in water. They are food for fish and small aquatic animals. Excess algal growths can impart tastes and odors to water. Their biological activities affect the pH and dissolve oxygen of the water.
3. **Anorexia:** Loss of appetite, especially when prolonged.
4. **Bacteria:** Microscopic living organisms usually consisting of a single cell. Some bacteria may also cause human, animal and plant health problems.
5. **Bloating:** To cause or result in accumulation of gas in the digestive tract.
6. **Cell:** The functional and structural subunit of living organisms separated from its surrounding by a limiting membrane.
7. **Chloramines:** Compounds formed by the reaction of hypochlorous acid or aqueous chlorine with ammonia.
8. **Chlorination:** The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results.
9. **Chlorinator:** A metering device which is used to add chlorine to water.
10. **Chlorine demand:** Difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand change with dosage, time, temperature, pH and nature and amount of the impurities in the water.

11. **Coliform:** A group of bacteria found in the intestines of warm-blooded animals, plants, soil, air and water. The presence of coliform is an indication that the water is polluted and may contain pathogenic organisms.
12. **Contact Time:** The length of time water is exposed to a disinfectant.
13. **Contaminant:** Any physical, chemical, biological, or radiological substance or matter that has an adverse effect.
14. **Cross connection:** Any actual or potential connection between a drinking water system and an unapproved water supply or other possible source of contamination.
15. **CT or CT_{calc}:** The product of “residual disinfectant concentration” (C) in mg/L, determined before or at the first customer, and the corresponding “disinfectant contact time” (T) in minutes.
16. **Cyst:** The infectious stage of *Giardia lamblia* and some other protozoan parasites that has a protective wall, which facilitates survival in water and other environments.
17. **Diabetes mellitus:** A variable disorder of carbohydrate metabolism caused by a combination of hereditary and environmental factors and usually characterized by inadequate secretion or utilization of insulin, excessive urine production, excessive amounts of sugar in the blood and urine, thirst, hunger and weight loss.
18. **Disinfectant:** Any oxidant, including but not limited to chlorine, chlorine dioxide, chloramines and ozone that is added to water in the treatment or

distribution process and is intended to kill or inactivate pathogenic microorganisms.

19. **Disinfectant contact time** (“T” in CT calculations): The time in minutes that it takes for water to move from the point of disinfectant application or the previous point of disinfectant residual measurement to a point before or at the point where residual disinfectant concentration (C) is measured.
20. **Disinfection**: The process designed to kill most microorganisms in water, including all pathogenic bacteria.
21. **Disinfection by-product**: A compound formed by the reaction of a disinfectant such as chlorine with organic material in the water supply.
22. **Distribution system**: Water pipes, storage reservoirs, tanks and other means used to deliver drinking water to consumers or to store it before delivery.
23. **Endemic**: Describes a disease that is always present in a certain population.
24. **Enteric**: Of or pertaining to the intestines.
25. **Epidemic**: A term used to describe a disease that is rare then suddenly affect more people than usually expected.
26. **Exposure**: Contact between a person and a chemical. Exposures are calculated as the amount of chemical available for the absorption by a person.
27. **Fecal coliform bacteria**: Bacteria found in the intestinal tracts of animals. Their presence in water is an indicator of pollution and possible contamination by pathogens.

28. **Filtration:** The process of removing suspended particles from water by passing it through one or more permeable membranes or media of small diameter, like sand, anthracite or diatomaceous earth.
29. **Free residual chlorine level:** The concentration of chlorine in water that is not combined with other constituents and thus serves as an effective disinfectant.
30. **Gastroenteritis:** An inflammation of the stomach and intestine resulting in diarrhea, with vomiting and cramps when irritation is excessive. When caused by an infectious agent, it is often associated with fever.
31. **Groundwater:** The supply of fresh water found beneath the earth's surface, usually in aquifers, which is often used for supplying wells and springs.
32. **Hepatitis:** Inflammation of the liver usually caused by an acute viral infection. Yellow jaundice is one symptom of hepatitis.
33. **Immunocompromised:** Weakening of the body's immune system.
34. **Indicator Organism:** An organism used to indicate a particular condition, commonly applied to coliform bacteria, e.g. *E. coli* or *S. fecalis*, when their presence is used to indicate the degree of water pollution due to fecal contamination.
35. **Infectious Disease:** A disease caused by the entrance into the body of organisms (as bacteria, protozoa or viruses) which grow and multiply there.
36. **Jaundice:** Yellowness of the skin, mucous membranes, and secretions resulting from liver malfunction.

37. **Malaise:** An indefinite feeling of debility or lack of health often indicative of or accompanying the onset of an illness.
38. **Morbidity:** The state of being ill or having a disease.
39. **Mortality:** The death rate, measure as the number of deaths per certain population.
40. **Myocarditis:** Inflammation of the heart muscle, which can be caused by a virus, certain drugs, or radiation therapy.
41. **Nephelometric turbidity units:** The units in which the turbidity of a water sample is measured when the degree to which light is scattered is assessed with a nephelometric turbidimeter. From the greek “nephelous”, meaning “cloudy”.
42. **Oocyst:** The infectious stage of *Cryptosporidium parvum* and some other parasites that has a protective wall, which facilitates survival in water and other environments.
43. **Parasite:** An organism that lives on or in other organisms, from which it obtain nutrients.
44. **Pathogens:** Microorganisms that can cause disease in humans, animals and plants. They may be viruses, bacteria or parasitic protozoa and are found in sewage, runoff from animal farms or rural areas populated with domestic or wild animals, and in water used for swimming.
45. **pH:** pH is an expression of the basic or acid condition of a liquid. The pH may range from 0 to 14, where 0 is most acid, 14 most basic and 7 neutral.

Natural waters usually have a pH between 6.5 and 8.5. Concentration of Hydronium ion.

46. **Point of disinfectant application:** The point where disinfectant is applied and water downstream of that point is not subject to recontamination by surface water runoff.
47. **Poliomyelitis:** An acute infectious virus disease characterized by fever, motor paralysis, and atrophy of skeletal muscles often with permanent disability and deformity and marked by inflammation of nerve cells in the ventral horns of the spinal cord.
48. **Population at risk:** A population subgroup that is more likely to be exposed to a chemical, or is more sensitive to a chemical, than is the general population.
49. **Potable water:** Water that is safe and satisfactory for drinking and cooking.
50. **Protozoa:** Diverse eukaryotic, typically unicellular nonphotosynthetic microorganism generally lacking a rigid cell wall.
51. **Public water system:** A system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections or regularly serves at least, 60 days out of the year.
52. **Raw water:** Water in its natural state, prior to any treatment.
53. **Residual disinfectant concentration:** The concentration of a disinfectant after a given contact time.

54. **Risk:** The potential for harm to people exposed to agents, biologicals or chemicals. In order for there to be risk, there must be hazard and there must be exposure.
55. **Route of exposure:** The avenue by which a chemical comes in contact with an organism.
56. **Safe Drinking Water Act (SDWA):** An Act passed by the U.S. Congress in 1974, establishing a cooperative program among local, state and federal agencies to insure safe drinking water for consumers.
57. **Safe water:** Water that does not contain harmful bacteria, toxic materials or chemicals. Water may have taste and odor problems, color and certain mineral problems and still be considered safe for drinking.
58. **Seizure:** Sudden uncontrolled waves of electrical activity in the brain, causing involuntary movement or loss of consciousness.
59. **Sepsis:** The infection of a wound or tissue with bacteria, causing the spread of the bacteria into the bloodstream; also known as systematic inflammatory response syndrome caused by a microbe.
60. **Siphonage:** A reversal of the normal flow of water or other liquid caused by a negative pressure gradient.
61. **Surface water:** All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, seas, estuaries) and all springs, wells, or other collectors which are directly influenced by surface water.
62. **Tenesmus:** A distressing but ineffectual urge to evacuate the rectum or urinary bladder.

63. **Trihalomethane:** Family of organic compounds named as derivatives of methane. THMs are generally the byproduct from chlorination of drinking water that contains organic material and they are suspected of causing cancer.
64. **Total coliform:** Bacteria that are used as indicators of fecal contaminants in drinking water.
65. **Turbidimeter:** A device that measures the amount of suspended solid in a liquid.
66. **Turbidity:** The cloudy appearance of water caused by the presence of suspended and colloidal matter.
67. **Virus:** The smallest forms of microorganisms capable of causing disease. A noncellular entity that consist minimally of protein and nucleic acid and that can replicate only after entry into specific types of living cells.
68. **Waterborne disease outbreak:** The significant occurrence of acute infectious illness, epidemiological associated with the ingestion of water from a public water system that is deficient in treatment, as determined by the appropriate local or state agency.
69. **Water supply system:** The collection, treatment, storage and distribution of potable water from source to consumer.

Appendix A: Summary of Non-PRASA Systems Characteristics and 1999 Bacteriological Profile

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
115011	Cubuy-Marine	Canóvanas	S	152		X		0	0	0
115031	Finca. Los Garcia	Canóvanas	S	84	X			0	0	0
207002	Camp. Pen. Sabana Hoyos	Sabana Hoyos	G	400			X	17	0	0
207042	Arrozal-Los Muertos	Arecibo	G	350	X			3	0	0
220032	Acued. Las Delicias	Ciales	S	48	X			0	3	4
220042	Cumbre Arriba	Ciales	G	340		X		14	0	1
238002	Alturas Piza	Jayuya	S	200		X		0	1	8
238012	Zamas	Jayuya	S	960		X		0	1	8
238022	Santa Rosa	Jayuya	S	460		X		0	1	7
238032	Alturas de Collores	Jayuya	S	320		X		1	2	4
238072	Santa Bárbara	Jayuya	S	500	X			0	1	3
238082	Veguitas Gripiñas	Jayuya	S	130	X			0	0	5
238122	Santa Bárbara II	Jayuya	S	424	X			0	0	4
242012	Lucas Lugo	Lares	G	68	X			0	0	0
242032	Acueducto Hac. Planell	Lares	S	60	X			0	1	4
242042	Acued. De la Comunidad	Lares	G	100	X			1	4	3
242052	Acued. Com. Magueyes	Lares	G	140		X		6	2	0
242062	Vega Acevedo	Lares	G	396		X		0	0	0
242122	Com. Las Cuarenta	Lares	G	212		X		18	2	0
242142	Alejandrina Orjales	Lares	G	28	X			2	2	4
272012	Vivi Abajo	Utuaado	S	40	X			0	0	3
272032	Finca William Lugo	Utuaado	G	45	X			1	0	3
272072	El Verde	Utuaado	S	240	X			1	0	0
272082	Acueducto La Grama	Utuaado	S	60	X			0	1	3
272102	Hacienda Rullán	Utuaado	S	240	X			0	1	2
272142	Arenas-Chorreras	Utuaado	S	220	X			1	0	3

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
272152	Arenas 2	Utuaado	S	48	X			0	1	3
272162	La Conchita	Utuaado	S	112		X		0	1	3
272182	Puente Blanco	Utuaado	S	48	X			2	0	2
272212	Tim Rivera Casellas	Utuaado	S	64	X			0	1	2
272252	Sistema Rural Graulao	Utuaado	S	64	X			1	2	5
272262	Veguita	Utuaado	S	300	X			0	1	2
272272	Salto Caguana	Utuaado	S	340		X		7	1	0
272282	Finca Carbonell	Florida	G	240	X			0	0	3
272292	Acueducto Comunal	Utuaado	S	300		X		8	1	2
302013	Cerro Gordo	Aguada	G	740		X		6	2	1
302023	Jaguey Chiquito	Aguada	G	680		X		14	1	0
302033	Quebrada Larga	Aguada	G	408		X		12	2	0
302043	Cerro Gordo Arriba II	Rincón	G	304		X		6	1	1
302053	Com. Aislada Desarrollo	Aguada	G	440		X		12	1	1
302063	Com. Cerro Gordo	Aguada	G	304		X		14	1	4
302073	Escuela Atalaya	Aguada	G	270		X		9	0	0
306013	Piñales Arriba	Añasco	G	240			X	3	0	0
306023	Corcobada	San Sebastián	G	360		X		3	0	2
306043	Caguabo	Rincón	G	440	X			1	0	1
306053	Comunidad Hatillo	Añasco	G	300		X		3	0	2
306063	La Chozza II	Añasco	G	84		X		2	0	1
329013	Estación M	Mercedita	G	2,500			X	0	5	1
348043	La Aurora	Maricao	S	70	X			1	0	1
348053	Aceituna	Maricao	S	80	X			1	0	1
348083	Llanadas	Maricao	S	100	X			2	0	1
348123	La Josefa	Maricao	S	80	X			2	0	1
351023	Sonador II	San Sebastián	G	340			X	15	4	0

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
364013	Periche	San Germán	S	1,100			X	4	0	3
364033	Rosario Peñón	San Germán	S	320		X		7	0	5
364043	Com. Rio Piedras	San Germán	S	220		X		2	0	3
364063	Comunidad Méndez	San Germán	S	60		X		0	0	3
367013	Acueducto Rural Guacio	San Sebastián	G	304		X		6	0	0
377023	Sector Laguna	Las Marías	S	100	X			2	1	0
401014	Las Cruces	Utua	G	130		X		9	4	2
401024	Guilarte Helechales	Castañer	G	25		X		1	5	0
401034	Pellejas	Adjuntas	G	260	X			0	5	0
401064	Comunidad Palomo	Adjuntas	S	200	X			0	1	2
401074	Sector Los Hernández	Adjuntas	G	245		X		2	1	0
401144	Limani	Adjuntas	G	150	X			0	12	1
401164	Tanama Comunal	Adjuntas	S	35	X			0	0	3
401234	Garzas Juncos	Adjuntas	G	460	X			11	8	0
401284	Juan González	Adjuntas	G	500		X		16	3	2
401294	Reventón	Adjuntas	S	152	X			0	3	0
401354	Esc. Residencial Agrícola	Adjuntas	G	80		X		0	5	0
422014	San Diego	Coamo	G	368			X	9	4	1
422074	La Cuesta	Coamo	S	172		X		0	0	10
422084	Coamo Arriba	Coamo	S	320		X		1	0	7
422094	Comunidad Monteria	Coamo	G	360		X		7	5	7
431014	Pelchas	Guayanilla	S	120			X	2	0	5
439014	Colonia Santi	Juana Diaz	G	76	X			0	2	2
439024	Fort Allen	San Juan	G	1,000			X	5	0	0
439034	Guaraguao	Juana Diaz	S	450		X		0	1	11
455014	Damián Abajo	Orocovis	S	400		X		1	0	3
455044	La Sapia	Ciales	S	260	X			3	1	7

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
455054	Finca Geraldo Pagán	Orocovis	S	680		X		11	2	5
455064	Bosque Toro Negro	Villalba	S	60		X		0	0	3
455114	Comunidad Sabana	Orocovis	G	720		X		2	2	8
455134	Pellejas Gallera I	Orocovis	G	48		X		1	3	1
455164	Pellejas II	Orocovis	G	500		X		6	2	0
455214	El Perico II	Orocovis	G	88	X			1	3	7
455234	Damián Arriba	Orocovis	G	320		X		2	9	0
455244	Asociación Sector Coli	Orocovis	G	200		X		4	0	8
455254	Caimito	Orocovis	S	400		X		2	3	6
455274	Acueducto Taita	Orocovis	G	56		X		2	5	4
455284	La Sapia II La Colina	Orocovis	S	56	X			0	2	3
455294	Comunidad Saltos Cabra	Orocovis	G	500		X		2	10	0
457024	Maltillo	Peñuelas	S	400	X			0	1	3
457034	Soplaera	Peñuelas	S	200		X		0	2	8
457044	Corp. Pro Salud y Mejora	Peñuelas	S	320	X			0	3	7
457054	Pandura	Peñuelas	S	240	X			0	2	6
457064	Belleza-La Haya	Peñuelas	S	600	X			0	1	2
457084	Corozal	Peñuelas	G	130	X			0	2	1
457094	Corea Metralla	Peñuelas	S	1,000	X			0	0	3
457114	La Gelpa	Peñuelas	G	400		X		2	4	3
458004	Las Mesas	Coto Laurel	S	120		X		0	0	3
458014	Hacienda Burenes	Ponce	S	80	X			0	0	3
458034	Bo. Santas Pascuas	Ponce	S	500	X			1	0	3
458044	Bo. Monte Llanos	Ponce	G	432		X		0	4	6
458054	La Yuca	Mercedita	G	500		X		15	0	1
458174	Servicio de Agua	Ponce	S	310		X		2	1	11
458194	Anón Carmelita	Ponce	S	680	X			0	1	2

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
458214	Ponce Darlington	Ponce	G	220			X	14	4	0
458234	El Tesoro	Ponce	S	240	X			0	0	0
476034	Semil I	Villalba	S	30	X			1	0	2
476054	La Julita	Villalba	S	108		X		1	1	2
476064	Villa Blanca	Villalba	S	800	X			4	0	0
476094	Lajitas	Villalba	S	40	X			1	0	2
476124	Vacas II	Villalba	S	500	X			0	0	3
476134	Vacas III	Villalba	S	500		X		17	0	2
476154	Vista Alegre	Villalba	S	340		X		7	2	2
476204	Sierrita	Villalba	S	268	X			2	0	1
476224	Aceituna I	Villalba	S	69	X			0	0	3
476234	Aceituna II	Villalba	S	95	X			0	0	3
476314	Sierrita Caonilla	Villalba	G	100	X			0	0	3
478014	Bo. Rubias	Maricao	S	360		X		6	0	0
478034	La Montaña	Castañer	S	160		X		0	0	3
478044	Cerrote	Castañer	S	140		X		9	1	0
478054	La Jurada	Yauco	S	300		X		0	0	9
478064	Guaraguao	Yauco	S	950			X	8	0	1
478094	Mogote	Yauco	G	140			X	0	0	2
478104	Com. Quebrada Grande	Yauco	G	300			X	3	5	1
505055	Cuyón	Aibonito	S	382		X		4	0	0
505075	Algarrobo Nuevo	Aibonito	G	90		X		0	0	0
510055	Cañabón Abajo	Barranquitas	G	320		X		1	2	8
510065	Tabor	Barranquitas	G	600		X		8	0	2
510095	Acued. Com. Quebradillas	Barranquitas	G	2,500			X	11	4	2
510105	La Cueva del Indio	Barranquitas	S	88		X		2	1	7
510115	Los Muchos	Barranquitas	G	280		X		5	5	1

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
510125	La Tiza II	Barranquitas	G	204		X		12	0	0
510145	Palmarito Cintron	Corozal	G	560	X			1	2	1
510165	Comunidad Doña Mayo	Barranquitas	G	300		X		17	3	0
510195	Helechal Guayabo	Barranquitas	G	640			X	15	3	1
510205	Sector Hoya Fria	Barranquitas	S	260		X		2	1	4
518015	Sector Pepe Hoyos	Cayey	S	160	X			1	1	2
518025	Farallón	Cayey	G	450		X		3	2	0
518045	Camp. Penal Guavate	Cayey	S	420			X	12	6	1
518075	Vecinos Com. Luis	Cayey	S	250		X		1	0	2
521025	Carrasquillo	Cidra	G	375			X	15	3	3
521035	Pelegrin Santos	Cidra	G	260		X		17	1	1
521075	Almirante	Cidra	G	180		X		13	2	1
523015	Palomas I	Comerio	S	112	X			0	0	11
523025	Palomas II	Comerio	S	125	X			0	0	1
523045	Fca. Fco. Hernandez	Comerio	S	184		X		11	0	1
523055	Comunidad Maisonet	Comerio	S	608		X		8	3	1
523095	Cedrito	Comerio	G	320		X		22	0	0
523105	Acueducto Doña Elena	Comerio	S	1000		X		0	0	1
530035	Pozo Hondo	Guayama	G	100			X	0	2	0
530045	Los Barros	Guayama	S	275	X			0	1	2
530075	Villa Verde	Guayama	S	250		X		0	0	3
549015	Quebrada Arenas	Maunabo	S	175	X			2	0	0
549055	Lizas II	Maunabo	S	150	X			0	0	2
556015	Mulas	Patillas	S	900		X		6	3	0
556025	Bo. Real	Patillas	S	1000		X		2	2	6
556035	Quebrada Arriba	Patillas	S	800		X		8	1	0
556045	Los Barros Marin	Patillas	S	108		X		3	3	4

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
556055	Bo. Mamey	Patillas	G	340		X		6	2	2
556065	Bo. Rios	Patillas	S	300		X		0	1	6
556075	Bo. Jacoboa Higuero	Patillas	G	200		X		0	1	6
556085	Apeadero	Patillas	S	240		X		1	4	3
556095	Guardarraya	Patillas	S	30	X			0	0	3
563015	Corporacion Azucarera	Mercedita	G	1500			X	16	0	1
604016	Corujos	Aguas Buenas	G	460			X	0	4	6
604036	Comunidad Rivera	Aguas Buenas	G	325			X	6	2	1
604046	Multas Centro	Aguas Buenas	G	560			X	5	3	0
604056	Sector Tiza	Aguas Buenas	G	400		X		1	6	1
604066	Juan Asencio	Aguas Buenas	G	920		X		2	9	3
604076	Comunidad Madriguera	Aguas Buenas	G	700		X		14	1	2
604086	Bayamoncito	Aguas Buenas	S	800		X		9	4	4
604096	Las Torres Andino	Aguas Buenas	G	380		X		5	4	0
604166	Pajitas Falcon	Aguas Buenas	G	194		X		4	13	2
613016	Cañaboncito	Caguas	G	360		X		11	3	1
613036	Parcelas Nuevas	Caguas	G	580		X		16	3	0
613046	Turabo Arriba	Caguas	G	620		X		8	6	1
613056	Los Velazquez	Caguas	G	160		X		18	1	0
613106	Sec. Lozada y Pozo Dulce	Caguas	G	480		X		13	2	2
613176	Sector Lajitas	Caguas	S	65	X			0	0	7
613196	Asoc. Dueños El Paraiso	Caguas	G	76			X	7	1	0
613216	Borinquen Naranjito II	Caguas	S	44	X			1	2	5
613246	Usuarios Pozo Profundo	Caguas	G	200		X		17	0	2
613256	Piñas Beatriz II	Caguas	S	400	X			1	0	8
613266	Borinquen Praderas	Caguas	S	540		X		0	5	2
613296	La Union	Caguas	S	440		X		18	0	0

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
613356	Finca Mi Recreo	Rio Piedras	S	120		X		0	0	6
613366	La Sierra	Caguas	G	2100			X	14	4	0
613376	Buenos Aires	Caguas	G	192		X		2	2	0
619016	Base Roosevelt Road	Ceiba	S	8500			X	7	0	0
627016	Juan Diego	Fajardo	S	160	X			0	3	8
633046	Jaguas	Gurabo	G	400	X			2	1	5
633106	Los Vazquez	Gurabo	S	31	X			0	2	2
644076	Lijas	Las Piedras	S	600		X		4	1	4
644086	Comunidad Asomante	Las Piedras	G	800		X		20	0	0
653016	Comite Buen Vecino	Naguabo	S	1950		X		8	3	3
653026	Com. Rancho Grande	Naguabo	S	1446		X		12	8	3
661046	Barcelona	Palmer	S	320	X			0	0	0
666016	Quemados	Caguas	G	325		X		17	4	0
666026	Macanea	San Lorenzo	S	300		X		0	3	6
666036	Los Diaz	San Lorenzo	G	240			X	0	7	3
666046	Quemado I Sector Ortiz	Caguas	G	600		X		9	3	5
666056	La Cuchilla	San Lorenzo	G	380		X		14	5	3
666066	Acued. Sector Manuel	San Lorenzo	G	160	X			0	4	5
666076	Quemados II Vicente	San Lorenzo	G	580		X		18	1	0
666086	Corp. Sector Canter	San Lorenzo	G	250			X	6	5	0
666096	Los Gomez	San Lorenzo	G	244			X	13	1	0
666106	Comunidad El Cedro	San Lorenzo	G	180	X			0	0	0
677016	Tejas	Yabucoa	G	1440			X	16	0	1
677056	Piedras Blancas	Yabucoa	S	852			X	7	1	2
677066	Sodoma	Yabucoa	G	525		X		10	3	0
677076	Guayabota	Yabucoa	S	2900			X	8	2	1
677146	Calabaza Abajo	Yabucoa	G	1428			X	1	4	2

PWS ID	System Name	Town	Source	Population	Treatment			1999 Bacti Results		
					No	Tablet	Hypo	N	PN	PP
677186	Asociación Vecinos	Yabucoa	G	168			X	6	0	0
677196	Acueducto Comunal	Yabucoa	S	520	X			0	0	0
724027	Mana I	Corozal	G	320		X		10	1	1
724047	Magueyes	Corozal	S	240	X			0	0	5
724077	Com. Palmarito Centro	Corozal	G	744		X		5	5	0
724087	Copar	Corozal	S	1000			X	19	3	0
724097	Maná III	Corozal	G	132		X		1	5	2
724117	Com. Eladio Abreu	Corozal	S	320		X		1	3	6
754037	Guadiana Alejandro	Naranjito	G	600	X			6	1	0
754057	Com. Anones Maya	Naranjito	G	1260		X		6	2	0
754067	Anones Centro I	Naranjito	G	1200		X		3	2	4
754077	Feijoo	Naranjito	G	460		X		9	0	1
754087	Lolo Padilla	Naranjito	G	400		X		0	0	6
754097	Las Cruces	Naranjito	G	1200		X		19	0	0
754107	Com. Nieves Sánchez	Naranjito	G	740		X		2	1	2
754117	El Llano de los Padilla	Naranjito	G	60			X	22	0	0
770037	Base Sabana Seca	Sabana Seca	G	1100			X	4	0	0

Appendix B: Aquaward Tablets Information

1. Manufacturer Information

ELTECH International Corporation
1110 Industrial Boulevard
Sugar Land, Texas 77478
(713) 274-8440/ (800) 621-9189/ (800) 424-9300

2. General Product Information

Product Name: AQUAWARD Chlorinating Tablets
Synonyms: Calcium Hypochlorite
Product Use: Disinfecting Agent for Water and Wastewater

3. Hazardous Ingredients

Chemical	% Mixture
Calcium Hypochlorite	70

4. Physical Properties

Solubility: 6% by weight (min)	pH: 10.4 (1% soln)
Density (@ 20 °C): 1.0	Color: White Tablet

5. Fire and Explosion Data

Special Fire Fighting Procedures:

This product is a strong oxidizer. Use only water in the event of a fire or a violent reaction may result by contamination. Wear self-contained breathing apparatus.

Unusual Fire/Explosion Hazard:

Contamination with organics, acids, alkalis, and strong reducing agents will result in fire or rapid decomposition. Spontaneous decomposition temperature for this product is 350 °F. In large fires fueled by other materials the product may smolder for prolonged periods emitting dense black smoke.

6. Health Hazard Information

Routes of Exposure:

Ingestion:	Highly toxic. May cause severe inflammation and erosion to the lining of the esophagus and stomach.
Eye Contact:	Mild/moderate exposure to dust causes irritation of the eyes. Severe exposure can cause permanent (irreversible) damage.
Skin Contact:	Mild/moderate exposure to dust may irritate the skin. Greater exposure can cause severe irritation.
Inhalation:	Mild/moderate exposure to dust causes irritation to the mucous membranes of the respiratory passages (nasal and throat).

Effects of Overexposure:

- Acute:** Ingestion may result in erosion of the esophagus and stomach, vomit, gastric bleeding and possible circulatory collapse. Exposure may cause temporary or permanent tissue damage to skin, eyes and respiratory passages.
- Chronic:** Prolonged and intensive exposure may result in tissue damage to body surfaces unless promptly treated.

Emergency and First Aid Procedures:

- Eyes:** Flush eyes with large amounts of water for at least 15 minutes, holding lids apart to ensure flushing of entire eye surface. Seek medical attention.
- Skin:** Wash with soap and water. Remove contaminated clothing and footwear.
- Inhalation:** Get person out of contaminated area to fresh air. If breathing has stopped, resuscitate and administer oxygen if readily available. Seek medical attention.
- Ingestion:** Never give anything by mouth to an unconscious person. Feed bread soaked in milk, followed by olive or cooking oil. Do not induce vomiting. Call a physician immediately.

7. Reactivity Data

Conditions contributing to instability: Contamination with flammables and organics may cause fire or explosion. Acids will release chlorine and bromine gas.

Incompatibility (materials to avoid): Acids, flammables, organic materials, readily oxidizable materials and strong reducing agents.

Hazardous decomposition or byproducts: Chlorine gas and hydrogen chloride.

8. Spill or Leak Procedures**Neutralizing Chemicals:**

Sodium sulfite, sodium bisulfite or sodium metabisulfite.

Steps to be taken if Material is Released and/or Spilled:

Wear appropriate protective gear: rubber gloves and boots. Chemical splash goggles and breathing apparatus if necessary.

Dilute spill area with large quantities of water, at least 100 gallons of water/pound of material. Avoid contact with resulting solution. Neutralize with sodium sulfite, sodium bisulfite or sodium metabisulfite. Collected neutralized solution should be disposed through sewage treatment plant. Prior approval from plant personnel should be obtained. File environmental spill notifications if necessary.

Waste Disposal Methods:

Do not dispose of material in dry form in waste container: fire may result. Proceed with spill procedure as outlined above.

Additional Precautions:

Do not attempt to recover solid material. Do not reuse empty container but place in trash collection.

9. Industrial Hygiene Control Measures**Ventilation Requirements:**

Work in well ventilated areas. Storage area should be well ventilated.

Specific Personal Protective Equipment:

Respiratory protection is not required under normal use, however, when necessary, use NIOSH/MSHA approved respirator following manufacturer's recommendations. NIOSH approved dust mask is essential where dusting may occur.

Chemical safety glasses should be worn. Protective gloves should be worn. Rubber or other chemically resistant materials are recommended as suitable material. Protective clothing should be worn so as to minimize skin contact. Avoid contact with clothing. Fire may result from contact of dry material with cloth or flammables.

10. Special Precautions

Highly corrosive. Causes skin and eye damage. May be fatal if swallowed. Irritate nose and throat. Do not breathe dust and fumes. Wash thoroughly with soap and water after handling. Remove and wash contaminated clothing before reuse.

This product is toxic to fish. Do not discharge into lakes, streams, ponds or public waters unless in accordance with an NPDES permit.

Strong oxidizing agent. Mix this product only with water. Use clean dry utensils. Open container only where adequate ventilation is available. Do not add this product to any dispensing device containing remains of any other product. In case of contamination/decomposition, do not reseal container. If possible, isolate container in open air and flood with large volumes of water.

Storage:

Keep product dry and in a tightly closed container when not in use. Store in cool, dry, well ventilated areas, keeping it away from heat sources and/or open flames. Do not drop, roll or skill container. Keep in original container. DO NOT store/transfer/repack this product in any other container without the approval/authorization of Eltech International Corp.

Appendix C: Summary of Data Collection and Statistical Analysis

**Summary of Data Collection
Finca Geraldo Pagán System
Wednesday May 31, 2000**

Source		pH	Temperature (°C)	Turbidity (NTU)	Chlorine Concentration (mg/L)	Total Coliform (col/ 100 mL)	Fecal Coliform (col/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface	Raw Water	7.8	21.0	4.1	---	23	23	---	---
	Treated Water	7.3	23.0	3.2	1.0	0	0	2.7	48.0
Ground	Raw Water	7.9	21.0	1.1	---	0	0	---	---
	Treated Water	8.4	22.0	0.1	0.6	0	0	3.3	80.6

**Summary of Data Collection
Finca Geraldo Pagán System
Thursday June 1st, 2000**

Source		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/100 mL)	Fecal Coliform (colonies/100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface	Raw Water	7.5	21.0	4.0	---	5,000	40	---	---
	Treated Water	7.8	22.0	3.2	0.5	0	0	1.0	22.3
Ground	Raw Water	8.0	20.5	4.4	---	0	0	---	---
	Treated Water	7.7	21.0	0.1	1.1	0	0	6.0	128.6

**Summary of Data Collection
Finca Geraldo Pagán System
Friday June 2, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/100 mL)	Fecal Coliform (colonies/100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	8.3	21.0	3.8	---	9,000	40	---	---
	Treated Water	7.6	23.0	3.0	0.9	0	0	2.4	57.5
Groundwater	Raw Water	7.7	22.0	0.2	---	2.2	2.2	---	---
	Treated Water	7.4	21.0	0.1	1.3	0	0	8.7	157.1

**Summary of Data Collection
Finca Geraldo Pagán System
Monday June 5, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/100 mL)	Fecal Coliform (colonies/100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.9	21.0	3.6	---	2,200	20	---	---
	Treated Water	7.4	22.0	2.7	1.7	0	0	6.7	137.1
Groundwater	Raw Water	8.2	21.0	0.7	---	2	2	---	---
	Treated Water	8.1	22.0	0.8	1.2	0	0	5.0	142.3

**Summary of Data Collection
Finca Geraldo Pagán System
Tuesday June 6, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/ 100 mL)	Fecal Coliform (colonies/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.6	21.0	3.7	---	3,500	80	---	---
	Treated Water	7.4	22.0	2.6	1.1	20	20	4.1	95.4
Groundwater	Raw Water	7.6	22.0	0.2	---	20	20	---	---
	Treated Water	7.8	22.0	0.3	1.1	20	20	5.1	96.9

**Summary of Data Collection
Finca Geraldo Pagán System
Wednesday June 7, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/ 100 mL)	Fecal Coliform (colonies/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.6	21.0	4.5	---	9,000	80	---	---
	Treated Water	7.4	23.0	4.6	1.2	0	0	5.4	114.2
Groundwater	Raw Water	7.8	21.0	0.1	---	2	2	---	---
	Treated Water	7.9	21.0	0.1	1.1	0	0	2.9	62.1

**Summary of Data Collection
Finca Geraldo Pagán System
Thursday June 8, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/ 100 mL)	Fecal Coliform (colonies/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.9	21.0	3.5	---	1,400	40	---	---
	Treated Water	7.7	23.0	3.2	1.0	0	0	4.3	106.3
Groundwater	Raw Water	7.8	21.0	0.4	---	20	20	---	---
	Treated Water	7.9	22.0	0.1	0.9	0	0	0.6	13.1

**Summary of Data Collection
Finca Geraldo Pagán System
Friday June 9, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/ 100 mL)	Fecal Coliform (colonies/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.6	21.0	3.1	---	1,600	40	---	---
	Treated Water	7.5	24.0	2.6	1.2	0	0	5.2	143.7
Groundwater	Raw Water	7.9	21.0	0.1	---	0	0	---	---
	Treated Water	7.9	22.0	0.1	0.9	0	0	4.1	92.3

**Summary of Data Collection
Finca Geraldo Pagán System
Monday June 12, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/ 100 mL)	Fecal Coliform (colonies/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.6	21.0	3.7	—	500	110	---	---
	Treated Water	7.5	23.0	2.1	1.0	20	20	3.0	76.2
Groundwater	Raw Water	7.9	22.0	0.3	---	0	0	---	---
	Treated Water	8.0	22.0	0.7	0.9	0	0	0.6	16.9

**Summary of Data Collection
Finca Geraldo Pagán System
Tuesday June 13, 2000**

		pH	Temperature (°C)	Turbidity (NTU)	Residual Chlorine Concentration (mg/L)	Total Coliform (colonies/ 100 mL)	Fecal Coliform (colonies/ 100 mL)	Log Inactivation of Giardia	Log Inactivation of Viruses
Surface Water	Raw Water	7.6	22.0	3.8	---	330	110	---	---
	Treated Water	7.6	23.0	2.4	1.0	20	20	3.9	98.5
Groundwater	Raw Water	7.6	21.0	2.1	---	0	0	---	---
	Treated Water	7.8	23.0	0.2	1.0	0	0	1.7	36.1

**Statistical Analysis: pH
Raw (1) and Treated (2) Surface Water
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
7.8	7.3
7.5	7.8
7.7	7.4
7.9	7.4
7.6	7.4
7.6	7.4
7.9	7.7
7.6	7.5
7.6	7.5
7.6	7.6

	1	2	Total
n	10	10	20
ΣX	76.8	75	151.8
ΣX^2	590	562.72	1152.72
SS	0.176	0.22	0.558
Mean	7.68	7.5	7.59

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	0.162	1	0.16	8	0.011
Error	0.396	18	0.02		
Total	0.558	19			

Conclusion: At a 5% significant level, the data provide sufficient evidence to conclude that the mean pH of the raw & treated surface waters are different.

Statistical Analysis: pH
Raw (1) and Treated (2) Groundwater
One-Way ANOVA for 2 Independent Samples

Sample 1	Sample 2
7.9	8.4
8.0	7.7
8.3	7.6
8.2	8.1
7.6	7.8
7.8	7.9
7.8	7.9
7.9	7.9
7.9	8.0
7.6	7.8

	1	2	Total
n	10	10	20
ΣX	79	79.1	158.1
ΣX^2	624.56	626.130	1250.69
SS	0.46	0.449	0.9095
Mean	7.9	7.91	7.905

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	0.005	1	0	0	1.0
Error	0.909	18	0.05		
Total	0.9095	19			

Conclusion: At a 5% significant level, the data provide sufficient evidence to conclude that the mean pH of raw & treated groundwater are equal.

**Statistical Analysis: Temperature
Raw (1) and Treated (2) Surface Water
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
21	23
21	22
21	23
21	22
21	22
21	23
21	23
21	24
21	23
22	23

	1	2	Total
n	10	10	20
ΣX	211	228	439
ΣX^2	4453	5202	9655
SS	0.9	3.6	18.95
Mean	21.1	22.8	21.95

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	14.45	1	14.45	57.8	0.000001
Error	4.5	18	0.25		
Total	18.95	19			

Conclusion: At a 5% significant level, the data provide sufficient evidence to conclude that the mean residual chlorine concentration of temperature of raw & treated surface waters are equal.

**Statistical Analysis: Temperature
Raw (1) and Treated (2) Groundwater
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
21	22
20.5	21
22	21
21	22
22	22
21	21
21	22
21	22
22	22
21	23

	1	2	Total
N	10	10	20
ΣX	212.5	218	430.5
ΣX^2	4518.25	4756	9274.25
SS	2.625	3.6	7.7375
Mean	21.25	21.8	21.525

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	1.5125	1	1.51	4.31	0.0525
Error	6.225	18	0.35		
Total	7.7375	19			

Conclusion: At a 5% significant level, the data provide sufficient evidence to conclude that the mean temperature of the raw & treated groundwater are equal.

**Statistical Analysis: Turbidity
Raw (1) and Treated (2) Surface Water
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
4.1	3.2
4.0	3.2
3.8	3.0
3.6	2.7
3.7	2.6
4.5	4.6
3.5	3.2
3.1	2.6
3.7	2.1
3.8	2.4

	1	2	Total
n	10	10	20
ΣX	37.8	29.6	67.4
ΣX^2	144.14	91.86	236.00
SS	1.256	4.244	8.862
Mean	3.78	2.96	3.37

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	3.362	1	3.36	10.84	0.004049
Error	5.5	18	0.31		
Total	8.862	19			

Conclusion: At a 5% significance level, the data provide sufficient evidence to conclude that the mean turbidity for raw & treated surface water are not equal.

**Statistical Analysis: Turbidity
Raw (1) and Treated (2) Groundwater
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
1.1	0.1
4.4	0.1
0.2	0.1
0.7	0.8
0.2	0.3
0.1	0.1
0.4	0.1
0.1	0.1
0.3	0.7
2.1	0.2

	1	2	Total
n	10	10	20
ΣX	9.6	2.60	12.2
ΣX^2	25.82	1.32	27.14
SS	16.604	0.644	19.698
Mean	0.96	0.26	0.61

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	2.45	1	2.45	2.55	0.1278
Error	17.248	18	0.96		
Total	19.698	19			

Conclusion: At a 5% significant level, the data provide sufficient evidence to conclude that the mean turbidity of raw & treated water are equal.

**Statistical Analysis: Residual Chlorine Concentration
Surface (1) and Groundwater (2) Sources
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
1.0	0.6
0.5	1.1
0.9	1.3
1.7	1.2
1.1	1.1
1.2	1.1
1.0	0.9
1.2	0.9
1.0	0.9
1.0	1.0

	1	2	Total
n	10	10	20
ΣX	10.6	10.10	20.70
ΣX^2	12.04	10.55	22.59
SS	0.804	0.349	1.1655
Mean	1.06	1.01	1.035

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	0.0125	1	0.01	0.17	0.684981
Error	1.153	18	0.06		
Total	1.1655	19			

Conclusion: At a 5% significant level, the data provide sufficient evidence to conclude that the mean residual chlorine concentration of surface & groundwater sources are equal.

**Statistical Analysis: Inactivation of *Giardia lamblia* cysts
Surface (1) and Groundwater (2) Sources
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
2.7	3.3
1.0	6.0
2.4	8.7
6.7	5.0
4.1	5.1
5.4	2.9
4.3	0.6
5.2	4.1
3.0	0.6
3.9	1.7

	1	2	Total
n	10	10	20
ΣX	38.70	38.00	76.7
ΣX^2	174.65	202.42	377.07
SS	24.881	58.02	82.9255
Mean	3.87	3.8	3.835

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	0.0245	1	0.02	0	1.000
Error	82.901	18	4.61		
Total	82.9255	19			

Conclusion: At the 5% significance level, the data provide sufficient evidence to conclude that the mean inactivation ratio of *Giardia lamblia* cysts for surface & groundwater are equal.

**Statistical Analysis: Inactivation of Viruses
Surface (1) and Groundwater (2) Sources
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
48.0	80.6
22.3	128.6
57.5	157.1
137.1	142.3
95.4	96.9
114.2	62.1
106.3	13.1
143.7	92.3
76.2	16.9
98.5	36.1

	1	2	Total
n	10	10	20
ΣX	899.2	826	1725.2
ΣX^2	94504.82	91489.76	185994.58
SS	13648.756	23262.16	37178.828
Mean	89.92	82.6	86.26

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	267.912	1	267.91	0.13	0.722628
Error	36910.916	18	2050.61		
Total	37178.828	19			

Conclusion: At the 5% significance level, the data provide sufficient evidence to conclude that the mean inactivation ratio of viruses for surface & groundwater are equal.

**Statistical Analysis: Inactivation of Total Coliform Bacteria
Surface (1) and Groundwater (2) Sources
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
100.0	100.0
100.0	100.0
100.0	100.0
100.0	100.0
75.0	100.0
100.0	
100.0	
100.0	
96.0	
94.0	

	1	2	Total
n	10	5	15
ΣX	965	500	1465
ΣX^2	93677	50000	143677
SS	554.5	0	595.333
Mean	96.5	100	97.667

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	40.833	1	40.83	0.96	0.345070
Error	554.5	13	42.65		
Total	595.333	14			

Conclusion: At the 5% significance level, the data provide sufficient evidence to conclude that the mean inactivation ratio of total coliform bacteria for surface & groundwater are equal.

**Statistical Analysis: Inactivation of Fecal Coliform Bacteria
Surface and Groundwater (2) Sources
One-Way ANOVA for 2 Independent Samples**

Sample 1	Sample 2
100.0	100.0
100.0	100.0
100.0	100.0
100.0	100.0
99.4	
100.0	
100.0	
100.0	
81.8	
81.8	

	1	2	Total
n	10	4	14
ΣX	963.0	400	1363
ΣX^2	93262.840	40000	133262.84
SS	525.94	0	565.0543
Mean	96.3	100	97.3571

ANOVA SUMMARY

Source	SS	df	MS	F	P
Treatment (between groups)	39.1143	1	39.11	0.89	0.364
Error	525.94	12	43.83		
Total	565.0543	13			

Conclusion: At a 5% significance level, the data provide sufficient evidence to conclude that the mean inactivation of fecal coliform bacteria for surface & groundwater are equal.

**Appendix D: Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Saturday May 20, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	7.7	4.0
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	18094.2	9399.6
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	517.0	376.0
Baffling Factor	0.1	0.1
T₁₀ (m)	51.7	37.6
Chlorine Residual Concentration (mg/L)	0.7	0.9
CT Value (Actual)	36.2	33.8
pH	7.8	8.2
Temperature (° C)	21.0	20.0
CT Giardia (Calculated)	43.0	53.0
Log Inactivation Giardia	2.5	1.9
CT Viruses (Calculated)	2.8	3.0
Log Inactivation Viruses	51.7	45.1

Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Wednesday May 31, 2000

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	5.0	10.0
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	11749.5	23499.0
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	335.7	940.0
Baffling Factor	0.1	0.1
T₁₀ (m)	33.6	94.0
Chlorine Residual Concentration (mg/L)	1.0	0.6
CT Value (Actual)	33.6	56.4
pH	7.3	8.4
Temperature (° C)	21.0	21.0
CT Giardia (Calculated)	37.0	51.0
Log Inactivation Giardia	2.7	3.3
CT Viruses (Calculated)	2.8	2.8
Log Inactivation Viruses	48.0	80.6

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Thursday June 1st, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	4.3	8.7
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	10104.6	20444.1
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	288.7	817.8
Baffling Factor	0.1	0.1
T₁₀ (m)	28.9	81.8
Chlorine Residual Concentration (mg/L)	0.5	1.1
CT Value (Actual)	14.5	90.0
pH	7.8	7.7
Temperature (° C)	22.0	21.0
CT Giardia (Calculated)	42.0	45.0
Log Inactivation Giardia	1.0	6.0
CT Viruses (Calculated)	2.6	2.8
Log Inactivation Viruses	22.3	128.6

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Friday June 2nd, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	5.7	9.0
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	13394.4	21149.1
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	382.7	846.0
Baffling Factor	0.1	0.1
T₁₀ (m)	38.3	84.6
Chlorine Residual Concentration (mg/L)	0.9	1.3
CT Value (Actual)	34.5	110.0
pH	7.6	7.4
Temperature (° C)	23.0	21.0
CT Giardia (Calculated)	44.0	38.0
Log Inactivation Giardia	2.4	8.7
CT Viruses (Calculated)	2.4	2.8
Log Inactivation Viruses	57.5	157.1

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Monday June 5, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	7.8	8.2
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	18329.2	19269.2
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	523.7	770.8
Baffling Factor	0.1	0.1
T₁₀ (m)	52.4	77.1
Chlorine Residual Concentration (mg/L)	1.7	1.2
CT Value (Actual)	89.1	92.5
pH	7.4	8.1
Temperature (° C)	22.0	22.0
CT Giardia (Calculated)	40.0	55.0
Log Inactivation Giardia	6.7	5.0
CT Viruses (Calculated)	2.6	2.6
Log Inactivation Viruses	137.1	142.3

**nactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Tuesday June 6, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	8.4	6.1
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	19739.2	14334.4
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	564.0	573.4
Baffling Factor	0.1	0.1
T₁₀ (m)	56.4	57.3
Chlorine Residual Concentration (mg/L)	1.1	1.1
CT Value (Actual)	62.0	63.0
pH	7.8	7.4
Temperature (° C)	22.0	22.0
CT Giardia (Calculated)	45.0	37.0
Log Inactivation Giardia	4.1	5.1
CT Viruses (Calculated)	2.6	2.6
Log Inactivation Viruses	95.4	96.9

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Wednesday June 7, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	8.5	4.2
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	19974.2	9869.6
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	570.7	394.8
Baffling Factor	0.1	0.1
T₁₀ (m)	57.1	39.5
Chlorine Residual Concentration (mg/L)	1.2	1.1
CT Value (Actual)	68.5	43.5
pH	7.4	7.9
Temperature (° C)	23.0	21.0
CT Giardia (Calculated)	38.0	45.0
Log Inactivation Giardia	5.4	2.9
CT Viruses (Calculated)	2.4	2.8
Log Inactivation Viruses	114.2	62.1

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Thursday June 8, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	9.5	1.0
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	22324.1	2349.9
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	637.8	94.0
Baffling Factor	0.1	0.1
T₁₀ (m)	63.8	9.4
Chlorine Residual Concentration (mg/L)	1.0	0.9
CT Value (Actual)	63.8	8.5
pH	7.7	7.9
Temperature (° C)	23.0	22.0
CT Giardia (Calculated)	45.0	44.0
Log Inactivation Giardia	4.3	0.6
CT Viruses (Calculated)	2.4	2.6
Log Inactivation Viruses	106.3	13.1

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Friday June 9, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	9.8	7.1
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	23029.0	16684.3
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	658.0	667.4
Baffling Factor	0.1	0.1
T₁₀ (m)	65.8	66.7
Chlorine Residual Concentration (mg/L)	1.2	0.9
CT Value (Actual)	79.0	60.0
pH	7.5	7.9
Temperature (° C)	24.0	22.0
CT Giardia (Calculated)	46.0	44.0
Log Inactivation Giardia	5.2	4.1
CT Viruses (Calculated)	2.2	2.6
Log Inactivation Viruses	143.7	92.3

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Monday June 12, 2000**

Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	6.8	1.3
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	15979.3	3054.9
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	456.6	122.2
Baffling Factor	0.1	0.1
T₁₀ (m)	45.7	12.2
Chlorine Residual Concentration (mg/L)	1.0	0.9
CT Value (Actual)	45.7	11.0
pH	7.5	8.0
Temperature (° C)	23.0	22.0
CT Giardia (Calculated)	45.0	53.0
Log Inactivation Giardia	3.0	0.6
CT Viruses (Calculated)	2.4	2.6
Log Inactivation Viruses	76.2	16.9

**Inactivation of *Giardia lamblia* cysts and Viruses
Finca Gerardo Pagán System
Tuesday June 13, 2000**

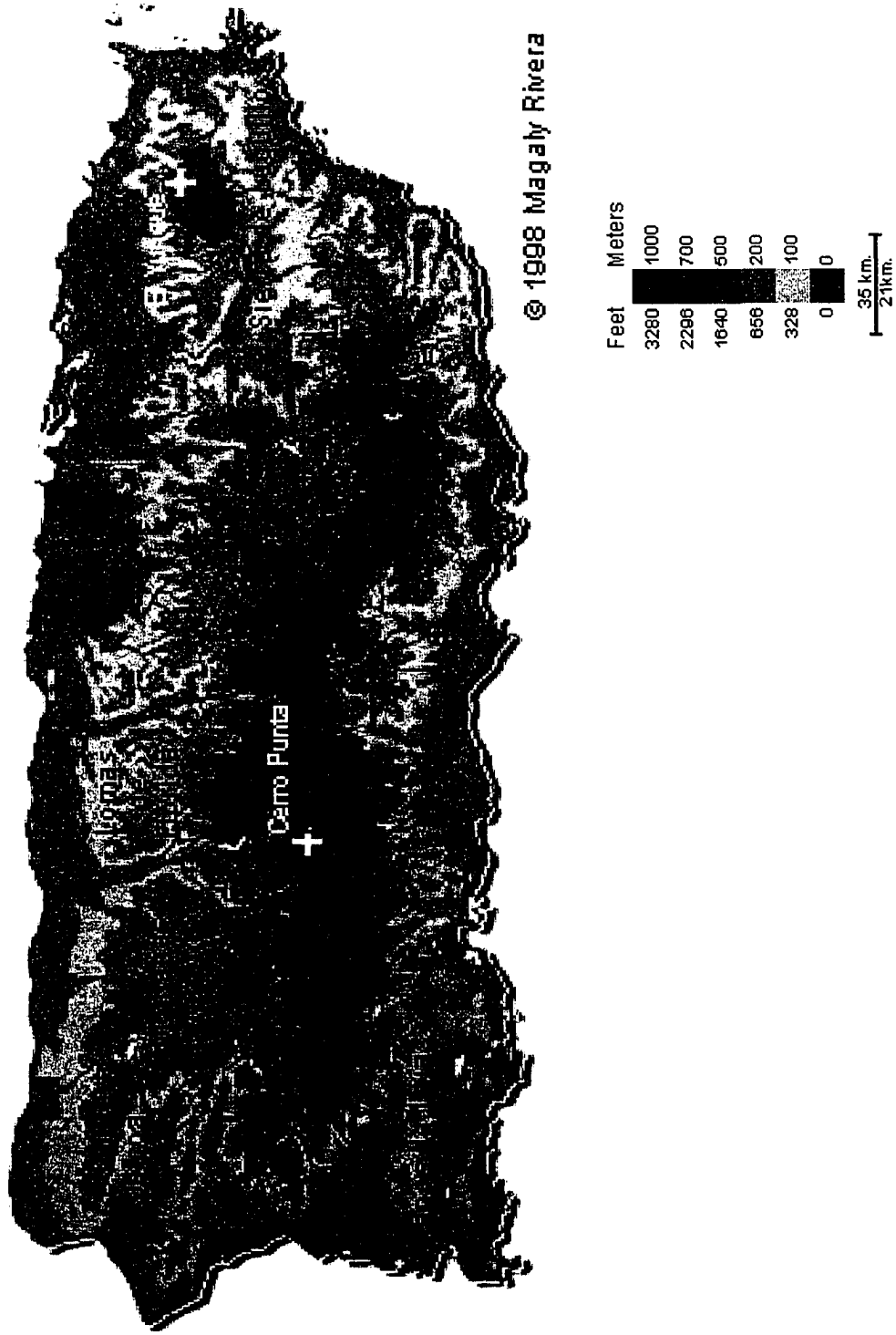
Parameter	Surface Water System	Groundwater System
Water Depth (ft.)	8.8	2.7
Tank Diameter (ft.)	20.0	20.0
Water Volume (gal)	20679.1	6344.7
Peak Hour Flow (gpm)	35.0	25.0
Theoretical Detention Time (m)	590.8	253.8
Baffling Factor	0.1	0.1
T₁₀ (m)	59.1	25.3
Chlorine Residual Concentration (mg/L)	1.0	1.0
CT Value (Actual)	59.1	25.3
pH	7.6	7.8
Temperature (° C)	23.0	21.0
CT Giardia (Calculated)	45.0	45.0
Log Inactivation Giardia	3.9	1.7
CT Viruses (Calculated)	2.4	2.8
Log Inactivation Viruses	98.5	36.1

CT VALUES FOR INACTIVATION OF GIARDIA CYSTS BY FREE CHLORINE AT 25 °C																								
Chlorine Concentration (mg/L)	pH <=6			pH = 6.5			pH = 7.0			pH = 7.5														
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0												
<=0.4	4	8	12	16	20	24	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	28	35	42
0.6	4	8	13	17	21	25	5	10	15	20	25	30	6	12	18	24	30	36	7	14	22	29	36	43
0.8	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44
1.0	4	9	13	17	22	26	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45
1.2	5	9	14	18	23	27	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46
1.4	5	9	14	18	23	27	6	11	17	22	28	33	7	13	20	26	33	39	8	16	24	31	39	47
1.6	5	9	14	19	23	28	6	11	17	22	28	33	7	13	20	27	33	40	8	16	24	32	40	48
1.8	5	10	15	19	24	29	6	11	17	23	28	34	7	14	21	27	34	41	8	16	25	33	41	49
2.0	5	10	15	19	24	29	6	12	18	23	29	35	7	14	21	27	34	41	8	17	25	33	42	50
2.2	5	10	15	20	25	30	6	12	18	23	29	35	7	14	21	28	35	42	9	17	26	34	43	51
2.4	5	10	15	20	25	30	6	12	19	24	30	36	7	14	22	29	36	43	9	17	26	35	43	52
2.6	5	10	16	21	26	31	6	12	19	25	31	37	7	15	22	29	37	44	9	18	27	35	44	53
2.8	5	10	16	21	26	31	6	12	19	25	31	37	8	15	23	30	38	45	9	18	27	36	45	54
3.0	5	11	16	21	27	32	6	13	19	25	32	38	8	15	23	31	38	46	9	18	28	37	46	55
Chlorine Concentration (mg/L)	pH = 8			pH = 8.5			pH = 9.0																	
	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0						
<=0.4	8	17	25	33	42	50	10	20	30	39	49	59	12	23	35	47	58	70						
0.6	9	17	26	34	43	51	10	20	31	41	51	61	12	24	37	49	61	73						
0.8	9	18	27	35	44	53	11	21	32	42	53	63	13	25	38	50	63	75						
1.0	9	18	27	36	45	54	11	22	33	43	54	65	13	26	39	52	65	78						
1.2	9	18	28	37	46	55	11	22	34	45	56	67	13	27	40	53	67	80						
1.4	10	19	29	38	48	57	12	23	35	46	58	69	14	27	41	55	68	82						
1.6	10	19	29	39	48	58	12	23	35	47	58	70	14	28	42	56	70	84						
1.8	10	20	30	40	50	60	12	24	36	48	60	72	14	29	43	57	72	86						
2.0	10	20	31	41	51	61	12	25	37	49	62	74	15	29	44	59	73	89						
2.2	10	21	31	41	52	62	13	25	38	50	63	75	15	30	45	60	75	90						
2.4	11	21	32	42	53	63	13	26	39	51	64	77	15	31	46	61	77	92						
2.6	11	22	33	43	54	65	13	26	39	52	65	78	16	31	47	63	78	94						
2.8	11	22	33	44	55	66	13	27	40	53	67	80	16	32	48	64	80	96						
3.0	11	22	34	45	56	67	14	27	41	54	68	81	16	32	49	65	81	97						

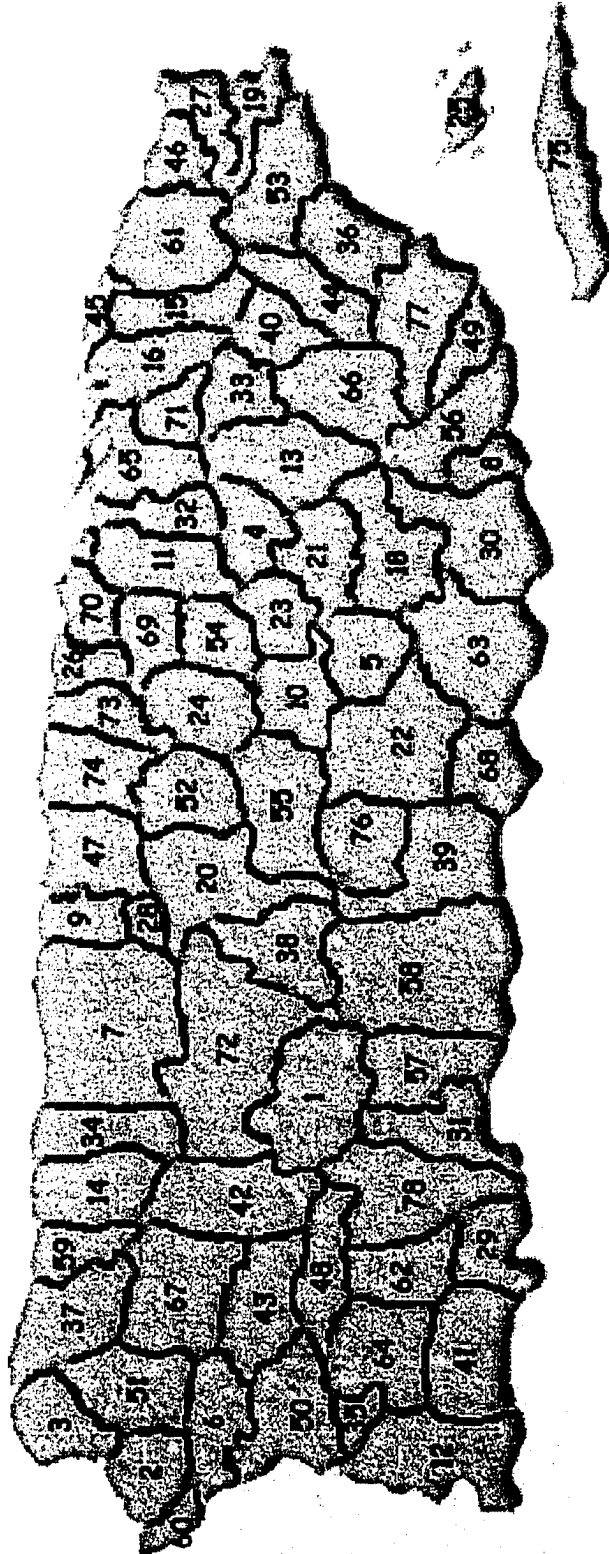
CT VALUES FOR INACTIVATION OF VIRUSES BY FREE CHLORINE, pH 6-9																									
Inactivation (Log)	Temperature (°C)																								
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25					
2	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0					
3	5.6	5.2	4.8	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0					
4	7.6	7.2	6.8	6.4	6.0	5.6	5.2	4.8	4.4	4.0	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.2	2.0					

Source: AWWA, 1991

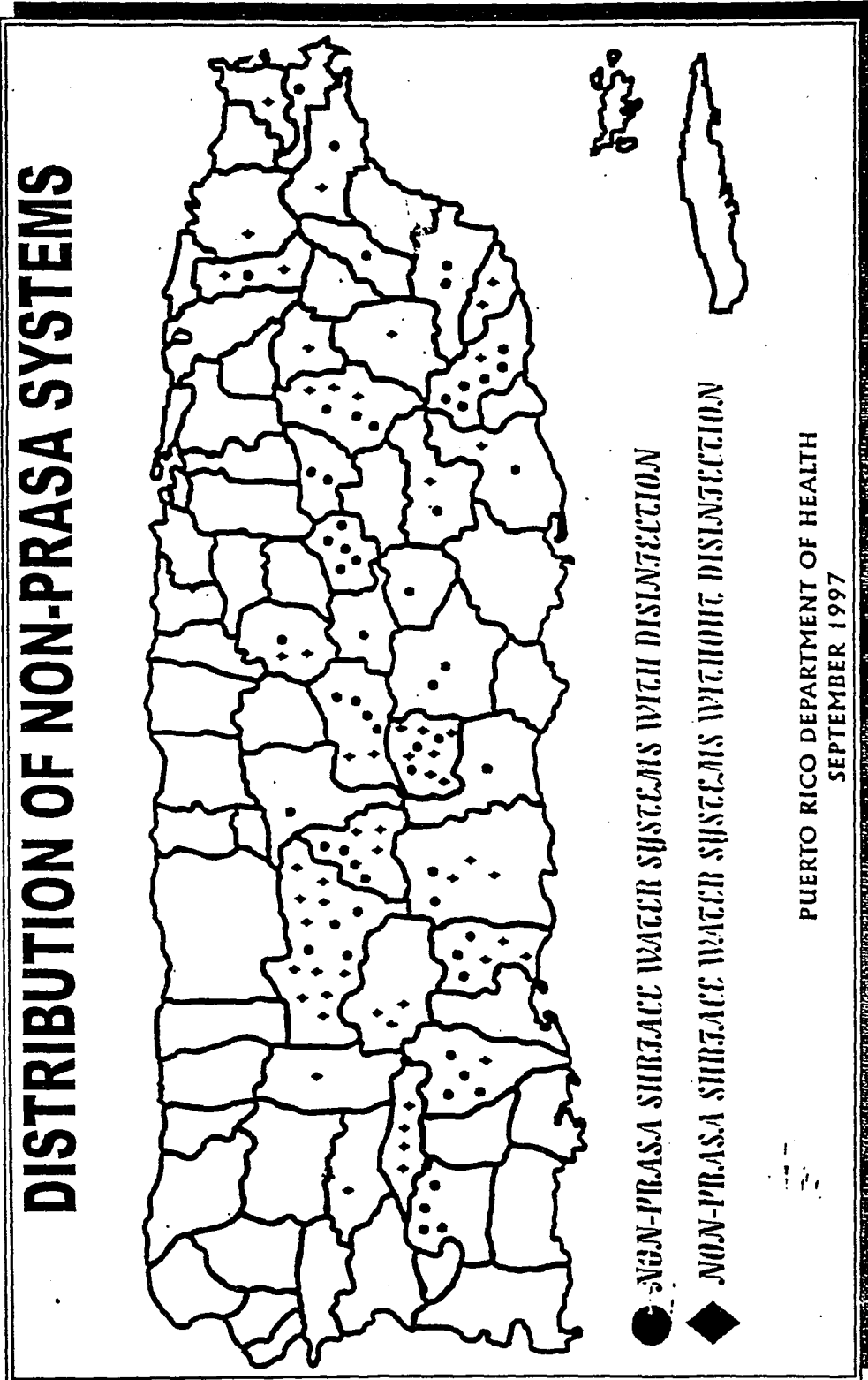
Appendix E: Puerto Rico Maps



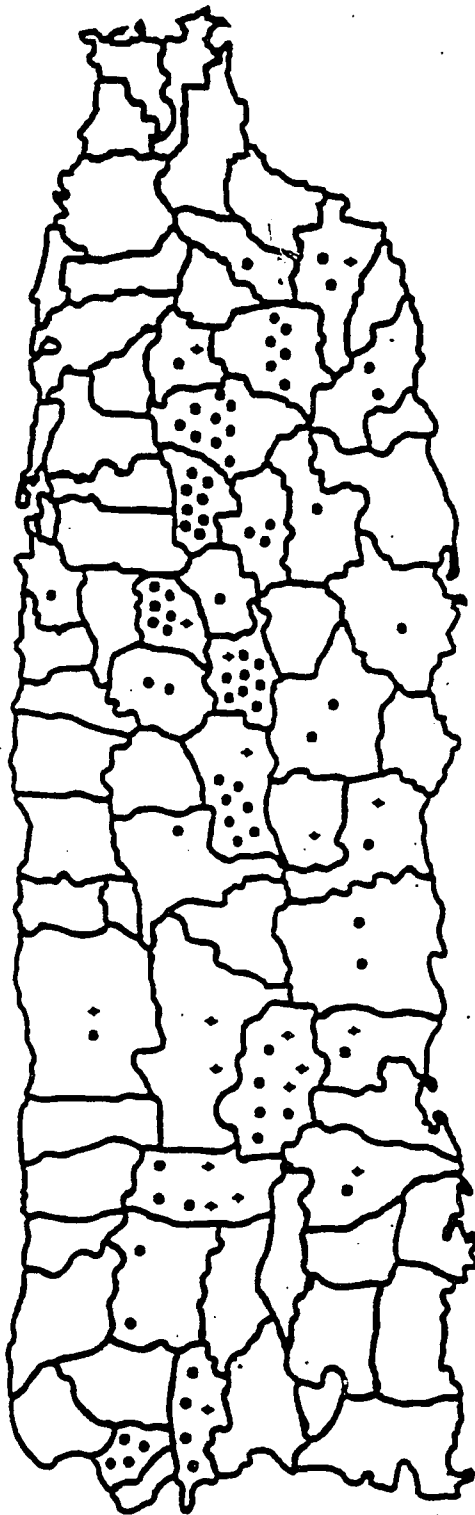
Puerto Rico Municipalities



- 1. Adjuntas
- 2. Aguada
- 3. Aguadilla
- 4. Aguas Buenas
- 5. Aibonito
- 6. Añasco
- 7. Arecibo
- 8. Arroyo
- 9. Barceloneta
- 10. Barranquitas
- 11. Bayamon
- 12. Cabo Rojo
- 13. Caguas
- 14. Camuy
- 15. Canovanas
- 16. Carolina
- 17. Cataño
- 18. Cayey
- 19. Ceiba
- 20. Ciales
- 21. Cidra
- 22. Coamo
- 23. Comerio
- 24. Corozal
- 25. Culebra
- 26. Dorado
- 27. Fajardo
- 28. Florida
- 29. Guánica
- 30. Guayama
- 31. Guayanilla
- 32. Guaynabo
- 33. Gurabo
- 34. Hatillo
- 35. Hormigueros
- 36. Humacao
- 37. Isabela
- 38. Jayuya
- 39. Juana Diaz
- 40. Juncos
- 41. Lajas
- 42. Lares
- 43. Las Marias
- 44. Las Piedras
- 45. Loiza
- 46. Luquillo
- 47. Manati
- 48. Maricao
- 49. Maunabo
- 50. Mayaguez
- 51. Moca
- 52. Morovis
- 53. Naguabo
- 54. Naranjito
- 55. Orocovis
- 56. Patillas
- 57. Peñuelas
- 58. Ponce
- 59. Quebradillas
- 60. Rincon
- 61. Rio Grande
- 62. Saban Grande
- 63. Salinas
- 64. San German
- 65. San Juan
- 66. San Lorenzo
- 67. San Sebastian
- 68. Santa Isabel
- 69. Toa Alta
- 70. Toa Baja
- 71. Trujillo Alto
- 72. Utuado
- 73. Vega Alta
- 74. Vega Baja
- 75. Vieques
- 76. Villalba
- 77. Yabucoa
- 78. Yauco



DISTRIBUTION OF NON-PRASA SYSTEMS



● NON-PRASA GROUNDWATER SYSTEMS WITH DISINFECTION

◆ NON-PRASA GROUNDWATER SYSTEMS WITHOUT DISINFECTION



PUERTO RICO DEPARTMENT OF HEALTH
SEPTEMBER 1997

REFERENCES

1. Abbaszadegan, M.; Hasan, M.N.; Gerba, C.P.; Roessler, P.F.; Wilson, B.R.; Kuennen, R. & Dellen, E.V. The Disinfection Efficacy of a Point-of-Use Water Treatment System against Bacterial, Viral and Protozoan Waterborne Pathogens. *Water Research*, 91:3:574 (1997).
2. Ainsworth, L. & Hampton, J. A Safe Option for Disinfection: On-Site Sodium Hypochlorite Generation. *Engineering and Management*. (December 1997).
3. Ainsworth, L. On-Site Chlorine Generation. *Public Works*. (July 1998).
4. American Water Works Association. Standard Methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington, D.C., 1992.
5. American Water Works Association. Waterborne Pathogens. Manual of Water Supply Practices, First Edition, Denver (1999).
6. American Water Works Association. What's in a Word? New Dictionary Zeros in on Drinking Water. *Opflow*, 26:4:11 (April 2000).
7. American Water Works Research Division. Emerging Pathogens-Bacteria. *Journal of the American Water Works Association*, 91:9:101 (September 1999).
8. American Water Works Research Division. Emerging Pathogens-Viruses, Protozoa and Algal Toxins. *Journal of the American Water Works Association*, 91:9:110 (September 1999).
9. American Water Works Water Quality Committee. Disinfection at Small Systems, *Journal of the American Water Works Association*, 92:5:24 (May 2000).
10. Atlas, R.M. Microbiology, Fundamentals and Applications. Macmillan Publishing Company, New York (1984).
11. Atherholt, T.B.; LeChevallier, M.W.; Norton, W.D. & Rosen, J.D. Effect of Rainfall on *Giardia* and *Crypto*. *Journal of the American Water Works Association*, 90:9 (September 1998).
12. Baker, L. Public Drinking Water. United States Environmental Protection Agency, Technical Committee Reports.
[Http://www.epa.gov/opperspdp/futures/Arizona/humhlth/water/public.txt](http://www.epa.gov/opperspdp/futures/Arizona/humhlth/water/public.txt)

13. Barrot, L.P.; Graham, N.J. & Lloyd, B.J. Further Evaluation of an On-Site Chlorine Gas Generator (Moggod) for Small Community Water Disinfection in Developing Countries. *Aqua*, 43:4:145 (1994).
14. Bellamy, W.; Carlson, K.; Pier, D.; Ducoste, J. & Carlson, M. Determining Disinfection Needs. *Journal of the American Water Works Association*. 92:5:44 (May 2000).
15. Benenson, A.S. Control of Communicable Diseases in Men, American Public Health Association, United States (1990).
16. Berberich, C. Chlorine for Drinking Water Disinfection. *American Water Works Association Mainstream* (May 1995).
17. Black, E.K. & Finch, G. Detection and Occurrence of Waterborne Bacterial and Viral Pathogens. *Water Environment Research*, 66:292 (June 1994).
18. Blatchley, E.R. Disinfection and Antimicrobial Processes. *Water Environment Research*, 66:361 (June 1994).
19. Bocelli, D.L.; Tryby, M.E.; Uber, J.G.; Rossman, L.A.; Zierolf, M.L. & Polycarpou, M.M. Optimal Scheduling of Booster Disinfection in Water Distribution Systems. *Journal of Water Resources Planning and Management*, 124:4:99 (March/April 1998).
20. Brignoni, R.M. & Saez, J.M. Enforcement and Compliance Strategy for Non-PRASA Systems, Achievement Report, 1997. United States Environmental Protection Agency and Puerto Rico Department of Health.
21. Camel, V. & Bermond, A. The Use of Ozone and Associated Oxidation Processes in Drinking Water Treatment. *Water Research*, 32:11: 3208 (1998).
22. Christman, K. The History of Chlorine. Chlorine Chemistry Council. [Http://www.c3.org/newsroom/clips/history.html](http://www.c3.org/newsroom/clips/history.html)
23. Chlorine Chemistry Council. Facts About Chlorine and Drinking Water. [Http://www.c3.org/newsroom/factsheets/waterfacts.html](http://www.c3.org/newsroom/factsheets/waterfacts.html)
24. Chlorine Chemistry Council. Drinking Water Chlorination White Paper: A Review of Disinfection Practices and Issues.
25. Chlorine Chemistry Council. Chlorine Story. [Http://c3.org/chlorine-what-is-it/chlorine-story.html](http://c3.org/chlorine-what-is-it/chlorine-story.html)

26. Clark, S. & Alvarez, M. Reducing Turbidity Cuts Microbial Risks. *Opflow*, 26:2:6 (February 2000).
27. Colwel, R.R. Global Climate & Infectious Disease: The Cholera Paradigm. *Science*, 274:2025 (December 1996).
28. Craun, G.F.; Berger, P.S. & Calderon, R.L. Coliform Bacteria and Waterborne Disease Outbreaks. *Journal of the American Water Works Association*, 89:3:96 (March 1997).
29. Craun, G.F. Methods for the Investigation and Prevention of Waterborne Disease Outbreaks. United States Environmental Protection Agency (September 1990).
30. Craun, C.F.; Hubbs, S.A.; Frost, F.; Calderón, R.L. & Vía, S.H. Waterborne Outbreaks of Cryptosporidiosis. *Journal of the American Water Works Association*, 90:9:81 (September 1998).
31. Cruz, A.D. & Boswell, T.D. Atlas of Puerto Rico. Cuban American National Council, Inc. Miami, Florida (1997).
32. Department of Public Works & Chem Hill: Water System Study. City of Milwaukee, Wisconsin (August 1994).
33. Dailloux, M.; Laurain, C.; Weber, M. & Hartemann, P.H. Water and Nontuberculosis Mycobacteria. *Water Research*, 33:10:2219 (1999).
34. Dufour, A.P. *Escherichia coli*: The Fecal Coliform. "Bacterial Indicators/Health Hazards Associated with Water, ASTM STP 635, A.W. Hoadley and B.J. Dutka, Eds, American Society for Testing & Materials (1977).
35. Engen, T. Water: Realities for the 21st Century. *Clearwaters*, 28:1:6 (Spring 1998).
36. Evison, J.A. Biological Indicators of Water Quality. John Wiley and Sons, NY (1979).
37. Faubert, G. Waterborne Cryptosporidiosis & the Need for Legislation. *Parasitology Today*, 14:12:501 (December 1998).
38. Faust, S.D. & Aly, O.M. Chemistry of Water Treatment. 2nd Edition. Ann Arbor Press, Michigan (1998).

39. Ford, T.E. Microbiological Safety of Drinking Water: United States and Global Perspectives. *Environmental Health Perspectives*, 107:1:191 (February 1999).
40. Galal-Gorchev, H. Chlorine in Water Disinfection. *Pure and Applied Chemistry*, 68:9:1731 (1996).
41. Gauthier, V.; Gerard, B.; Portal, J.M.; Block, J.C. & Gatel, D. Organic Matter as Loose Deposits in Drinking Water Distribution System. *Water Research*, 33:4:1014 (1999).
42. Graczyk, T.K.; Fayer, R. & Cranfield, M.R. Zoonotic Transmission of *Cryptosporidium parvum*: Implications for Waterborne Cryptosporidiosis. *Parasitology Today*, 13:9:348 (September 1997).
43. Gregory, J. Turbidity and Beyond. *Filtration and Separation*. 35:1:63 (January 1998).
44. Gruner, E.; Flepp, M.; Gabathuler, U.; Thong, K.L. & Altwegg, M. Outbreak of Typhoid Fever in a Non-Endemic Area: Comparison of Three Molecular Typing Methods. *Journal of Microbiological Methods*, 28:179 (1997).
45. Haas, C.N.; Joffe, J.; Anmangandla, U.; Jacangelo, J.C. & Heath, M.: Water Quality and Disinfection Kinetics. *Journal of the American Water Works Association*, 88:3:95 (1996).
46. Haas, C.N. & Rose, J.B. Distribution of *Cryptosporidium* Oocysts in a Water Supply. *Water Research*, 30:10:2251 (1996).
47. Haas, C.N. Disinfection in the Twenty-First Century. *Journal of the American Water Works Association*, 92:2:72 (February 2000).
48. Hammer, M.J. Water & Wastewater Technology. John Wiley & Sons, Inc., New York (1975).
49. Hammonds Technical Services, Inc.: Innovative Water Chlorination System. [Http://www.foodexplorer.com/manu/newproduct/FE03736.htm](http://www.foodexplorer.com/manu/newproduct/FE03736.htm).
50. Harms, L.; Wallis-Lage, C. & Ratnayaka, D. Disinfection. World of Water 2000: The Past, Present & Future. Waterworld and Water and Wastewater International, United States (1999).
51. Herwaldt, B.L.; Craun, G.F.; Stokes, S.L. & Juranek, D.D. Outbreaks of Waterborne Disease in the United States: 1989-1990. *Journal of the American Water Works Association*, 84:4:129 (April 1992).

52. Hoffbuhr, J.W. Nor Any Drop to Drink, *Journal of the American Water Works Association*, 92:5:6 (May 2000).
53. Hoyert, D.L.; Kochanek, K.D. & Murphy, S.L. Deaths: Final Data for 1997. National Vital Statistics Reports, Center for Disease Control & Prevention, 47:19:1 (June 30, 1999).
54. Hunter, J.M. & Arbona, S.I. Paradise Lost: An Introduction to the Geography of Water Pollution in Puerto Rico. *Soc. Sci. Med.*, 40:10:1331 (1995).
55. Jamison, D.T.; Creese, A. & Prentice, T. The World Health Report 1999: Making a Difference. Geneva: World Health Organization (1999).
56. Kasper, L.H. & Buzoni-Gatel, D. Some Opportunistic Parasitic Infections in AIDS: Candidiasis, Pneumocystosis, Cryptosporidiosis, Toxoplasmosis. *Parasitology Today*, 14: 4:150 (1998).
57. Kenzie, W.R.; Hoxie, N.J.; Proctor, M.E.; Gradus, M.S.; Blair, K.A.; Peterson, D.E.; Kazmierck, J.J.; Addiss, D.G.; Fox, K.R.; Rose, J.B. & Davis, J.P. A Massive Outbreak in Milwaukee of *Cryptosporidium* Infection Transmitted through the Public Water Supply. *The New England Journal of Medicine*, 331:3:161 (July 1994).
58. Keswick, B.H.; Satterwhite, T.K.; Johnson, P.C.; Dupont, H.L.; Secor, S.L.; Bitsura, J.A.; Gary, G.W. & Hoff, J.C. Inactivation of Norwalk virus in Drinking Water by Chlorine. *Applied and Environmental Microbiology*, 50:2:261 (August 1985).
59. Kott, Y.: Current Concepts of Indicator Bacteria. "Bacterial Indicators/Healths Hazards Associated with Water", ASTM STP 635, A.W. Hoadley and B.J. Dutka, Eds., American Society for Testing and Materials (1977).
60. Kramer, M.H.; Herwaldt, B.L.; Calderon, R.L. & Juranek, D.D. Surveillance for Waterborne Disease Outbreaks – United States, 1993-1994. *Morbidity and Mortality Weekly Report*, 45:SS-1:1 (April 12, 1996).
61. Kukula, M.; Maunula, L.; Silvennoinen, E. & Bonsdorff, C.H. Outbreak of Viral Gastroenteritis Due to Drinking Water Contaminated by Norwalk-like Virus. *The Journal of Infectious Diseases*, 180:1771 (1999).
62. Kuo, J.F. & Smith, S.O. Disinfection. *Water Environmental Research*, 68:4:503 (1996).
63. LeChevallier, M.W. The Case for Maintaining a Disinfectant Residual. *Journal of the American Water Works Association*, 91:1:65 (January 1999).

64. Laughlin, J. History of Water. World of Water 2000: The Past, Present and Future. Waterworld and Water & Wastewater International, United States (1999).
65. Leclerc, H.; Mossel, D.A.; Trinel, P.A. & Gavini, F. "Microbiological Monitoring- A New Test for Fecal Contamination, "Bacterial Indicators/Health Hazards Associated with Water, ASTM STP 635, A.W. Hoadley and B.J. Dutka, Eds., American Society for Testing & Material (1977).
66. Lee, P. Public Health in the Next Century. *Journal of the American Water Works Association*, 92:1 (January 2000).
67. Levine, W.C.; Stephenson, W.T. & Craun, G.F. Waterborne Disease Outbreaks, 1986-1988. *Morbidity and Mortality Weekly Report*, 39:SS-1:1 (March 1, 1990).
68. Levy, D.; Bens, M.S.; Craun, G.F.; Calderon, R.L.; Herwald, B.L. Surveillance for Waterborne-Disease Outbreaks – United States, 1995-1996. *Morbidity and Mortality Weekly Report*, 47:SS-5:1 (December 11, 1998).
69. Lindquist, A. Emerging Pathogens of Concern in Drinking Water. United States Environmental Protection Agency, Microbiological and Chemical Exposure Assessment Research Division, Cincinnati, Ohio.
70. MacKenzie, W.R.; Neill, M.D.; Hoxie, N.J.; Proctor, M.E.; Gradus, S.M.; Blair, K.A.; Peterson, D.E.; Kazmierczak, J.J.; Adiss, D.G.; Fox, K.R.; Rose, J.B. & Davis, J.P. A Massive Outbreak in Milwaukee of *Cryptosporidium* Infection Transmitted through the Public Water Supply. *The New England Journal of Medicine*, 331:3 (1993).
71. Mack, W.N. Total Coliform Bacteria. Bacterial Indicators/Health Hazards Associated With Water. ASTM STP 635, A.W. Hoadley and B. J. Dutka, Eds. American Society for Testing and Materials (1977).
72. Mahin, T. & Pancorbo, O. Waterborne Pathogens. *Water Environment and Technology*, 11: 4:51 (April 1999).
73. Minnigh, H.A. Public Perception of Potable Water Supply in Puerto Rico. *From Watershed to Well*.
74. Monarca, S.; Zanardini, A.; Feretti, D.; Dalmiglio, A.; Egizia, F.; Manica, P. & Nardi, G. Mutagenicity of Extracts of Lake Drinking Water Treated with Different Disinfectants in Bacterial and Plant Tests. *Water Research*, 32:9:2289 (1998).

75. Morgan, U.M. & Thompson, R.C.A. PCR Detection of *Cryptosporidium*: The Way Forward? *Pathology Today*, 14:16:241 (December 1998).
76. Morris, C. Aspects of the Quantitative Assessment of Germicidal Efficiency. Disinfection of Water and Wastewater. J. Donald, Ed. Ann Arbor Science Publishers, Inc. Michigan (1975).
77. Murphy, M. Water for People Turns Water on Worldwide. *American Water Works Mainstream*, 43:1:5 (November 1999).
78. Murphy, S. Emerging Microbes 101: A Basic Course. *Journal of the American Water Works Association*, 91:9:10 (September 1999).
79. Murphy, M. Helping People Help Themselves. *Journal of the American Water Works Association*, 92: 4:148 (April 2000).
80. Nasser, A.M. and Oman, S.D. Quantitative Assessment of the Inactivation of Pathogenic and Indicator Viruses in Natural Water Sources. *Water Research*. 33:7:1748 (May 1999).
81. National Association of People with AIDS. What's on Tap? *Cryptosporidium* in U.S. Public Drinking Water, Washington, DC (1995).
82. National Geographic Society. Millenium in Maps. Washington, DC (August 1998).
83. Neutra, R.R. & Ostro, B. An Evaluation of the Role of Epidemiology in Assessing Current and Future Disinfection Technologies for Drinking Water. *The Science of the Total Environment*, 127:91-138 (1992).
84. Ott, W.R. Environmental Statistics and Data Analysis. Lewis Publishers, Florida (1995).
85. Ottaway, B. Disinfection. Drinking Water Help Homepage. [Http://overworld.compuserve.com/homepage/ottaway/disinfection](http://overworld.compuserve.com/homepage/ottaway/disinfection)
86. Palin, A.T. Disinfection: Water and Wastewater. Donald J., ed. Water Disinfection - Chemical Aspects and Analytical Control. American Society for Testing and Material (1977).
87. Panamerican Health Organization (PAHO). Health in the Americas (1998).
88. Pan American Health Organization (PAHO). Partnership Formed to Improve Drinking Water Safety in Latin America. [Http://www.paho.org/english](http://www.paho.org/english). (July 1999).

89. Pan American Health Organization. Statement for the Record by the PAHO for the House Committee on International Relations. Hearing on Child Survival and Infectious Disease Program. April 15, 1999 [Http://www.paho.org/english](http://www.paho.org/english).
90. Patterson, K.S.; Lykins, Jr. & Richardson, S.D. Mutagenicity of Drinking Water Following Disinfection. *Aqua*, 44:1:1 (1995).
91. Pennsylvania Department of Environmental Protection. Small Drinking Water Systems Technology Report. [Http://www.dep.state.pa.us/dep/deputate/watermgt/WSM/Facts/fs2210htm](http://www.dep.state.pa.us/dep/deputate/watermgt/WSM/Facts/fs2210htm).
92. Pillai, J.; Mathew, K.; Gibbs, R. & Ho, G.E. H₂S Paper Strip Method - A Bacteriological Test for Fecal Coliform in Drinking Water at Various Temperatures. *Water Science Technology*, 40: 2:85 (1999).
93. Pontius, F.W. Drinking Water Disinfection with Chlorine: An Effective Public Health Practice. *Health & Environmental Digest* (April 1997).
94. Puerto Rico Department of Health. Non-PRASA Systems Inventory. September 1997 - September 1998.
95. Puerto Rico Department of Health. El Cloro y su Importancia en la Desinfección del Agua que Consumimos (November 1993).
96. Puerto Rico Department of Health. Finca Geraldo Pagán Sanitary Survey (March 16, 1996).
97. Puerto Rico Department of Health FY-88 Annual Report (January 1989).
98. Puerto Rico Department of Health FY-89 Annual Report (January 1990).
99. Puerto Rico Department of Health FY-92 Annual Report (January 1993).
100. Puerto Rico Department of Health FY-93 Annual Report (January 1994).
101. Puerto Rico Department of Health FY-94 Annual Report (January 1995).
102. Puerto Rico Department of Health FY-95 Annual Report (January 1996).
103. Queensland Health: Leptospirosis. [Http://www.health.qld.gov.au/phs/cdu.htm](http://www.health.qld.gov.au/phs/cdu.htm)
104. Schmitt, J. & Flemming, H.C. Water Binding in Biofilms. *Water Science Technology*, 39:7:77 (1999).

105. Shaw, S.E. & Regli, S. US Regulations on Residual Disinfection. *Journal of the American Water Works Association*, 91:1:75 (January 1999).
106. Shears, P. Shigella Infections. *Annals of Tropical Medicine and Parasitology*. 90:2:105 (1998).
107. Smith, H.V. & Rose, J.B. Waterborne Cryptosporidiosis: Current Status. *Parasitology Today*, 14:1:14 (January 1998).
108. Sobsey, M.D. Health Risks from Enteric Microbes in Water and their Control by Disinfection. *ESE Notes*, 30:2 (1995).
109. Steinbrueckner, B.; Haerter, G.; Pelz, G. & Kist, M. Routine Identification of *Campylobacter jejuni* and *Campilobacter coli* from human stool samples. *FEMS Microbiology Letters*, 179:227 (1999).
110. St. Louis, M.E. Water Related Disease Outbreaks, 1985. *Morbidity and Mortality Weekly Report*, 37:SS-2:15 (June 1, 1988).
111. Temperley, T. Full of Eastern Promise. *Water Services*, Pp. 42-44, November 1994.
112. Teunis, P.F.; Medema, G.J.; Kruidenier, L. & Hauelaar, A.H. Assessment of the Risk of Infection by *Cryptosporidium* or *Giardia* in Drinking Water from a Surface Water Source.
113. Tibbets, J. What's in the Water: The Disinfectant Dilemma. *Environmental Health Perspectives*, 103:1:30 (January 1995).
114. Thomas, R.D. Drinking Water and Health. National Academy Press, Washington, DC (1986).
115. Tibbetts, J. What's in the Water: The Disinfectant Dilemma. *Environmental Health Perspectives*, 103:1:30 (January 1995).
116. Toranzos, G. Microbiological Water Quality Issues. Puerto Rico Department of Health Fourth Seminar on Drinking Water and Applicable Regulation. May 4-5, San Juan, Puerto Rico (1998).
117. Trax, J. Source Water Protection for Small System. *Journal of the American Water Works Association*, 91:8:10 (August 1999).
118. Trusell, R.D. Safeguarding Distribution System Integrity. *Journal of the American Water Works Association*, 91:1: 47 (January 1999).

119. Umble, A.K.; Kolo, L.E.; Newvine, L.A.; Roth, G. & Roth, J. Coliform Counts. *Water Environment and Technology*, 11: 4:57 (April 1999).
120. United States Water News Online. Safety of Water Supplies in Nation's Small Communities Focus on NRC Study (December 1996).
[Http://www.uswaternews.com/archive/96/supply/safwat.html](http://www.uswaternews.com/archive/96/supply/safwat.html)
121. United States Environmental Protection Agency. 40 Code of Federal Regulation, Section 141 (July 1996).
122. United States Environmental Protection Agency, Office of Water Supply. State of the Art of Small Water Treatment Systems, Washington, D.C. (1997)
123. United States Environmental Protection Agency. Preventing Waterborne Diseases. Office of Research and Development. Washington DC (April 1993).
124. United States Water News Online. Safety of Water Supplies in Nation's Small Communities Focus of NRC study (December 1996)
125. United States Environmental Protection Agency Guidance Manual. Alternative Disinfectants and Oxidants (April 1999).
126. United States Environmental Protection Agency. Drinking Water Glossary: A Dictionary of Technical and Legal Terms Related to Drinking Water. Office of Ground Water and Drinking Water Publications, Washington, DC (1994).
127. United States Environmental Protection Agency. Septic Tank Siting to Minimize the Contamination of Ground Water By Microorganisms. Office of Ground Water Protection (June 1987).
128. United States Environmental Protection Agency. Turbidity Removal for Small Public Water Systems. Office of Drinking Water, Washington, DC (June 1983).
129. United States Environmental Protection Agency & Puerto Rico Environmental Quality Board. Puerto Rico Pathogenic Organisms Survey Report (January 1986).
130. United States Environmental Protection Agency. Estimating Costs for Water Treatment as a Function of Size and Treatment Plant Efficiency. Municipal Environmental Research Laboratory, Ohio (August 1978).
131. United States Environmental Protection Agency. Emergency Disinfection of Drinking Water. Office of Groundwater and Drinking Water (July 1993).

132. United States Environmental Protection Agency. Small Systems Compliance Technology List for the Surface Water Treatment Rule and Total Coliform Rule. Office of Water (September 1998).
133. United States Environmental Protection Agency. Environmental Pollution Control Alternatives: Drinking Water Treatment for Small Communities (April 1990).
134. United States Environmental Protection Agency. Sources of Waterborne Disease Outbreaks. Office of Ground Water and Drinking Water. [Http:www.epa.gov/ogwdw000/standard/outbreak.html](http://www.epa.gov/ogwdw000/standard/outbreak.html)
135. United States Environmental Protection Agency. Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities. Office of Drinking Water (March 1990).
136. United States Environmental Protection Agency. Methods for the Investigation and Prevention of Waterborne Disease Outbreaks. Health Effects Research Laboratory (September 1990).
137. United States Environmental Protection Agency. Water on Tap: A Consumer's Guide to the Nation's Drinking Water. Office of Water (July 1997).
138. Van der Leeden, F.; Troise, F.L. & Todd, D.K. The Water Encyclopedia, Second Edition, Lewis Publishers, United States (1990).
139. Walker, R. Water Supply, Treatment and Distribution. Prentice Hall, Inc., Englewood Cliffs, New Jersey (1978).
140. Water Environment Federation. Water Sourcebook, Legacy, Inc., (January 1994).
141. White, C.; Haas, C.N.; Whitby, E.; Bailey, E. & Lane, S. Panel Discussion: The Disinfection Decision. *Water Environmental*, 10:41 (1997).
142. World Health Organization (WHO). Removing Obstacles to Healthy Development. Report on Infectious Diseases.
143. World Health Organization (WHO). Cholera in 1996. *Weekly Epidemiological Record*. 72:31:229 (August 1997).
144. World Health Organization (WHO). Cholera in 1998. *Weekly Epidemiological Record*. 74:31:257 (August 1999).

145. World Health Organization (WHO). Guidelines for the Control of Epidemics due to *Shigella Dysenteriae* Type 1. [Http://www.who.int/cdr/95.4](http://www.who.int/cdr/95.4)
146. World Health Organization (WHO). Foodborne Diseases: Possibly 350 Times More Frequent than Reported. Press Release WHO/58: (August 13, 1997). [Http://www.who.int/dsa/justpub/food.htm](http://www.who.int/dsa/justpub/food.htm)
147. World Health Organization (WHO). Emerging and Communicable Diseases, Surveillance and Control. [Http://www.who.int/emc/97.1](http://www.who.int/emc/97.1)
148. World Health Organization (WHO). Cholera Fact Sheet (March 1996) [Http://www.who.int/inf-fs/en/fact107.html](http://www.who.int/inf-fs/en/fact107.html)
149. World Health Organization (WHO). Cholera in 1995. ***Weekly Epidemiological Record***, 71:21:157 (1996).
150. World Health Organization (WHO). Cholera in 1997. ***Weekly Epidemiological Record***, 73:27:201 (1998).
151. World Health Organization (WHO). Leptospirosis Worldwide, 1999. ***Weekly Epidemiological Record***, 74:29:237 (1999).
152. World Health Organization (WHO). Leptospirosis, Australia, January 1998-March 1999. ***Weekly Epidemiological Record***, 74:15:113 (1999).
153. World Health Organization (WHO). Amoebiasis. ***Weekly Epidemiological Record***, 72:14:97 (1997).
154. World Health Organization (WHO). Hepatitis A vaccine. ***Weekly Epidemiological Record***, 75:5:38 (2000).
155. World Health Organization (WHO). Rotavirus vaccines. ***Weekly Epidemiological Record***, 74:5:33 (1999).
156. World Health Organization (WHO). Enterohaemorrhagic *Escherichia coli* Vaccines. ***Weekly Epidemiological Record***, 74:14:105 (1999).